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WEB ENABLED WEATHER BASED PREDICTION FOR INSECT PESTS OF RICE

ICAR-NATIONAL RESEARCH CENTRE FOR INTEGRATED PEST MANAGEMENT
NEW DELHI 110012

Technical Bulletin 39

NCIPM

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ICAR

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Citation : Vennila S., J Singh, P Wahi, M Bagri, DK Das and M Srinivasa Rao, 2016. Web enabled weather based prediction for insect pests of rice. ICAR-National Research Centre for Integrated Pest Management, New Delhi-110 012 India. 50p.

Published by : Director
ICAR-National Research Centre for Integrated Pest Management,
LBS Building, Pusa Campus, New Delhi 110012, India
Telephone No. : 91-11-25843935
Fax No. : 91-11-25841472
Email : director.ncipm@icar.gov.in
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Acknowledgements : *This work is an output of the project on "Pest Dynamics in relation to Climate Change (Target Crop: RICE)" under the NICRA funded by ICAR, New Delhi through the lead center CRIDA, Hyderabad*

Laser typeset & Printed by : National Printers, B-56, Naraina Industrial Area, Phase II, New Delhi-110028
Tel. : 011-42138030, 9811220790.

FOREWORD

Rice, the staple food for majority of the global human population plays a vital role in the Indian economy and livelihood. Insect-pests are yield-limiting factors of rice production with an estimated yield loss of 25%. The pest complex of rice that attacks the crop from nursery till maturity necessitates use of 22% of pesticide share in India even when the ecological approach of integrated pest management (IPM) is in focus. While factors affecting the pest population and their management are abiotic and biotic, the former is the driving force and trigger for the latter. Hence, describing the pest population in relation to environmental weather variables should aid in pest forecasting. Weather-based forecasts of insect pests provide information on the timing and intensity of the pest infestation beforehand that guides growers to take up timely, cost-effective and ecofriendly protection measures in addition to enhanced resilience to climatic variability.

Forewarning is an essential component of IPM, and predicting of pest incidence based on weather often requires systematically recorded specific field data in an elaborate manner over considerable period of time along with the meteorological data which can be easily retrieved and analyzed. In India, the efforts on pest forewarning have been put in application for field use in crops like potato and grapes. Attempts of forewarning of major rice pests for a few locations have been made possible based on historical data sets and specific field studies during the last decade through National Agricultural Technology and National Agricultural Innovation (NATP & NAIP) projects. The e-pest surveillance done under the National Innovations in Climate Resilient Agriculture (NICRA) by NCIPM has sustained and widened the scope of forewarning. The twin objectives of data base development for assessing the impact of changing weather on the rice pest scenario and development of pest-weather relations for use in pest forewarning have made possible the present compilation. Given the broad range of forecasting methods, available rule-based models in biological sciences are serving as simple and robust tools. The simple approach of developing weather criteria and thumb rules with reasonably higher prediction accuracies for two Lepidopterans, one Dipteran and four Homopteran insects of rice has made the translation of the predictions for a potential field use at times 'high severity'. While the strategy of making available the forecast (based on the weather of the current week on the severity of the specific insect-pest in the ensuing week) on the web facilitates an easy inference with the aid of the weather and pest severity-based rules specified in the current publication can also be used directly by anyone in conjunction with the weather readings of their own observatory or forecasts issued by the India Meteorological Department (IMD) for a given region.

The aim of this publication would be complete only when the plant protection workers of the real time pest dynamic (RTPD) centers take up the forewarning activity on weekly basis during the *kharif* season backed up with dissemination of information at times of anticipated outbreaks. The dynamics of insect-pests and weather depicted in annexures is of immense value for additional inferences. I compliment all the scientists involved in the project for their contributions to the data base and expect their involvement for use and feed back on forecast in the coming seasons. Further refinements and up-scaling of timely pest forecasts fortified with pest management advisories on a regular basis would be a boon to rice growers of the country.

(C. Chattopadhyay)

PREFACE

In any given cropping system of an agro climatic zone, the abiotic components of weather plays an important role, both directly and indirectly, in the development of insect pests and the rice based cropping systems are not exceptions. Study of population dynamics is a routine feature of all entomological studies, however their use is limited depending on the sampling unit, interval and duration. Data base obtained from secondary sources often times have the constraint of missing data sets and discrepancy in the values that cannot be verified easily. A focused effort is needed right from building up of data base to the study of weather influence in order to enable a valid forecast system. In the context of the climate variability and change and changing production practices including crop diversifications with altered pest complex and protection scenarios, there is a regular need for capturing the changing pest-weather relationships. The sophisticated tools of information and communication technology not only allows us to build a quality data base but also offers various approaches from basic heuristics to application of artificial intelligence for development of pest predictions. Recording of the light trap catches of insect pests and beneficial insects on daily basis has been a long standing practice across all rice growing regions of the country facilitated by the All India Co-ordinated Research Project for Rice along with the meteorological observations. Monitoring of insect pests of rice using light traps provide relative estimates of population abundance. Efforts have been made now and then over the last few decades to develop forewarning system for major insect pest(s) or disease(s) of rice, however with their validations or regular use for prediction almost nil.

National Innovations in Climate Resilient Agriculture (NICRA) with one of the target crops as rice for study of population dynamics in relation to climate change provided platform for the development of the heuristic models based on simple rules using the historical as well as real time data on insect pests and weather for identified locations across the country. Present bulletin has been a compilation of location specific rules of prediction dependent on weather based criteria evolved in relation to categorical severity levels of seven rice insect pests in addition to an initiative of 'e-pest alerts' making the possible pest forewarning to be an essential component of integrated pest management. While success of the predictions can be continuously improved through refinements considering the changing pest scenario and climate, immediate requirement is the need for the real time pest dynamic centers of rice to access the website on regular basis and issue 'pest alerts' at times prediction of 'high' severity levels. Since the web enabled prediction is specific to locations and insects, creating awareness amongst the potential users including the extension functionaries is of utmost importance. While a positive feedback would aspire us to develop mobile applications of forewarning, negative validation (model prediction is 'low' at times of observed 'high' severity) would redirect us to research further for improvement in forecast. I sincerely acknowledge all the rice workers of the co-opted partners of rice real time pest dynamics (RTPD) under NICRA for their contribution to the data base of insect pests and weather. The contributions by the scientists, research associates and senior research fellows and guidance by the project associates are thankfully acknowledged. It is hoped that the bulletin would inspire further development of simple approaches of pest forewarning in other crops. Importantly the print format is expected to give fillip to the use of web forecasts by the personnel involved in rice plant protection of the study locations.

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CONTENTS

INTRODUCTION

Rice (*Oryza sativa L.*) is the staple food for majority of global human population and plays a vital role in the Indian economy and livelihood. Rice cultivation in India extends from 8 to 35 ºN latitude and from sea level to as high as 3000 meters. Rice crop needs a hot and humid climate. It is best suited to regions which have high humidity, prolonged sunshine and an assured supply of water. The average temperature required throughout the life period of the crop ranges from 21 to 37^{o}C. Maximum temperature which the crop can tolerate is 40 to 42^{o}C (**Anonymous, 2014a**). Rice is grown in about 42.7 million hectares with a production and productivity of 105.24 million tonnes and 2462 kg/ha, respectively in India (**Anonymous, 2014b**). The rice growing areas of the country are grouped into North-Eastern, Eastern, Northern, Western and Southern regions. Rice is also grown under rainfed as well as irrigated conditions. While the irrigated rice accounts for 49.5 per cent of the total rice area in the country, rainfed rice ecosystems are categorized as upland and low land areas with the latter further classified as shallow (<50 cm), semi-deep (50-100cm) and deep (>100cm) water rice depending upon the standing depth of water in the field. Coastal saline and cold/hill areas of rice ecosystems usually subjected to salinity and low temperature problems, with almost 50% reduced productivity (**Anonymous, 2014c**). Depending upon temperature, rainfall, soil types, water availability and other climatic conditions rice growing seasons vary in different parts of India. In Eastern and Southern regions of the country two or three crops of rice are grown in a year wherein the mean temperature is found favorable for rice cultivation throughout the year. In Northern and Western parts of the country where the rainfall is high and winter temperature is fairly low, only one crop of rice is grown during the months between June and November.

The main rice growing season in the country is the *kharif* with the sowing time of June-July and harvesting time of November-December (winter rice). While about 84% of the country's rice crop is grown during *kharif* with medium to long duration varieties, 7% of the cropped area is grown during *pre-kharif* season (autumn rice) with short duration (90 to 110 days) varieties. Summer (*rabi*) rice is sown from November to February with harvests between March and June using early maturing varieties. Annexure I provides the general sowing and harvesting periods across major rice growing regions of India.

Farmers lose an estimated 37% of their rice crop to insect pests and diseases every year and 18% of pesticides are applied to rice (**Anonymous, 2014d**). While rice crop is attacked by more than 100 species of insects globally, 20 of them cause economic damage. Insect pests that can cause significant yield losses are stem borers, leafhoppers, plant hoppers (damage by feeding as well as by transmitting viruses), gall midge, defoliators (mainly Lepidopterans), and grain-sucking bugs (**Pathak and Khan, 1994**). The yield loss estimates due to yellow stem borer, brown plant hopper and gall midge are 25-30, 10-70 and 15-60%, respectively. Leaf folder (10%) and other pests (25%) also cause yield losses (**Krishnaiah and Varma, 2013**).

Weather influences all the agricultural operations including plant protection measures adopted by the farmers. Congenial weather conditions favor the higher incidence of insect pests, as their bionomics is intimately related with prevailing weather. Since the weather factors determine population abundance of a given species largely, establishing weather based forewarning of crop insect pests based on quantified pest-weather relationships provide necessary information regarding timing and intensity of the pest infestation well in advance. Such a forewarning approach aids in taking up timely cost effective and eco-friendly pest management measures. While the predictions of insect pest severity could be based on the light trap catches, their management should be based on real time observations on the standing crop *vis-a-vis* their economic threshold levels (Annexure II) Thus forewarning or forecast of the pests is a pre-requisite in pest management which can reduce the quantity of insecticide application and it is an useful component for successful area wide implementation of IPM.

METHODOLOGY

STUDY LOCATIONS AND INSECT PESTS

Seven locations *viz.,* Ludhiana (30°54'N, 75°48'E) of Punjab, Chinsurah (22°91'N, 82°E) of West Bengal, Raipur (21°30'N, 82°0'E) of Chhattisgarh, Karjat (18°91'N, 73°33'E) of Maharashtra, Hyderabad (17°37'N, 78°48'E) of Telangana, Mandya (12°52'N, 76°90'E) (Fig. 1) of Karnataka and Aduthurai (11°N, 79°3'E) of Tamil Nadu are the pest surveillance centers under studies of real time pest dynamics (RTPD). The agro climatic and ecological features of the locations are furnished in Table 1.

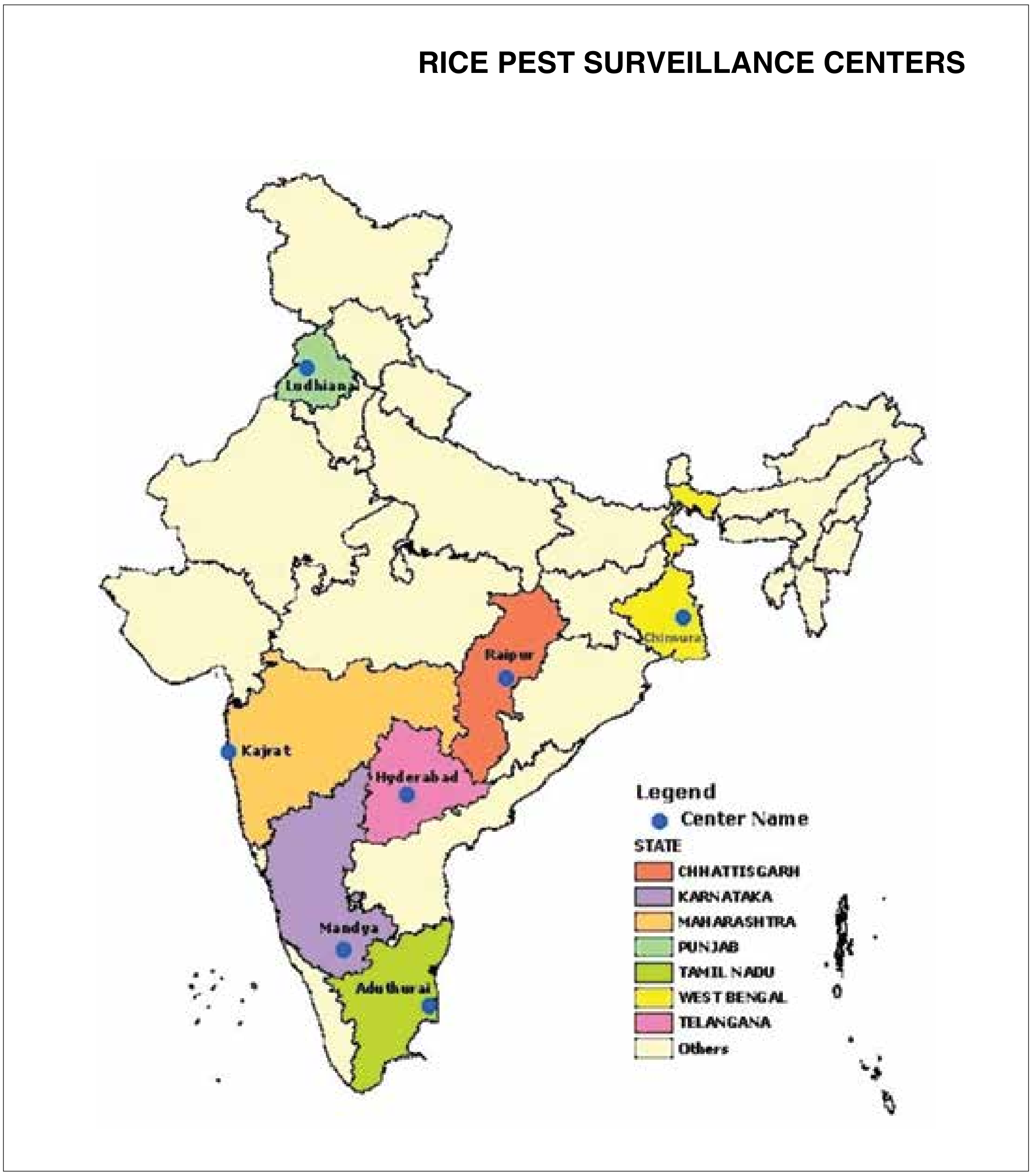


Fig. 1: Pest surveillance centers

Table 1: Agro climatic and ecological regions

Location	GPS co-ordinates	Agro Climatic Zone		Agro Ecological Region	
		No.	Name	No.	Name
Ludhiana-Punjab	30°54'N, 75°48'E	6	Trans Gangetic Plains	R4	Northern Plain and Central Highland including Aravallis, hot semi-arid eco-region
Chinsurah-West Bengal	22°91'N, 82°E	3	Lower Gangetic Plains	R15	Bengal and Assam plain hot sub humid (moist) to humid (inclusion of per humid) eco-region
Raipur-Chhattisgarh	21°30'N, 82°0'E	7	Eastern Plateau and Hills	R11	Eastern plateau (Chhattisgarh) hot semi-humid eco-region
Karjat-Maharashtra	18°91'N, 73°33'E	12	West Coast Plains and Ghat	R19	Western ghat & coastal plain hot humid per humid eco-region
Hyderabad-Telangana	17°37'N, 78°48'E	10	Southern Plateau and Hills	R7	Deccan plateau and Eastern ghat, hot semi- arid eco-region
Mandya-Karnataka	12°52'N, 76°90'E	10	Southern Plateau and Hills	R8	Eastern ghat, TN upland and deccan plateau hot semi- arid eco-region
Aduthurai-Tamil Nadu	11°N, 79°3'E	11	East Coast Plains and Hills	R18	Eastern coastal plain, hot sub-humid to semi-arid eco-region

Weather based predictions have been attempted on rice insect pests *viz.,* yellow stem borer (*Scirpophaga incertulas* Walker; Pyralidae; Lepidoptera), leaf folder (*Cnaphalocrocis medinalis* Guenee; Pyralidae; Lepidoptera), brown plant hopper (*Nilaparvata lugens Stal*; Delphacidae; Hemiptera), white backed plant hopper (*Sogatella furcifera* Horváth; Delphacidae; Hemiptera), green leaf hopper (*Nephotettix virescens* (Distant); Cicadellidae; Hemiptera) and *N.nigropictus* (Stal) (Cicadellidae: Hemiptera), gall midge (*Orseolia oryzae* Wood-Mason; Cecidomyiidae: Diptera) and caseworm (*Nymphula depunctalis*; Pyralidae; Lepidoptera).

DATA ACCRUAL AND ORGANIZATION

Historical data of the insect pests studied for the locations were either collected from the secondary sources of All India Co-ordinated Research Project on Rice or received from the RTPD centres. However the data base from 2011 is based on the Information and communication technology (ICT) modules *viz.,* client and reporting applications of the NICRA. Year round daily catches of the study insects in light traps (Chinsurah type) formed the basis for development of predictions. The data assembled were processed to obtain numbers/trap/standard meteorological week (SMW) in respect of the individual species of insects. Weather variables *viz.,* maximum temperature (°C), minimum temperature (°C), morning and evening relative humidity (%), rainfall (mm), sunshine hours (h/day) and wind velocity (km/h) on SMW basis for the specified locations were collected from respective meteorological observatories. The availability of weather and insect pest data varied with the locations and missing data were rectified in consultation with the locations (Table 2)

Table 2: Details of data sets on insect pests

Location	Yellow stem borer	Brown plant hopper	Green leaf hopper	Leaf folder	White backed plant hopper	Gall midge	Case worm
Ludhiana-PB	2011-2014	2011-14	-	2011-14	-	-	-
Chinsurah-WB	2011-2014	2011-2014	2011-2014	-	2011-2014	-	-
Raipur-CG	2000-2010	2000-2010	2000-2010	2011-14	-	2000-2010	2000-2010
Karjat-MH	2011-2014	-	2011-2014	-	-	-	-
Hyderabad-TS	2011-2014	2011-2014	2011-2014	-	-	-	-
Mandya-KA	2011-2014	2011-2014	2011-2014	-	-	-	-
Aduthurai-TN	2000-2010	2000-2010	2000-2010	2011-14	-	-	-

Fig. 2 specifies the details of the rice insect pests and locations for which development of weather based predictions are done.

Fig. 2 : Profile of insect pests and locations of predictions

APPROACH TOWARDS DEVELOPMENT OF WEATHER BASED PEST PREDICTION

Historical data of weather and selected rice insect pests along the SMWs pertaining to the whole year and *kharif* season (22-44 SMW) were used for the development of location specific prediction rules using heuristic approach. It is based on the iterative and exploratory analysis not guaranteed to be optimal or perfect, but practical and sufficient for the immediate goals. The data on the insect species in light traps obtained since 2011 through the RTPD studies facilitated by e- pest surveillance year round have been used to understand the scenario and trends on an yearly and seasonal (*kharif*) basis across study locations. Also the variability of the population of the insect pests considered for the development of the weather based criteria that existed in the data sets (over years) specific to each location are depicted in Annexure III. While deviations of weather variables *viz.,* maximum temperature and minimum temperature and rainfall from the normal have been depicted for the calendar years of 2011-2015, across season comparisons of other weather variables are furnished for understanding their changing pattern of climate (Annexure IV). The congenial conditions of weather in respect of the each insect species available from literature were also accounted for development of predictions. Steps involved in the formulation of the weather based pest predictions were:

1. Classification of pest severity levels into categories of low, moderate and high. The population levels under categories of pest severity based on light trap catches for each insect varied across locations depending on its relative abundance and dominance largely determined by the cropping system of the region.
2. Formulation of weather based criteria through comparison of weather variables *vis a vis* insect population. Weather factors lagged by one week of the insect data were accounted while formulating the weather based criteria.
3. Development of rules combining weather based criteria (step 2) and pest severity levels (step 1) for use in prediction.
4. Validation of developed weather based prediction.

Prediction accuracy was worked out for the whole year and *kharif* season (22-44 SMW) based on the week wise forecasts.

Prediction accuracy (%) = No. of weeks with correct prediction/Total number of weeks *100

WEB ENABLING OF FORECAST SYSTEM

Based on the rationale of weather based prediction of pests, a web application was developed, Web application was designed on 3-tier architecture consisting of Client Side Interface Layer (CSIL), Application Logic Layer (ALL) and Database Layer (DBL). CSIL was implemented by on ASP.net environment using C# language and JavaScript (for validation purpose). This has been implemented by the Visual Studio 2008 which provides a framework to create dynamic content on the server. Pest prediction rules were coded in C# language which are location and insect specific. Data Base Layer worked on Structured Query Language (SQL) server 2008 wherein site and time specific weather related data are being stored (Fig. 3).

A separate console was developed for administrator to feed all the weather based rules into the system. Only administrator has the provision of saving/editing the rule based information into the database (Fig. 4).

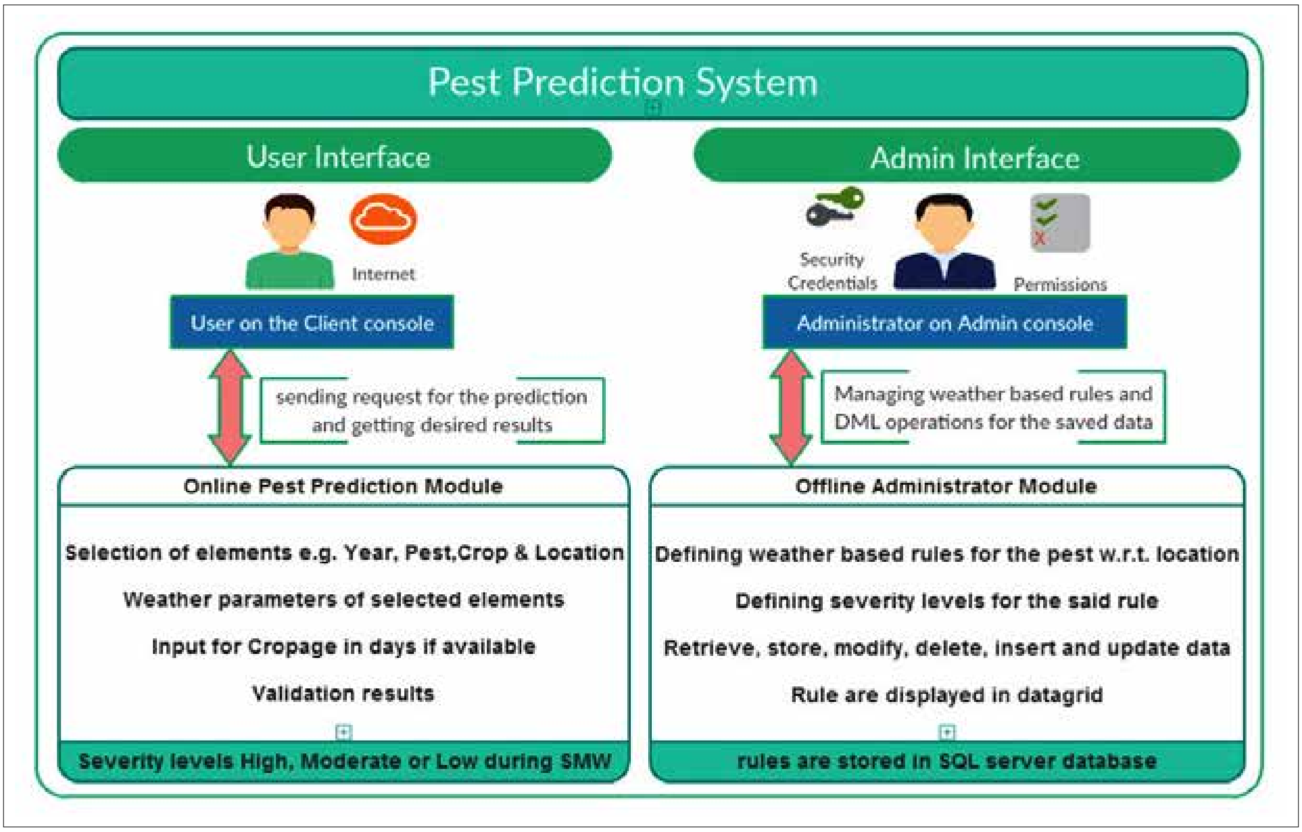


Fig. 3 : Architecture of weather based pest prediction system

Fig. 4 : Admin module of weather based pest prediction system

The web application required the defined incorporation of weather based criteria, pest severity levels and prediction rules for each pest with respect to individual locations. All weather parameters *viz.,* maximum temperature (Tmax.°C), minimum temperatures (Tmin.°C), mean temperature (Tmean.°C), morning relative humidity (RHI %), evening relative humidity (RHII %), mean relative humidity (RHmean), total rainfall (RF mm week), sunshine (SSH h/day) and wind speed (WS km/h) and rainy days besides crop age (days) are the parameters made available in the web console. Although screen shoots of pests predictions show crop age (in days), all the models are insensitive to it as of now. Web enabled forecasting of rice pests is made available through the web link: ***http://www.ncipm.org.in/nicra/ForewarningSystem/PestPrediction.aspx***.

The following paragraphs give an account of each rice pest considered for prediction in terms of their description and the damage they cause along with the defined pest severity levels categorized based on the light trap catches, the developed weather based criteria and the prediction rules framed for each location for *kharif* season in particular and prediction accuracies in respect of insect pests of *kharif* season.

WEATHER BASED MODELS AND PREDICTION ACCURACIES

YELLOW STEM BORER *(Scirpophaga incertulas)*

YSB (*S. incertulas*) (Pyralidae: Lepidoptera) is a monophagous insect pest of rice causing damage during both vegetative and reproductive crop stages. There are five species of stem borers distributed throughout India. Yellow stem borer (YSB) *Scirpophaga incertulas* (Walker) is the most widespread, dominant, destructive, and causing yield losses to the tune of 27-34% every year (**Prasad *et.al.*, 2007**). YSB attacks the rice crop from nursery till maturity. Left over nurseries after transplantation and stubbles after harvest serve as an inoculum source for infestation in the next season.

Description - YSB female moth (Fig. 5) has yellowish forewings with a single dark spot at their center while the male (Fig. 6) has numerous small brown spots. A female lays eggs in batches of 50-80 on the lower side of the leaf blades and the stem. Eggs are covered with yellow brown hairs of female tuft. Egg masses vary in size and the number of eggs per mass also varies. Removal of seedling tips before transplanting helps in reducing stem borer incidence in the field. The fully grown larva is pale yellow in color with orange yellow head. It passes winter in rice stubbles and destruction of rice stubbles also thus helps in reducing incidence of this pest. Stem borer completes its life cycle in 40-45 days. Stem borers can destroy rice at any stage of the plant from seedling to maturity. They feed upon tillers and causes the formation of dead hearts or drying of the central tiller and death of the meristem, during vegetative stage (Fig. 7) and causes white-ears at reproductive stage (Fig. 8).

Fig. 5 : YSB - Female moth

Fig. 6 : YSB - Male moth

Damage - Only larva causes damage to the crop. After hatching, larva bores in to stem and damages it. Female sex pheromone traps are used for monitoring and mass trapping of the adults besides light traps. The stem borer larvae cause hole at the base of the plants during the vegetative stage. On older plants, they bore through the upper nodes and feed towards the base. Excessive tunneling through the sheath can destroy the crop. Its damage can reduce the number of reproductive tillers. At late infection, plants develop white ears. YSB damage can lead to about 20% yield loss in early planted and 80% in late-planted rice. Recovery or prevention of 5% of the losses to stem borers could feed approximately 140 million people for one year **(Datta, S. K. 2000)**. At Ludhiana (Punjab), YSB occurred majorly at maximum tillering phase and dominant during flowering stage **(Prakash *et al.*, 2014)**.

Fig. 7 : Dead heart symptom during vegetative stage

Fig. 8 : White ear symptom at reproductive stage

Table 3 specifies the levels of pest severity, developed weather based criteria and the prediction rules in respect of locations.

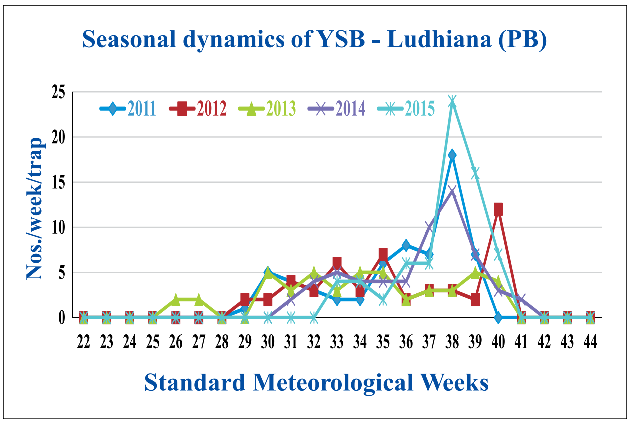
Table 3 : Weather based prediction for forewarning YSB

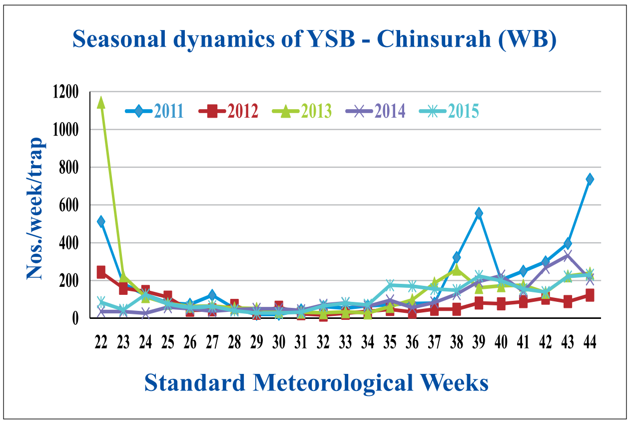
LOCATION	PEST SEVERITY	WEATHER CRITERIA	RULE*
Ludhiana (PB)	High (>100)	Tmax (30-33), Tmin (23-24), RHI (85-90), RHII (60-70) and RF (<10)	More than three
	Moderate (50-100)		Three
	Low (<50)		Two or less
Chinsurah (WB)	High (>200)	Tmax (33-36), Tmin (22-28) RHI (89-92), RF (≤10) and SSH (5-9)	More than three
	Moderate (100-200)		Three
	Low (<100)		Two or less
Raipur (CG)	High (>1000)	Tmax (31-34), Tmin (22-23), RHI (89-92%), RF (0-10) and SSH (6-9)	More than three
	Moderate (100-1000)		Three
	Low (<100)		Less than three
Karjat (MH)	High (>100)	Tmax (30-32), Tmin (23-24), RHI (94-95), RHII (70-78) and RF (<10)	More than three
	Moderate (50-100)		Three
	Low (<50)		Two or less
Hyderabad (TS)	High (>100)	Tmax 32-34, Tmin (24-25), RHI (70-75), RHII (40-55) and RF (<10)	More than three
	Moderate (50-100)		Three
	Low (<50)		Two or less
Mandya (KA)	High (>100)	Tmax (30-32), Tmin (21-22), RHI (90-94), RHII (45-55) and RF (<10)	More than three
	Moderate (50-100)		Three
	Low (<50)		Two or less
Aduthurai (TN)	High (>200)	Tmax (30-32) Tmin (20-22), RHI (90-93), RF (<10) and SSH (8- 9)	More than three
	Moderate (100-200)		Three
	Low (<100)		Two or less

Note : Pest severity is based on the light trap catches of moths (nos.) / week.
Weather criteria is based on weekly means of Tmax (maximum temperature in ^{o}C), Tmin (minimum temperature in ^{o}C), RHI (morning relative humidity in %), RHII (evening relative humidity in %), SSH (sunshine hours in h /day) and RF (total rainfall in mm on weekly basis).

* : Number of weather based criteria satisfied out of five.

The seasonal dynamics of the YSB moth catches in light trap (nos/week/trap) used in validation of the weather based prediction criteria and rules are furnished for the *kharif* season (22-44 SMW) of the RTPD locations.


Seasonal dynamics of YSB - Ludhiana (PB)
2011 2012 2013 2014 2015
Nos./week/trap
Standard Meteorological Weeks


Seasonal dynamics of YSB - Chinsurah (WB)
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Nos./week/trap
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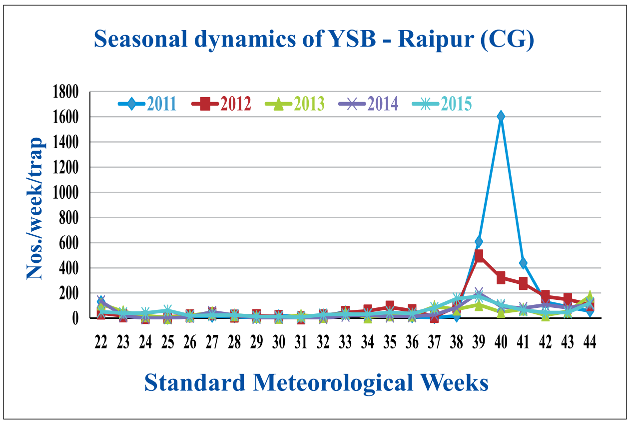
Seasonal dynamics of YSB - Raipur (CG)
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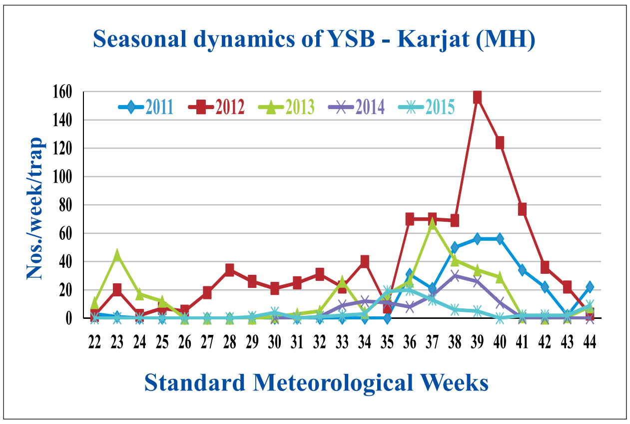
Seasonal dynamics of YSB - Karjat (MH)
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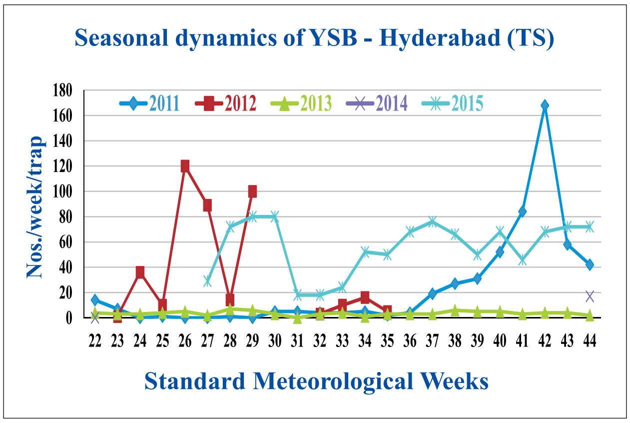
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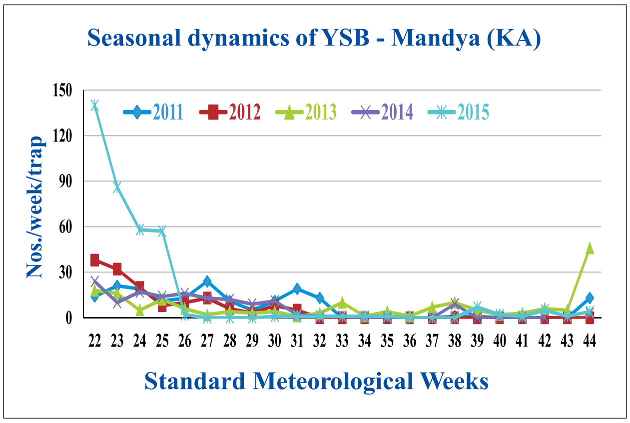
Seasonal dynamics of YSB - Mandya (KA)
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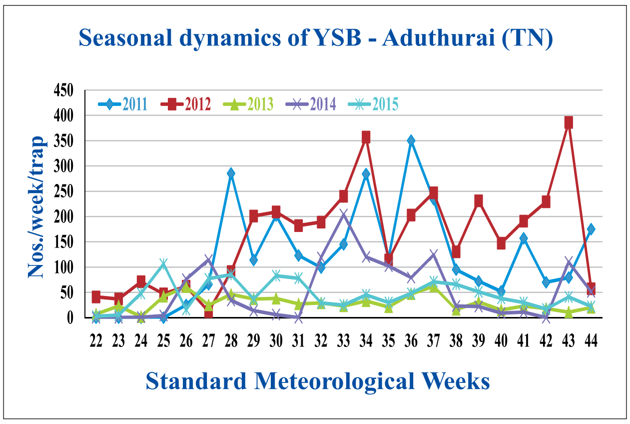
Nos./week/trap
Standard Meteorological Weeks


Seasonal dynamics of YSB - Aduthurai (TN)
2011 2012 2013 2014 2015
Nos./week/trap
Standard Meteorological Weeks

PREDICTION ACCURACY

LOCATION	*Kharif* Season				
	2011	2012	2013	2014	2015
Ludhiana (PB)	91.3	95.65	82.61	82.61	95.65
Chinsurah (WB)	52.17	56.52	34.78	52.17	60.87
Raipur (CG)	86.96	95.65	78.26	82.61	69.57
Karjat (MH)	86.96	73.91	82.61	86.96	86.36
Hyderabad (TS)	91.30	54.55	91.30	50.00	100.00
Mandya (KA)	39.13	17.39	82.61	86.96	73.91
Aduthurai (TN)	47.83	34.78	100.00	65.22	95.65

Validation of YSB for the *kharif* season indicated that prediction accuracy varied across the seasons. Greater than 80% accuracy of forecast was observed at Ludhiana (PB) that grows rice only during *kharif*. Maximum prediction accuracy at Chinsurah (WB) was 61%. Raipur (CG) and Karjat (MH) had relatively better forecasts during all seasons (>70%). Accuracies at Mandya (KA) and Aduthurai (TN) were better for 2013, 2014 and 2015 seasons over 2011 and 2012. The higher variations in predictions across the seasons was noticed at Hyderabad (TS).

A sample snapshot of the display of YSB prediction through web application is given in Fig. 9.

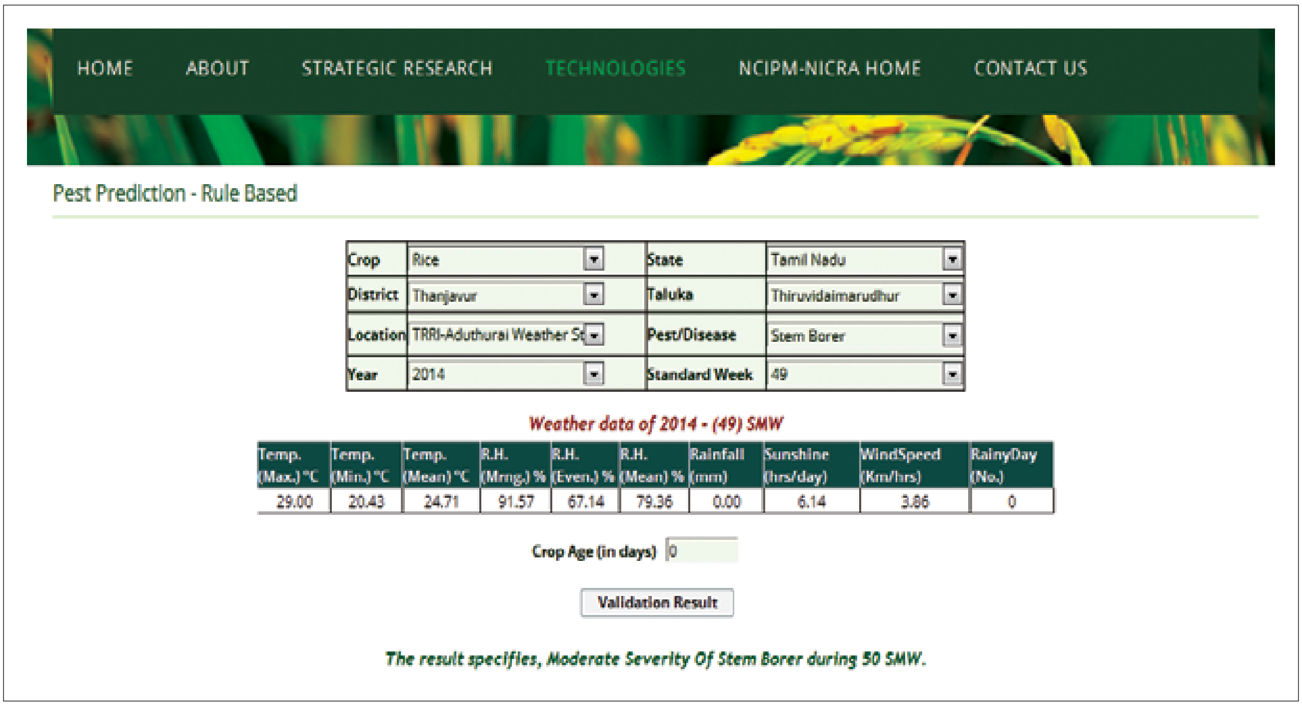


Fig. 9 : Screen shot on the prediction of YSB of rice at Aduthurai (TN)

LEAF FOLDER (*Cnaphalocrocis medinalis*)

The rice leaf folder, *Cnaphalocrocis medinalis* (Guenee) (Pyralidae: Lepidoptera) is one of the major pests of rice and causes serious economic loss when its severe infestation coincides with susceptible crop growth stages (maximum tillering to booting). Rice leaf folder occurs in all rice environments and are more abundant during the rainy seasons. They are commonly found in shady areas, and areas where rice is heavily fertilized. In tropical rice areas, they are active year-round, whereas in temperate countries they are active from May to October. Expanded rice areas with irrigation systems, multiple rice cropping and insecticide induced resurgences are important factors affecting its abundance. Indiscriminate applications of carbofuran and phorate leading to resurgence of leaf folder populations has further compounded the problem (**Pasalu *et al.*, 2005**).

Fig. 10 : Leaf folder moth

Description - The adults (Fig. 10) are nocturnal, and during the day they stay under shade to escape predation. Moths fly short distances when disturbed (**Anonymous, 2014d**). Eggs are flat and oval, laid singly and the hatched larvae distribute across the leaves starting with the late second instar. Larvae roll up leaves once they become solitary (Fig. 11).

Fig. 11 : Larva within rice shoot

Leaf folder undergoes two to three generations per season on rice crop. The first brood on rice is initiated mainly through the immigrating adults while the second and third broods develop within the crop and are the most damaging.

Damage - Leaf folder caterpillars fold the rice leaf around themselves and attach the leaf margins together with silk strands. They feed from inside the folded leaf by scraping the green mesophyll resulting in longitudinal white and transparent streaks of damage on the blade (Fig. 12). The general vigour and photosynthetic ability of infested plants gets reduced.

Fig. 12 : Leaf folder damage

In cases of severe infestation, the leaf margins and tips are dried up entirely and the crop gives a whitish/papery appearance. Heavy use of fertilizer encourages rapid multiplication of the insect. High humidity and shady areas of the field, as well as the presence of grassy weeds from rice fields and surrounding borders favor the development of the pest **(Anonymous, 2014e)**.

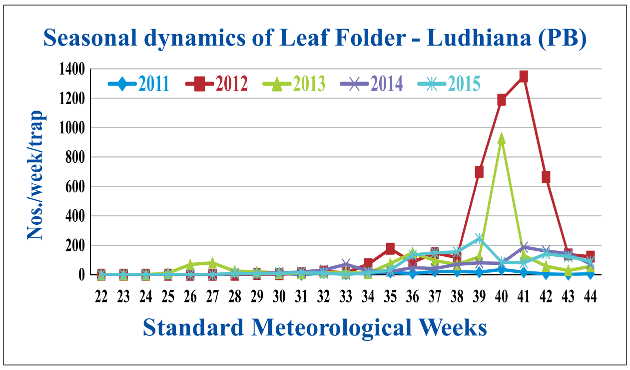
Table 4 : Weather based prediction for forewarning leaf folder

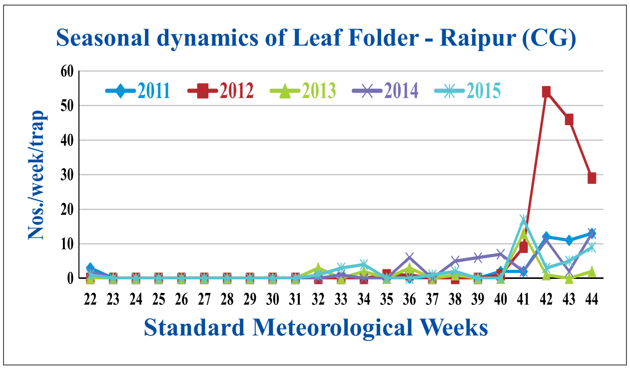
LOCATION	PEST SEVERITY	WEATHER CRITERIA	RULE*
Ludhiana (PB)	High (>1000)	Tmax (30-33), Tmin (20-24), RHI (88-94), RF (0-10) and SSH (7-9)	More than three
	Moderate(100-1000)		Three
	Low (<100)		Two or less
Raipur (CG)	High (>100)	Tmax (31-34), Tmin (22-23), RHI (89-92%), RF (0-10) and SSH (6-9)	More than three
	Moderate (50-100)		Three
	Low (<50)		Less than three
Aduthurai (TN)	High (>200)	Tmax (30-32) Tmin (20-22), RHI (90-93), RF (<10) and SSH (8- 9)	More than three
	Moderate (100-200)		Three
	Low (<100)		Two or less

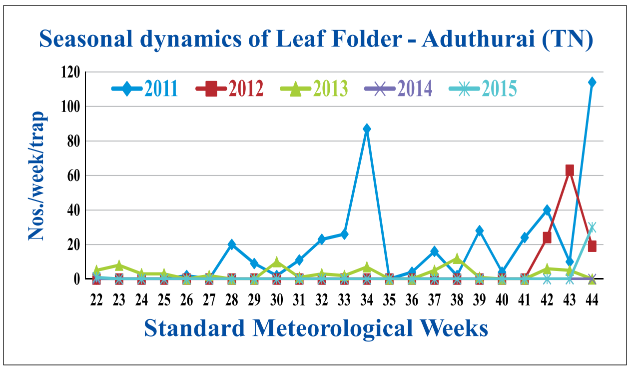
Note : Pest severity is based on the light trap catches of moths (nos.) / week.
Weather criteria is based on weekly means of Tmax (maximum temperature in ^{o}C), Tmin (minimum temperature in ^{o}C), RHI (morning relative humidity in %), SSH (sunshine hours in h/day) and RF (total rainfall in mm on weekly basis).

* : Number of weather based criteria satisfied out of five.

The seasonal dynamics of the leaf folder moths in light trap (nos./week/trap) used in validation of the weather based prediction criteria and rules are furnished for the *kharif* season (22-44 SMW) of the RTPD locations.







The order of importance of the leaf folder incidence across RTPDs is; Ludhiana (PB)> Aduthurai (TN)> Raipur (CG). 2012 and 2013 seasons at Ludhiana (PB) had moderate to high severity levels during the maturity stage (30-42 SMW) of the crop. But for 2012, Raipur (CG) had low severity of leaf folder. Highly fluctuating populations of leaf folder are noticed at Aduthurai (TN) between 2011 and 2013, sudden population increase is noticed in the 44^{th} SMW of 2015, although 2014 had the least severity.

PREDICTION ACCURACY

The accuracy of weather based prediction is always greater than 95% at Aduthrai (TN). The range of accuracy of predictions varied between 65 -78 and 65-90% for Ludhaina (PB) and Raipur (CG), respectively.

LOCATION	*Kharif* Season				
	2011	2012	2013	2014	2015
Ludhiana (PB)	65.22	78.26	73.91	73.91	65.22
Raipur (CG)	73.91	78.26	91.30	86.96	65.22
Aduthurai (TN)	95.65	100.00	100.00	95.65	100.00

A sample snapshot of the display of leaf folder prediction through web application is given in Fig. 13.

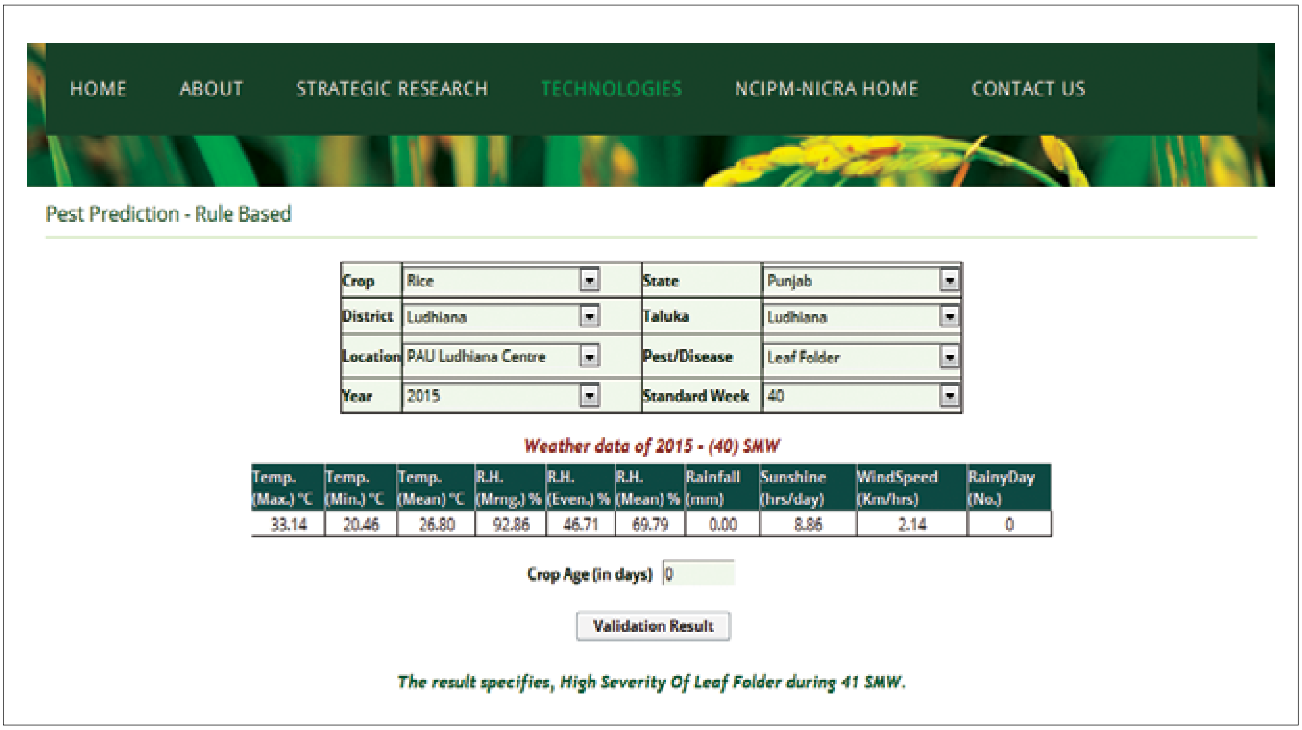


Fig. 13 : Screen shot on the prediction of rice leaf folder for Ludhiana (PB)

BROWN PLANT HOPPER (*Nilaparvata lugens*)

Plant hoppers are a problem in rainfed as well as in irrigated wet land environments. It also occurs in areas with continuous submerged conditions in the field, high shade, and humidity. Dense rice crop under continuously flooded conditions and excess use of nitrogenous fertilizers provides very congenial environment for plant hopper population build up. Brown plant hopper (BPH) is one of the five key species of plant and leaf hoppers which are known to be important pests of rice. BPH (*Nilaparvata lugens*) belongs to the family of Delphacidae (Homoptera:Hemiptera). BPH is known for their resistance to commonly used insecticides including the neonicotinoids. Hence crop failures due to severe pest outbreaks are very common in many rice-growing tracts of India.

Fig. 14 : BPH feeding near the base of tillers

Description - BPH are small (about 5 mm long) insects, and both the nymphs and adults suck sap from plants. They feed near the base of the rice plant above water level (Fig. 14) that they often escape detection. BPH usually exists in two forms namely the long-winged or macropterous form and the short-winged or brachypterous form. The rice field is first invaded by the macropterous BPH (Fig. 15) and if younger rice plants exist, the next generation will be largely brachypterous. BPH are known to undertake long range migration.

Fig. 15 : Macropterous BPH

Damage - High population of plant hoppers cause leaves to initially turn orange-yellow before becoming brown and drying. Severe attack causes drying of tillers and hills, resulting in a scorched appearance in the fields called 'hopperburn' wherein complete drying of the plants is observed and can result in 100% crop loss (Fig. 16). In field conditions, plants nearing maturity can have hopper burns if infested with about 400-500 nymphs/plant. BPH can also transmit rice ragged stunt and grassy stunt diseases. None of the diseases can be cured.

Fig. 16 : Hopperburn

BPH caused wide spread devastation of rice crop during *kharif* 2008 in North India and again during *kharif* 2010. It also becomes serious in sporadic pockets. Under favorable conditions they multiply very fast. Temperature, relative humidity and prevailing wind direction determine the severity of incidence and spread of BPH. Use of synthetic pyrethroids coupled with high relative humidity (>85%) favoured the population buildup of *N. lugens* during the first fortnight of December resulting in 'hopper burn' across experimental and farmer's fields of Thanjavur (TN).

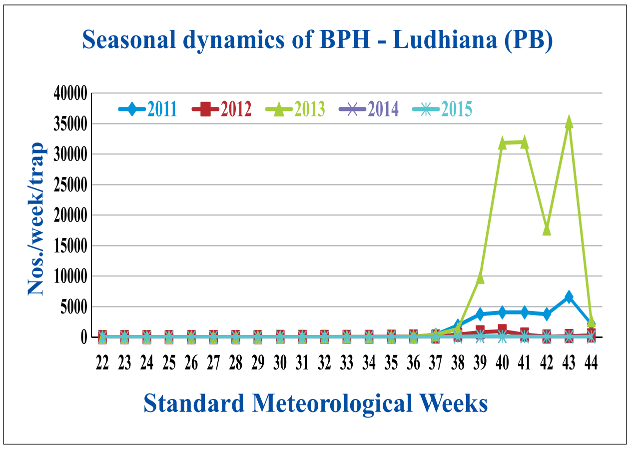
Table 5 : Weather based prediction for forewarning BPH

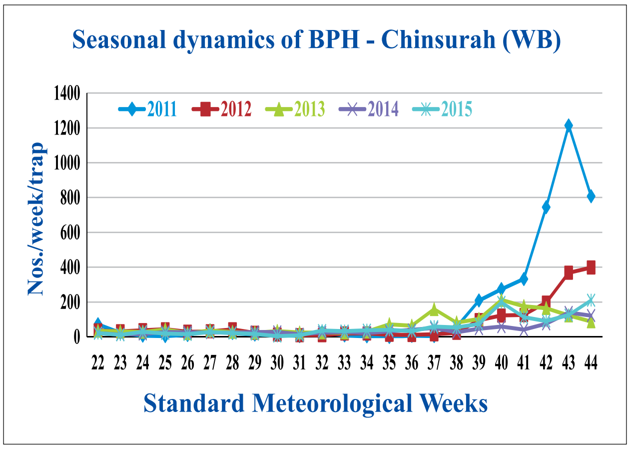
LOCATION	PEST SEVERITY	WEATHER CRITERIA	RULE*
Ludhiana (PB)	High (>1000)	Tmean (26-28), RHmean (66-75), RF (≤ 25) SSH (8-10) and WS (0-5)	More than three
	Moderate (200-1000)		Three
	Low (<200)		Less than three
Chinsurah (WB)	High (>200)	Tmax (33-34), Tmin (22-25), RF (0-10), RHI (89-92), RHII (55-65) and SSH (6-9).	Greater than four
	Moderate (100- 200)		Four
	Low (<100)		Less than four
Raipur (CG)	High (>1000)	Tmean (22-28), RHmean (60-80) RF (≤ 25), SSH (8-9) and WS (0-5)	More than three
	Moderate (200-1000)		Three
	Low (<200)		Less than three
Hyderabad (TS)	High (>200)	Tmax (30-33), Tmin (20-22), RF (0-10), RHI (80-90) and RHII (40-60)	Greater than three
	Moderate (100- 200)		Three
	Low (<100)		Less than three
Mandya (KA)	High (>200)	Tmax (30-32), Tmin (21-22), RHI (90-94), RHII (45-50) and RF (<10)	More than three
	Moderate (100-200)		Three
	Low (<100)		Two or less
Aduthurai (TN)	High (>500)	Tmean (24-28), RHmean (≥ 78%), RF (≤ 25) SSH (8-9) and WS (0-6)	More than three
	Moderate (100-500)		Three
	Low (<100)		Less than three

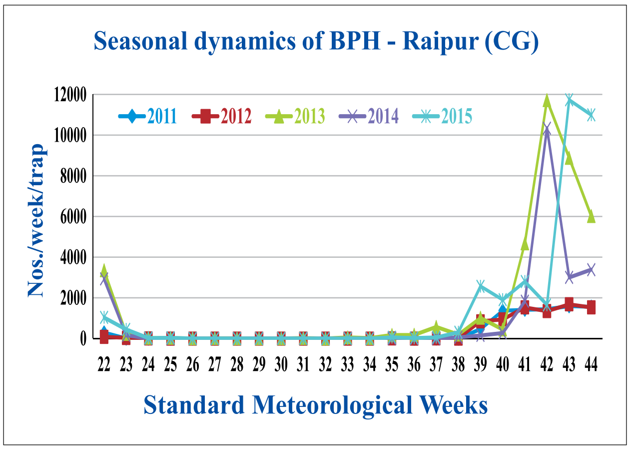
Note : Pest severity is based on the light trap catches of BPH (nos.) / week.
Weather criteria is based on weekly means of Tmax (maximum temperature in ^{o}C), Tmin (minimum temperature in ^{o}C), RHI (morning relative humidity in %), RHII (evening relative humidity in %), SSH (sunshine hours in h /day) and RF (total rainfall in mm on weekly basis).

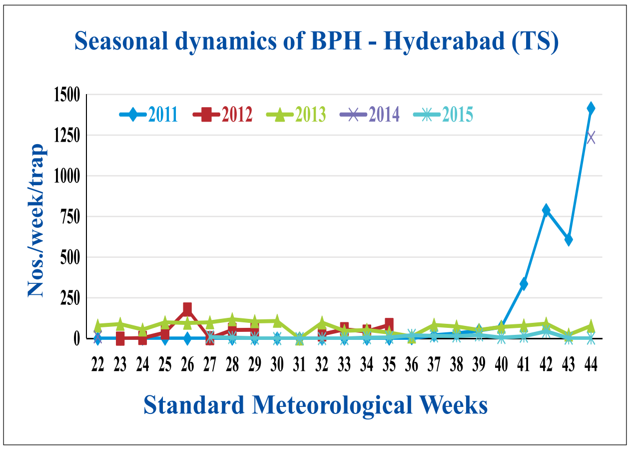
* : Number of weather based criteria satisfied out of five or six.

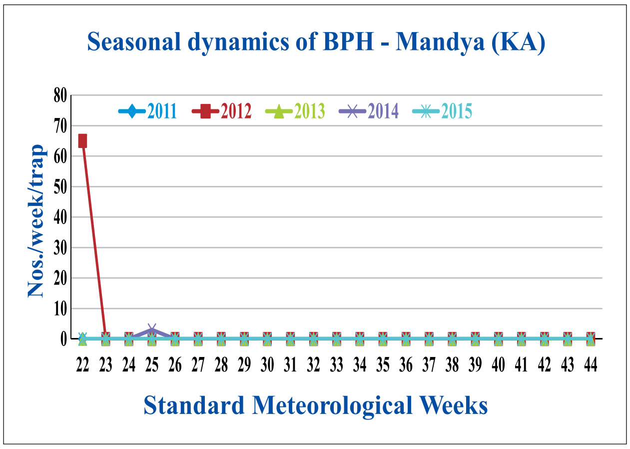
The pest prediction rules for BPH were developed for various locations with respect to the weather parameters *viz.*, mean temperature, mean relative humidity, rainfall, sunshine and wind speed. The significance/incidence of BPH across RTPD locations is of the order Ludhiana (PB)> Raipur (CG)> Chinsurah (WB) > Hyderabad (TS)>Aduthurai (TN)> Mandya (KA). Occasional early occurrences of BPH are common at Mandya (KA) and Aduthurai (TN). Incidence from 38 SMW is common among almost all locations except Mandya (KA). High severity of BPH at Ludhiana (PB) (>30000 nos./trap/week) during 2013 and Raipur (CG) (12000 nos./trap/week) for 2013 and 2015 was observed. *Kharif* 2014 had BPH severity (>10000 nos./trap/week) only at Raipur (CG). Ludhiana (PB), Hyderabad (TS) and Aduthurai (TN) has least severity of BPH in 2015.

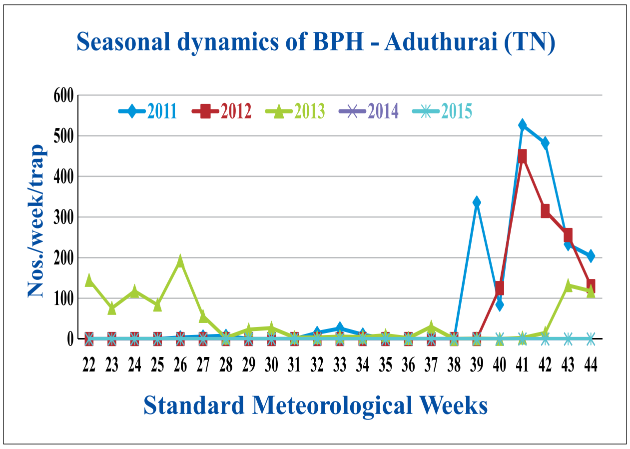












PREDICTION ACCURACY

Chinsurah (WB), Raipur (CG) and Aduthurai (TN) had greater than 70% accuracy of BPH prediction during all the seasons. Although the prediction levels at Ludhiana (PB) were higher during 2011 (83%)

and 2012 (74%), the three successive seasons between 2013 and 2015 had relatively reduced prediction accuracy (61%) possibly due to the fertilizer and insecticide induced severity over the weather dependent population development. The lowest prediction accuracy of 30% in 2012 at Mandya (KA) could be due to the occasional occurrence (60 nos./trap/week) of BPH possibly brought out by immigrants that did not establish further. Prediction criteria of Hyderabad had around 50% prediction accuracy relatively lower than for other seasons (2013 and 2014) seasons. Lowest prediction accuracies are noted whenever the BPH populations *per se* are very low for the season / location or populations tend to occur during the early crop season.

LOCATION	*Kharif* season				
	2011	2012	2013	2014	2015
Ludhiana (PB)	82.61	73.91	60.87	60.87	60.87
Chinsurah (WB)	73.91	73.91	73.91	86.96	73.91
Raipur (CG)	78.26	91.30	69.57	82.61	73.91
Hyderabad (TS)	78.26	81.82	52.71	50.00	83.33
Mandya (KA)	60.87	30.43	100.00	95.65	95.65
Aduthurai (TN)	95.65	95.65	82.61	78.26	78.26

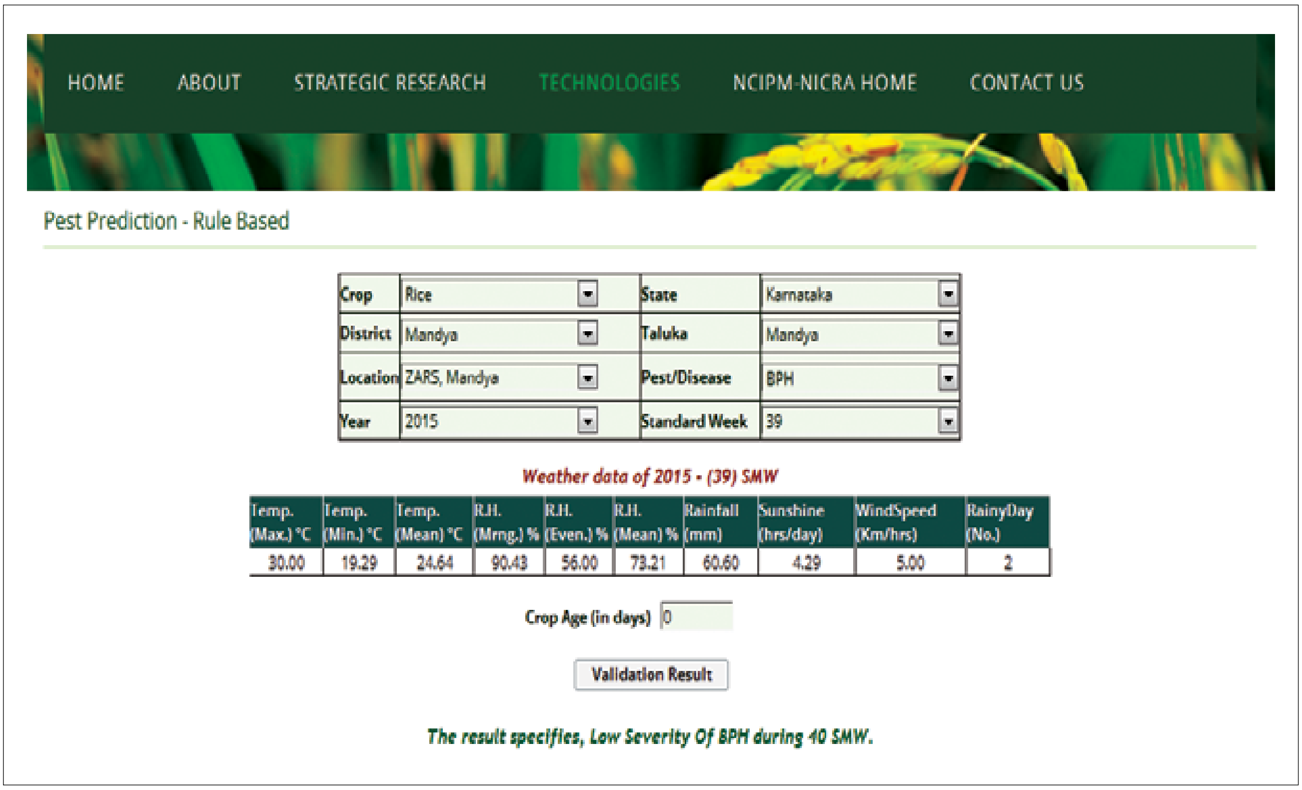


Fig. 17 : Screen shot on the prediction of BPH for Mandya (KA)

WHITE BACKED PLANT HOPPER (*Sogatella furcifera*)

White backed plant hopper (WBPH), *Sogatella furcifera (*Horvath) (Delphacidae: Homoptera (Hemiptera) on rice is one of the most important sucking pests in India in many rice growing tracts. During 70s and 80s WBPH used to be confined to North-Western belt of Punjab, Haryana, and Western Uttar Pradesh. Later, the pest has spread to almost all areas where rice is grown and started occurring together with BPH in many deltas of the Southern States. This has emerged as a serious pest in areas particularly where rice varieties resistant to BPH are grown **(Krishnaiah *et a*l. 2008)**. Some of the factors responsible for severe infestation levels are introduction of high-yielding but susceptible varieties, high input use especially use of nitrogenous fertilizers and use of broad spectrum synthetic insecticides. Temperature also plays a vital role in WBPH development, survival and reproduction. Serious incidence of WBPH coincides with maximum tillering stage with appearance of 'hopper burn' symptoms towards crop maturity.

Description - Like BPH, the white-backed plant hopper exists in two forms. The long-winged form invades rice fields and the next generations are short-winged forms that are reproduced at a faster rate. WBPH nymphs and adults (Fig. 18) are found on the upper portion of the stems (Fig. 19), majority at the junction between leaves and stems. Both nymphs and adults suck sap from plants and actively multiply under congenial weather conditions.

Fig. 18: White backed plant hopper

Fig. 19: WBPH feeding near the base of tillers

Damage - Serious damage usually occurs during the early stages of plant growth with symptoms of hopperburn due to intensive sucking by the insect **(Dale, 1994).** At a population density of 400-500 nymphs or 200 adults per plant, WBPH can cause complete loss of rice crop. WBPH under favorable conditions can cause 35-95% yield loss **(Sidhu, 1979).**

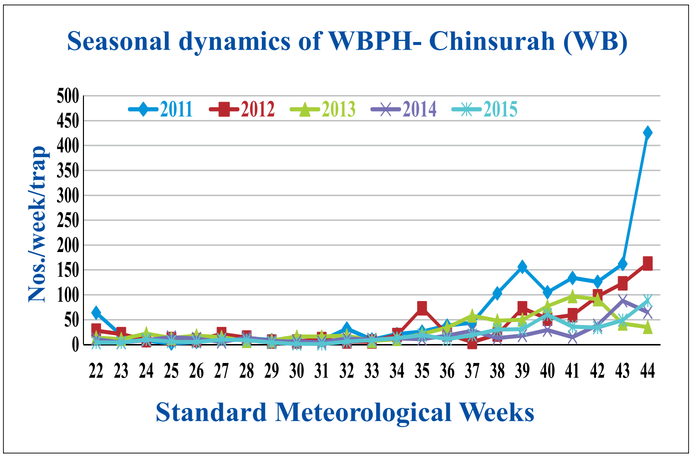
Table 6 : Weather based prediction for forewarning WBPH

LOCATION	PEST SEVERITY	WEATHER CRITERIA	RULE*
Chinsurah (WB)	High (>200)	Tmax (33-34), Tmin (22-25), RHI (89-92), RHII (55-65), RF (0-10) and SSH (6-9).	Greater than four
	Moderate (100- 200)		Four
	Low (<100)		Less than four

Note : Pest severity is based on the light trap catches of WBPH (nos.) / week.
Weather criteria is based on weekly means of Tmax (maximum temperature in °C), Tmin (minimum temperature in °C), RHI (morning relative humidity in %), RHII (evening relative humidity in %), SSH (sunshine hours in h /day) and RF (total rainfall in mm on weekly basis).

* : Number of weather based criteria satisfied out of six.

WBPH being a regular pest at Chinsurah (WB) and that data were available weather based prediction was attempted only for this location. Effective occurrence of WBPH at Chinsurah (WB) commences from 37/38 SMWs beyond which there is continuous population development. The incidence has been on the decline in the recent years (2011>2012>2013>2014>2015).



PREDICTION ACCURACY

Prediction accuracy was higher than 70% across seasons towards prediction of WBPH at Chinsurah (WB)

LOCATION	*Kharif* Season				
	2011	2012	2013	2014	2015
Chinsurah (WB)	69.57	86.96	100.00	95.65	91.30

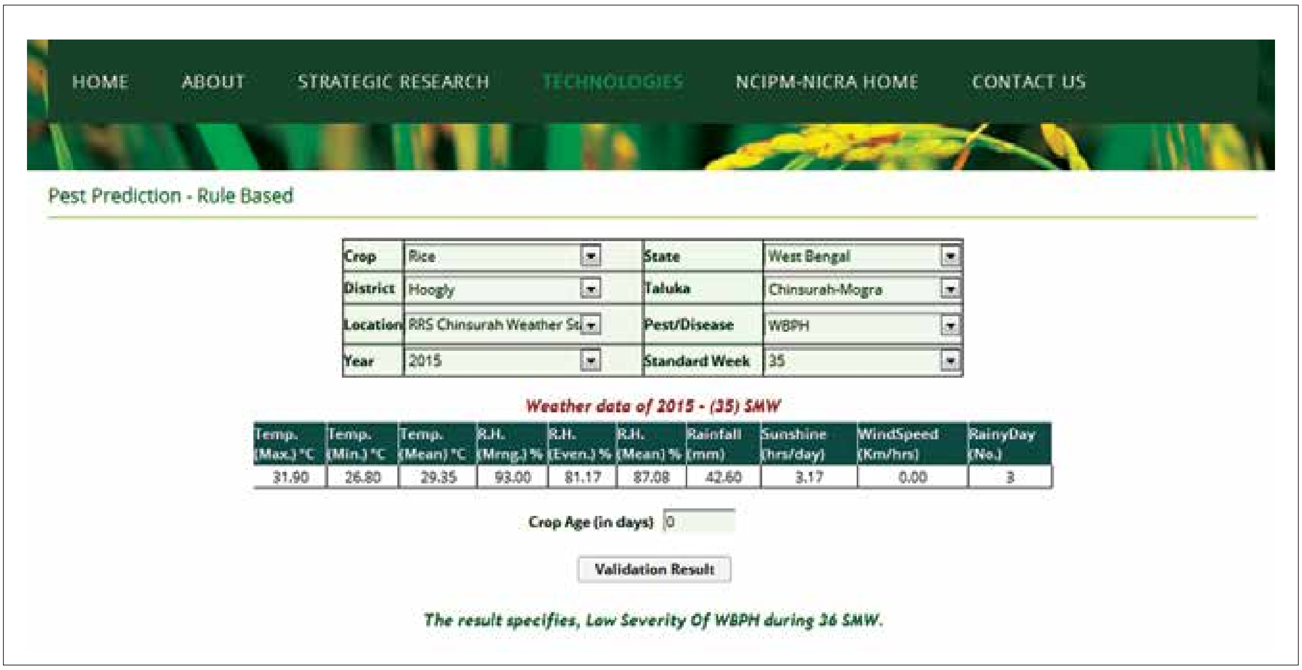


Fig. 20 : Screen shot on the prediction of WBPH for Chinsurah (WB)

GREEN LEAF HOPPER (*Nephotettix virescens; N. nigropictus*)

Green leafhoppers (*Nephotettix virescens* (Distant) and *N.nigropictus* (Stal.) (Cicadellidae: Homoptera: Hemiptera) are the most common leafhoppers in rice fields and are primarily important because they spread the vector viral disease tungro. All stages of the rice crop are attacked by the leafhoppers. Both nymphs and adults feed by extracting plant sap on the lateral surface (dorsal) of the leaf blades rather than the ventral surface (leaf sheaths and the middle leaves) with their needle-shaped mouthparts. GLH are common in rainfed and irrigated wetland environments and are not prevalent in upland rice. They also prefer rice plants that have been fertilized with large amount of nitrogen.

Fig. 21 : Nymphs of GLH

Description - Eggs are greenish and transparent, deposited in the midrib of leaf blade or sheath of rice or green grass. They are laid in batches of 10 to 15 arranged in a single row. The early instar nymphs are soft bodied and yellow white in color. Along the development of nymphs into adults through five instars, the color changes to green over a period of 18-20 days (Fig. 21). Adults are 3-5 mm long, bright green with variable black markings, wedge shaped (Fig. 22) with a characteristic diagonal movement. Males have black spots in middle of the forewings that are absent in females.

Fig. 22 : Adults of GLH

Damage – Direct damage by the GLH is by sucking plant sap leading to stunted growth and reduced tillering. At high population levels their feeding results in the drying of the plants and the infested rice fields appear blighted. Infestation at the time of panicle emergence affects grain formation **(Pasalu *et al*., 2015)**. Rice tungro virus (Fig. 23) is transmitted by both young (nymphs) and adult green leafhoppers (indirect damage) that feed on diseased plants. As these insects fly and feed on other plants, the virus particles from the stylets get introduced into healthy plants. The insects pick up virus particles within 7 minutes of feeding and can transmit these particles to other healthy plants. Symptoms appear 10-14 days after introduction of virus in plants. Tungro virus disease causes discoloration of leaves from light green to orange-yellow. At times of heavy infestation, the crop turns yellow and dry. The optimum conditions for multiplication of *N. virescens* and *N. nigropictus* are about 25^{o}C temperature and 80% relative humidity. Both the insects are more numerous during September and October months of *kharif*. **(Krishnaiah *et al.*, 2008).**

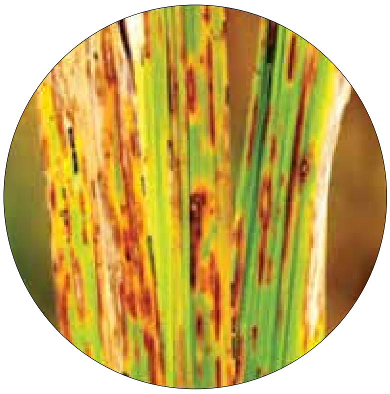


Fig. 23 : Symptoms of tungro virus disease

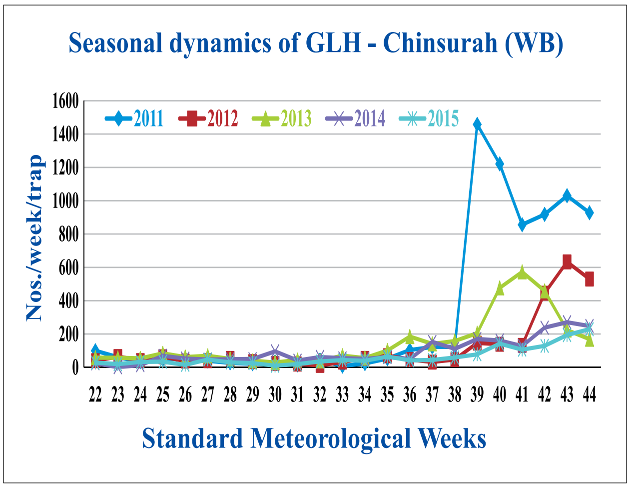
Table 7 : Weather based prediction for forewarning green leaf hopper

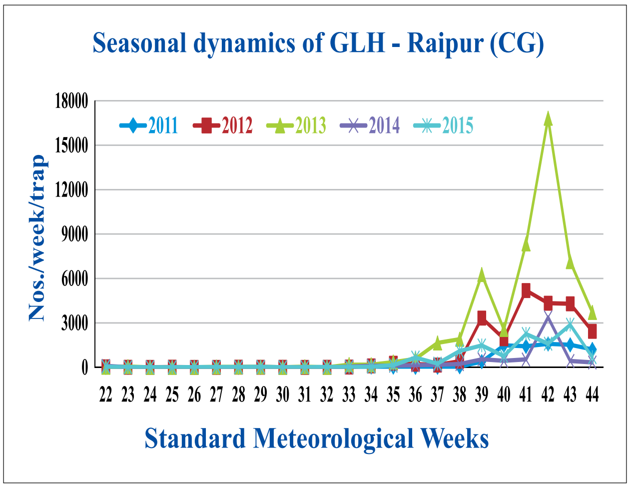
LOCATION	PEST SEVERITY	WEATHER CRITERIA	RULE*
Chinsurah (WB)	High (>2000)	Tmax (33-34), Tmin (22-25), RHI (89-92), RHII (55-65), RF (<10) and SSH (6-9)	Greater than four
	Moderate (1000-2000)		Four
	Low (<1000)		Less than four
Raipur (CG)	High (>2000)	Tmax (31-34), Tmin (20-23), RHI (89-93) , RF (<10) and SSH (8-9)	More than three
	Moderate (1000-2000)		Three
	Low (<1000)		Less than three
Karjat (MH)	High (>200)	Tmax (30-33), Tmin (22-24), RHI (80-90), RHII (40-60), RF (0-10) and SSH (5-7)	Greater than four
	Moderate (100- 200)		Four
	Low (<100)		Less than four
Hyderabad (TS)	High (>2000)	Tmax (30-32), Tmin (18-23), RHI (89-92), RHII (60-70) and RF (<10)	More than three
	Moderate (1000-2000)		Three
	Low (<1000)		Less than three
Mandya (KA)	High (>200)	Tmax (27-30), Tmin (15-20), RHI (85-92), RHII (50-55) and RF (<10)	More than three
	Moderate (100-200)		Three
	Low (<100)		Two or less
Aduthurai (TN)	High (>2000)	Tmax (30-32), Tmin (18-23), RHI (89-92), RHII (60-70), RF (<10) and SSH (6-9)	Greater than four
	Moderate (1000-2000)		Four
	Low (<1000)		Less than four

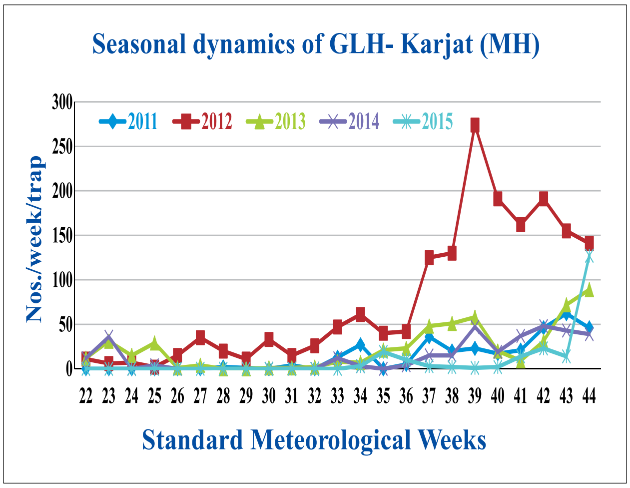
Note : Pest severity is based on the light trap catches of GLH (nos.) / week.
Weather criteria is based on weekly means of Tmax (maximum temperature in ^{o}C), Tmin (minimum temperature in ^{o}C), RHI (morning relative humidity in %), RHII (evening relative humidity in %), SSH (sunshine hours in h /day) and RF (total rainfall in mm on weekly basis).

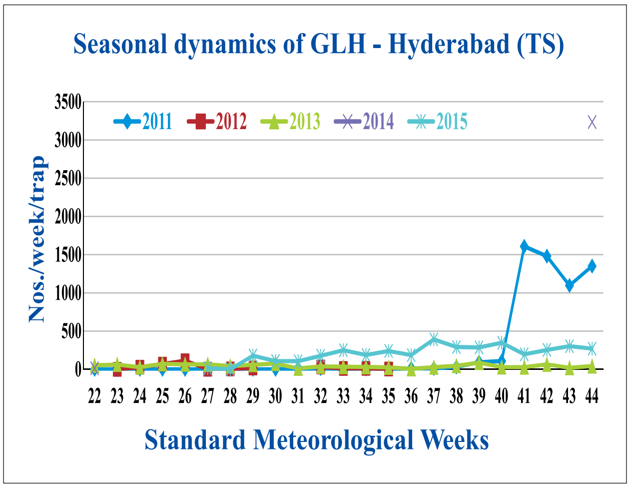
* : Number of weather based criteria satisfied out of five or six.

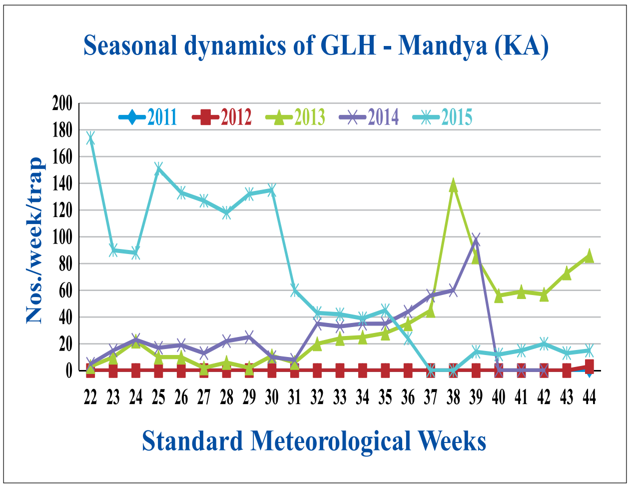
The importance of the GLH across the RTPD locations followed the order: Raipur (CG), Chinsurah (WB), Aduthurai (TN)> Hyderabad (TS)> Karjat (MH)>Mandya (KA). At Raipur (CG) and Chinsurah (WB), GLH has been a mid to late season pest with peaks between 39-42 SMWs. On the other hand Aduthurai (TN), Karjat (MH) and Mandya (KA) had infestations throughout the season albeit low level as compared to other locations. Highly fluctuating population was observed in 2015 at Mandya (KA). Relative GLH severity in respect of seasons for Raipur (CG) was 2013>2012>2015>2011>2014 and for Chinsurah (WB) was 2011>2012>2013>2014>2015. Aduthurai (TN) had the increasing trend of GLH during 2014 over all four seasons. Importance of GLH was considerably high in 2015 as compared to 2011-2014, but significant for 2011 beyond 40 SMW at Hyderabad (TS).

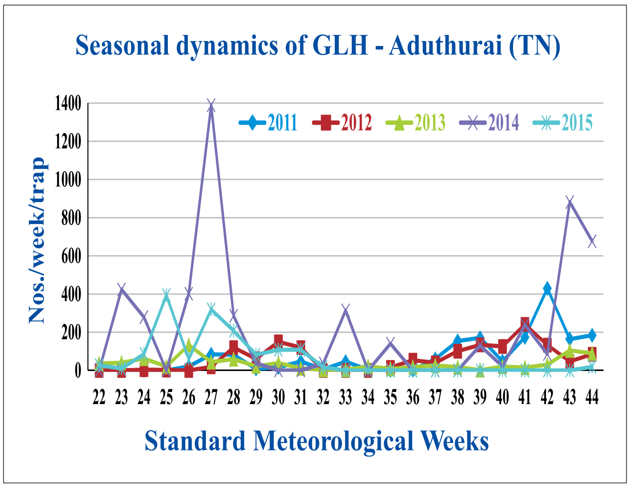












PREDICTION ACCURACY

Better GLH prediction accuracies existed for Chinsurah (WB) and Aduthurai (TN) (>90%). While Raipur (CG) had 70 and greater prediction accuracy, Hyderabad (TS) had >80% accuracy for the seasons 2011-13 and 2015 but for 2014 (50%) when late season moderate severity was observed. Similar is the scenario with Karjat (MH). This again confirms the high reliability of heuristic predictions at low severity levels of the insects including GLH. On the contrary, decreased levels of prediction accuracies in the recent (2014 and 2015) over past (2011-2013) seasons at Mandya (KA) had arisen due to the high severity predictions not validating well with the observed low severity thus suggesting the requirement for refinement of either the weather based criteria or pest severity levels along with the prediction rules.

LOCATION	***Kharif* Season**				
	2011	**2012**	**2013**	**2014**	**2015**
Chinsurah (WB)	86.96	95.65	100.00	95.65	91.30
Raipur (CG)	86.96	82.61	69.57	91.30	78.26
Karjat (MH)	100.00	60.87	95.65	95.00	91.30
Hyderabad (TS)	82.61	90.91	95.65	50.00	100.00
Mandya (KA)	60.87	56.52	100.00	39.13	34.78
Aduthurai (TN)	100.00	100.00	95.65	91.30	100.00

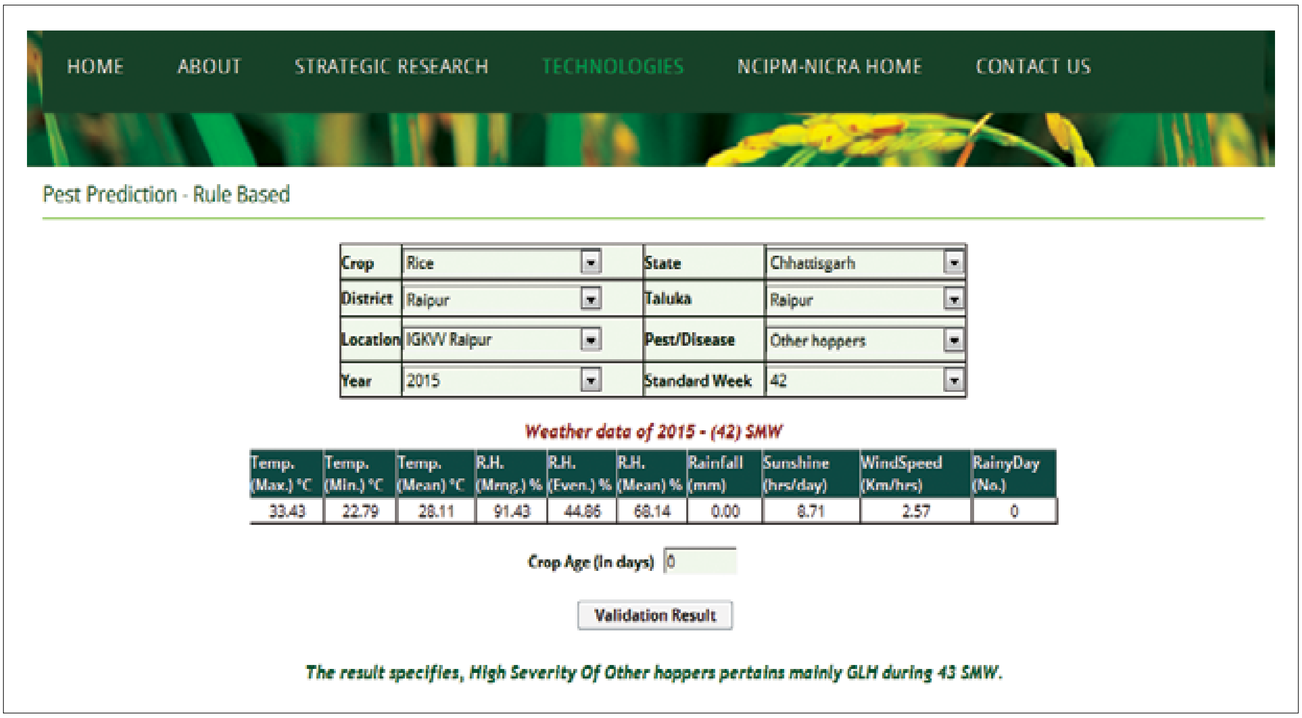


Fig. 24 : Screen shot on the prediction of GLH for Raipur (CG)

GALL MIDGE (*Orseolia oryzae*)

Asian rice gall midge (*O. oryzae*) (Cecidomyiidae: Diptera) is a major insect pest of rice causing significant economic loss to the crop over space and time. It is found in irrigated and rainfed wetland environments during the tillering stage of the crop. It is also common in upland and deep-water rice **(Pasalu *et al.*, 2005).** Gall midge causes yield losses of 30-40% in some parts of India. Gall midge is more severe, in late planted conditions. The optimum temperature for rice gall midge development is 22 to 26^{o}C (**Devi and Devi, 1997**).

Fig. 25 : Gall midge adult

Description - The adult fly is orange colored and mosquito (Fig. 25) like with slender and long legs. The female has bright yellow abdomen whereas the male is dark in color. The adults are nocturnal. The female lays reddish elongated eggs near the ligule of the leaf blade or sheath. For proper egg hatching of gall midge, 90 to 100% humidity is essential (**Krishnaiah *et al.*, 2008**). Maggots are pale (Fig. 26) to red colored, and remain inside the gall. High humidity and a thin film of water are required for larval dispersal and entry into the plant. Pupation occurs at the base of the gall and are dormant during dry seasons only to become active after the rains.

Fig. 26 : Gall midge maggot

Damage – Feeding by the maggots of the gall midge on the growing tip of rice plants results in elongation of the leaf sheath often referred as onion leaf or silver shoot (Fig. 27). A hollow cavity or tubular gall of approximately 1 cm wide and 10-30 cm long is formed at the base of tillers. Galls appear within a week after the larvae reach the growing point. In some cases there would be no gall development but necrosis of the growing tip is noticed. The symptom appears from the nursery to the flowering stage. Profuse tillering and stunting of plants are associated with gall formation. Stunted, deformed and wilted plants with rolled 'onion like' leaves are indicators of midge infestation in the rice fields. Infected tillers also fail to produce panicles while inhibiting the growth of leaves.

Fig. 27 : Onion leaf or silver shoot

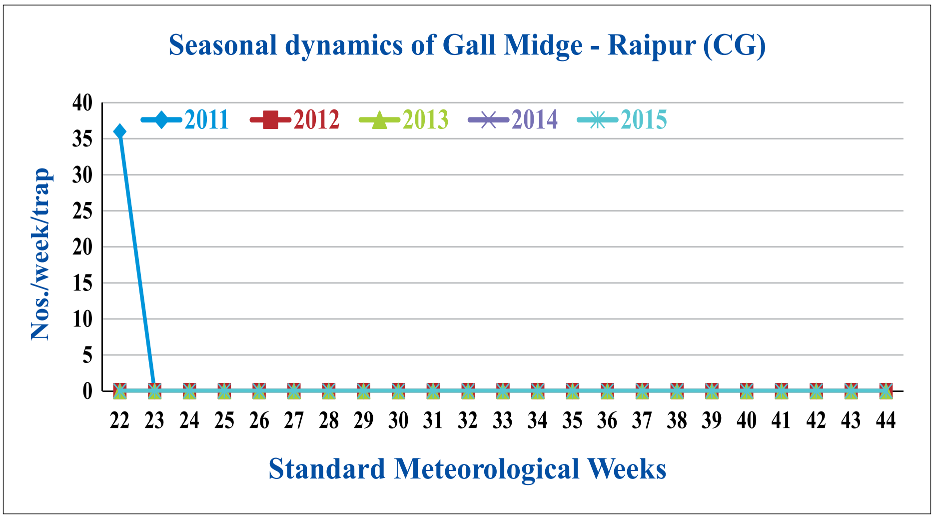
Table 8 : Weather based prediction rule for forewarning of gall midge at Raipur (CG)

LOCATION	PEST SEVERITY	WEATHER CRITERIA	RULE*
Raipur (CG)	High (>1000)	Tmax (31-34), Tmin (20-23), RHI (89-93), RF (<10) and SSH (8-9)	More than three
	Moderate (500- 1000)		Three
	Low (<500)		Less than three

Note : Pest severity is based on the light trap catches of gall midge adults (nos.) / week based on historical data (2000 onwards) Weather criteria is based on weekly means of Tmax (maximum temperature in °C), Tmin (minimum temperature in °C), RHI (morning relative humidity in %), RHII (evening relative humidity in %), SSH (sunshine hours in h /day) and RF (total rainfall in mm on weekly basis).

* : Number of weather based criteria satisfied out of five.

Raipur (CG) has been one of the hot spots for gall midge infestations in India with its occurrence as early as 31 SMW till 48 SMW as the latest period till 2008. However, since 2009 its continuous occurrence is not observed. During 2011, there was a starting population which did not progress further. In the context of climate variability, significantly higher rainfall over the 'normal' at Raipur (CG) during pre (May) and post (June-September) monsoon periods could be one of the major reasons for its decline (refer Annexure IV).



PREDICTION ACCURACY

The forecasts based on the developed criteria of weather and prediction rules based on long term data (2000-2010) indicated > 70% accuracy for the Raipur region.

LOCATION	SEASONS				
	2011	2012	2013	2014	2015
Raipur (CG)	86.96	86.96	91.30	86.96	69.57

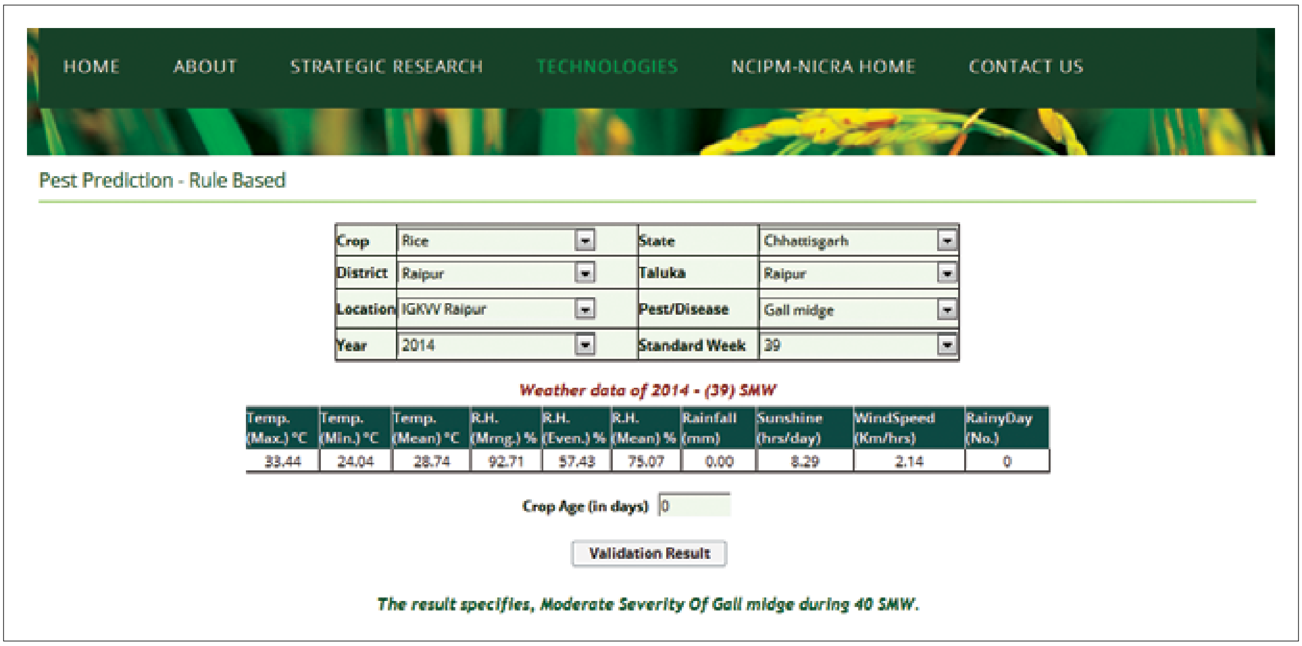


Fig. 28 : Screen shot on the prediction of gall midge for Raipur (CG)

CASE WORM (*Nymphula depunctalis*)

Rice caseworm (*Nymphula depunctalis* Guenée) (Pyralidae: Lepidoptera) is a sporadic insect pest of rice, and is commonly found in low lands with poorly drained and flooded fields of both wetland and irrigated environments. Insect build up is severe in early vegetative stage during floods. Transplanted young seedlings suffer heavy damage. Severe infestations are observed occasionally on dwarf, compact, heavy tillering, and high yielding varieties of rice during the rainy season. The entire crop may have to be re-sown or replanted during the severe infestation period.

Fig. 29 : Adult moth

Description - The adult is a small delicate moth with white wings speckled with pale brown wavy markings (Fig. 29) . Females are larger than males. Eggs are light yellow, disc like, smooth and irregular in shape. They are laid at night on the underside of the leaves floating on the water. Eggs hatch into green caterpillars with orange brownish head. Each larva lives inside a tubular case and hang down the leaves. Full-grown caterpillars measure up to 15 mm length. The larva enclose in its case that float on the water surface during the day, and crawls to the rice plant with its case to feed. Fully grown caterpillars are found in tubular cases made out of rice leaves and attach to the leaf blade. The larva is aquatic and can breathe with gills. The caterpillar skeletonizes the leaves in ladder like manner. Pupation is inside the cases, which are attached to the lower side of the basal leaves. Fresh pupae are milky white and gradually turn to light yellow.

Fig. 30 : Papery white leaf

Damage - Larvae feed on green tissues of the leaves by scrapping, and leaves become whitish and papery (Fig. 30). Caseworms cut off leaf tips to make leaf cases. Feeding damage includes cutting off the leaf tips to make leaf cases, patches of severe defoliation, stunted growth and death of plants. Floating of tubular cases on the water is one of the symptoms of damage. Tubular cases are found attached around the tillers.

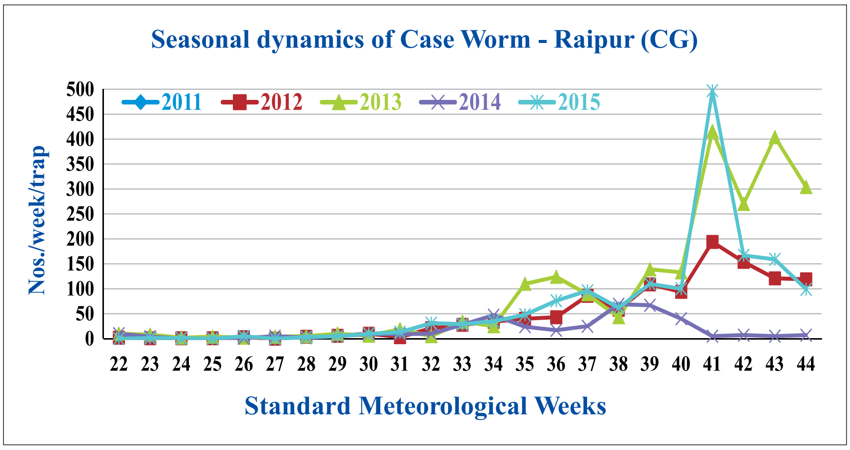
Table 9 : Weather based prediction for forewarning of case worm

LOCATION	PEST SEVERITY	WEATHER CRITERIA	RULE*
Raipur (CG)	High (>1000)	Tmax (31-34), Tmin (20-23), RHI (89-93), RF (<10) and SSH (8-9)	More than three
	Moderate (500-1000)		Three
	Low (<500)		Less than three

Note : Pest severity is based on the light trap catches of moths (nos.) / week.
Weather criteria is based on weekly means of Tmax (maximum temperature in °C), Tmin (minimum temperature in °C), RHI (morning relative humidity in %), RHII (evening relative humidity in %), SSH (sunshine hours in h /day) and RF (total rainfall in mm on weekly basis).

* : Number of weather based criteria satisfied out of five.

Caseworm has been a regular pest at Raipur (CG) with the highest light trap catches (>1000 nos/trap/week) during the mid-season over the last decade (2000-2008). Population levels never crossed 200 nos/week/trap between 2009 and 2012 seasons. However, 2013 and 2015 had shown relatively increasing caseworm at Raipur (CG) in response excess rainfall associated with higher relative humidity levels between 38-41 SMWs over other seasons.



PREDICTION ACCURACY

The forecasts based on the developed criteria of weather and prediction rules based on long term data (2000-2010) indicated > 70% accuracy.

LOCATION	SEASONS			
	2012	2013	2014	2015
Raipur (CG)	86.96	91.30	86.96	73.91

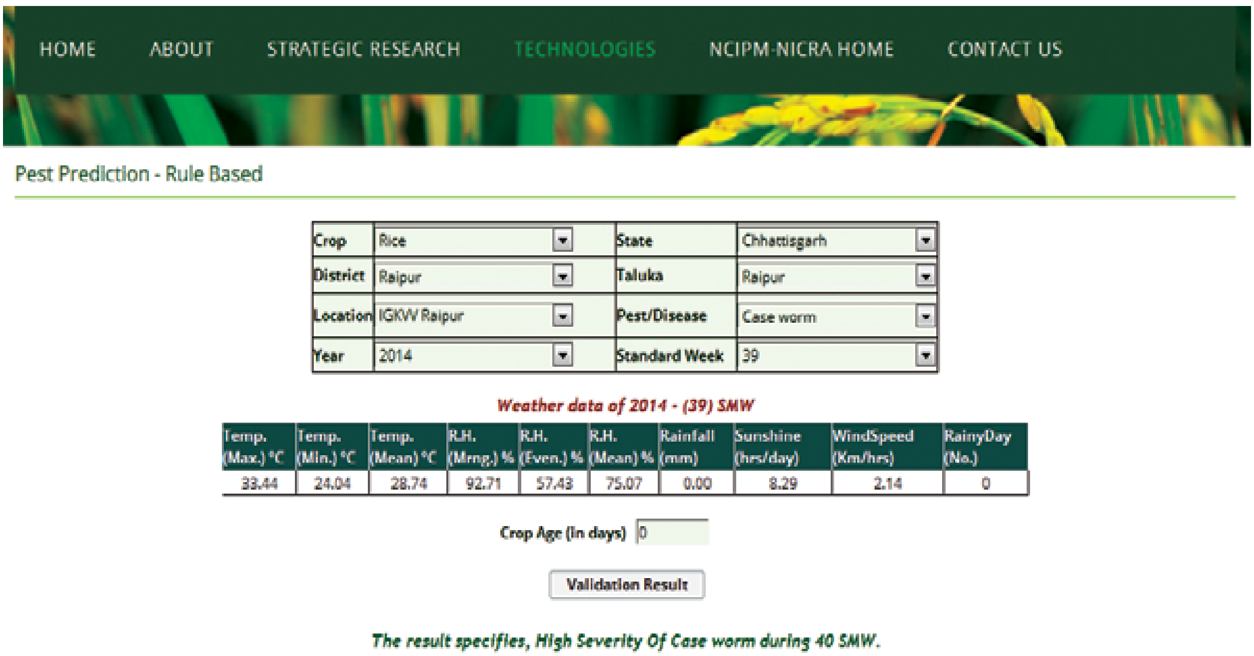


Fig. 31 : Screen shot on the prediction of case worm for Raipur (CG)

WAY FORWARD

The prevalent weather conditions that existed during the high (moderate when high was absent) pest severity levels over the seasons allowed to deduce the range of indicative environment conducive for the development of insect pests in respect of the locations during *kharif*. The existence of weather scenario within their respective prescribed range (Table 10) can also form the basis of prediction.

Table 10 : Weather guide favorable for development of rice insect pests

Location	Max Temp (°C)	Min Temp (°C)	RH Morning (%)	RH Evening (%)	Sunshine (hr/day)
YSB					
Ludhiana (PB)	30-34	16-25	87-97	35-67	-
Chinsurah (WB)	28-36	17-28	87-99	-	3-10
Raipur (CG)	32-34	18-24	89-92	-	8-9
Karjat (MH)	32-33	23-25	95-96	67-78	-
Hyderabad (TS)	31-36	23-27	71-82	42-65	-
Mandya (KA)	30-32	16-22	90-91	45-53	-
Aduthurai (TN)	29-36	23-25	66-96	-	2-8
Leaf Folder					
Ludhiana (PB)	31-34	16-24	89-94	-	5-10
Raipur (CG)	32-34	18-24	89-92	-	8-9
Aduthurai (TN)	29-36	23-26	90-98	-	2-8

Location	Max Temp (°C)	Min Temp (°C)	Mean Temp (°C)	RH Morning (%)	RH Evening (%)	Mean RH (%)	Sunshine (hr/day)	Wind (km/day)
BPH								
Ludhiana (PB)	-	-	21-28	-	-	62-82	2-10	1-3
Chinsurah (WB)	30-33	17-25	-	94-99	49-90	-	4-9	-
Raipur (CG)	-	-	23-35	-	-	41-85	2-9	1-8
Hyderabad (TS)	31-34	21-25	-	61-95	44-74	-	-	-
Mandya (KA)	30-32	16-22	-	90-91	45-47	-	-	-
Aduthurai (TN)	-	-	28-29	-	-	78-79	8-9	1-3

Location	Max Temp	Min Temp	RH Morning	RH Evening	Sunshine
WBPH					
Chinsurah (WB)	30-33	17-25	97-98	49-64	≯8
GLH					
Chinsurah (WB)	31-37	19-28	90-98	52-77	6-8
Raipur (CG)	29-34	17-25	84-96	-	2-9
Karjat (MH)	32-35	21-23	≯95	48-67	6-8
Hyderabad (TS)	31-34	21-23	61-94	44-67	-
Mandya (KA)	28-31	16-21	80-92	45-60	-
Aduthurai (TN)	32-36	≯25	84-91	52-64	4-7
Gall Midge and Case Worm					
Raipur (CG)	31-34	19-24	88-93	-	8-9

The validation of the developed weather based predictions year-round (Annexure V) including *rabi* and *summer* seasons denote a prediction potential for some of the rice pests in a few locations, although season specific forecasts would be an ultimate target.

CONCLUSION

The heuristic models developed for the major pests of rice for seven locations belonging to six agro-climatic zones of seven agro eco regions based on iterative approach would serve as simple and robust indicators of severity levels of the insect species being predicted. Since the iterative approach considered variabilities of the insect pest and weather over seasons, and does not require the assumptions of quantitative parametric analysis to be satisfied, the elasticity of prediction has been high.

Available research and literature into forewarning of rice pests are abundant with complex empirical equations **(Ramakrishnan *et al*., 1994; Krishnaiah, *et al*., (1997; 2004)),** but none has gone to the level of forecast utility as the developed models remained and in publications While forecast models were more of an academic value with only rare validations in the past, the use of web based tools make the models available for use by the interest groups of the locations concerned. The web enabled feature for the currently developed models through *http://www.ncipm.org.in/nicra/ForewarningSystem/PestPrediction.aspx* is a step forward for issue of 'pest alerts' on a weekly basis. The basic requirement for the functional 'pest alert' is the real time entry and uploads of the weather data by the RTPD locations using the user authenticated client application. High prediction accuracies seen at times of 'low' pest severity levels with the present models largely indicate the relatively lesser role played by weather in governing the population abundance over other biotic factors right from the host range, type of cropping systems, area under rice over space and time, varietal scenario, natural biological control forces and the cultivation practices including plant protection. Since the outbreaks are always associated with the congenial weather conditions, the weather based 'pest alerts' offer better preparedness for pest management. E-dissemination of 'pest alerts' through short mail services (SMS) only at times of 'high' pest severity prediction would be a viable option for an effective and efficient rice pest management. Since light trap catches and predicted severity levels do not directly indicate the field infestation levels, and that the curative pest management recommendations are based on economic thresholds (Annexure I), present forewarning system is recommended for the purpose of "pest alerts" in respect of the locations than for pest management advisory. In the context of climate variability and change, and more so due to the short term weather aberrations and variabilities it is highly pertinent to have a 'pest alert' backed up by direct field level monitoring for the need of pest management.

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Annexure I - Sowing and harvesting periods of rice across study locations

Region/State	Autumn		Winter		Summer	
	Sowing	Harvesting	Sowing	Harvesting	Sowing	Harvesting
Northern Region						
Punjab	May-Aug	Sep-Nov	-	-	-	-
Western region						
Maharashtra	-	-	Jun-July	Oct-Dec	-	-
Eastern Region						
West Bengal	Mar-June (Broadcast-ing) May - June (Trans-planting)	July-Nov	Apr-June (Broadcast-ing) July-Aug (Transplant-ing)	Nov-Dec	Oct-Feb	Apr-May
Southern Region						
Andhra Pradesh	Mar-April	July-Aug	May-June	Nov-Dec	Dec-Jan	April-May
Karnataka	May-Aug	Sep-Dec	June-Oct	Nov-March	Dec-Feb	April-July
Tamil Nadu	Sornavari		Early Samba		Late Samba	
	April-May	July-Aug	June-July	Nov-Dec	Oct-Nov	March-Apr
	Kar		Samba		Navarai	
	May-June	Aug-Sep	July-Aug	Dec-Jan	Dec-Jan	April-May
	Kuruvai		Thaladi/Pishanam			
	June-July	Sep-Oct	Sep-Oct	Dec-Jan	-	-

Annexure II - Economic threshold levels for insect pests of rice

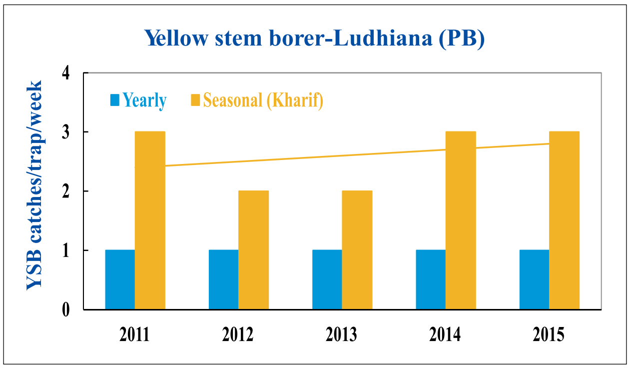
Crop Stage	Pest/Disease	Economic Threshold Level (ETLs)
Nursery	Yellow Stem Borer	5% dead hearts, 2% white ears or 1 egg mass/m^2 or 1 moth/m^2
Early to late tillering	Stem Borer	2 egg-mass/m^2 or 10% dead heart or 1 moth /m^2 or 25 moths/ trap/week
	Leaf folder	2 fully damaged leaves (FDL) with larva/hill
	Gall midge	1 gall/m^2 or 10% silver shoot
	BPH/WBPH	10-15 hoppers/hill
	Rice caseworm	2 FDL/hill
Panicle initiation to booting	Stem Borer	2 egg-mass/ m^2or 1 moth / m^2 or 25 moths/trap/week
	Leaf folder	2 FDL/hill
	BPH/WBPH	15-20 hoppers/hill

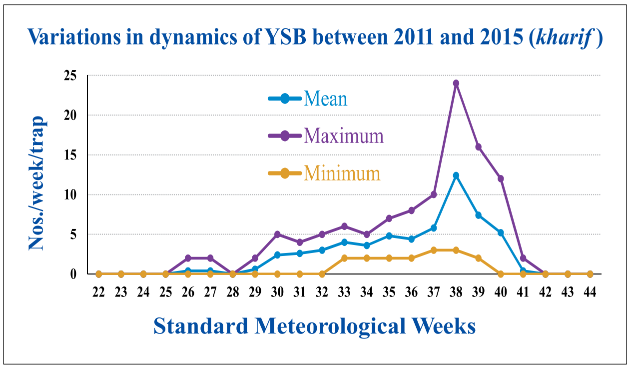
(Source: ***http://www.ncipm.org.in/NCIPMPDFs/ipmpackages/Rice%20Bulletin.pdf*** **)**

Annexure III – Scenario and seasonal dynamics of rice insect pests

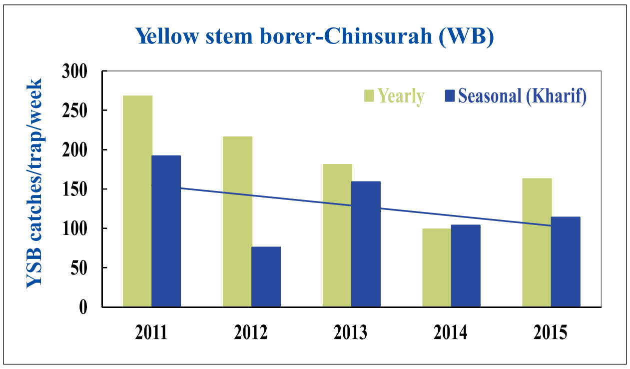
1. YSB

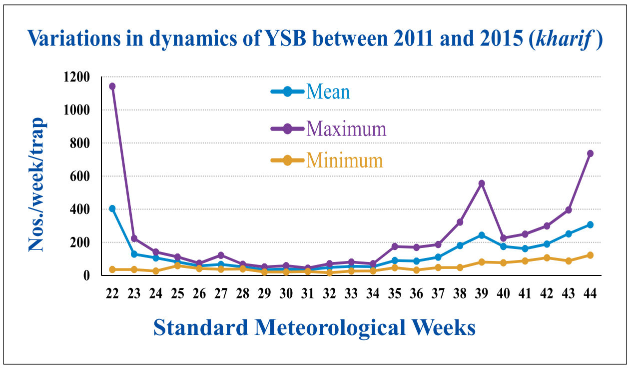
Ludhiana (PB)



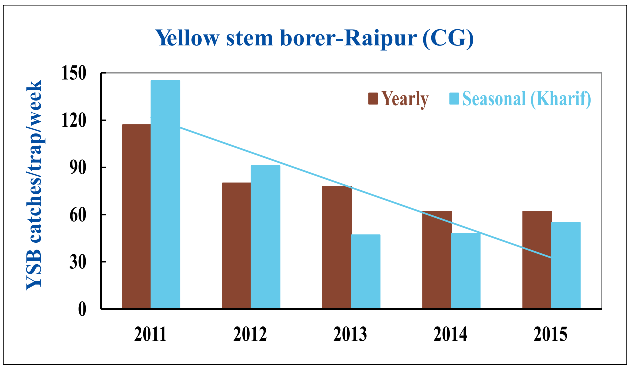


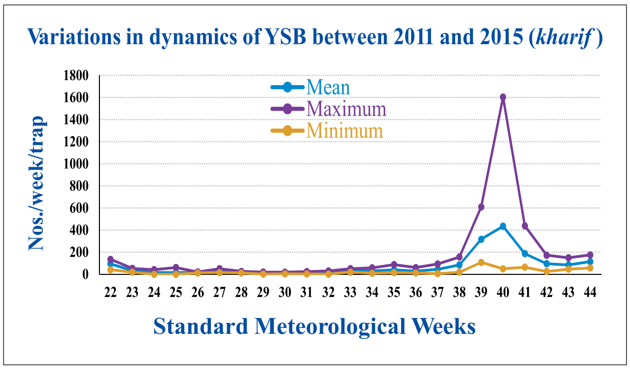
Chinsurah (WB)



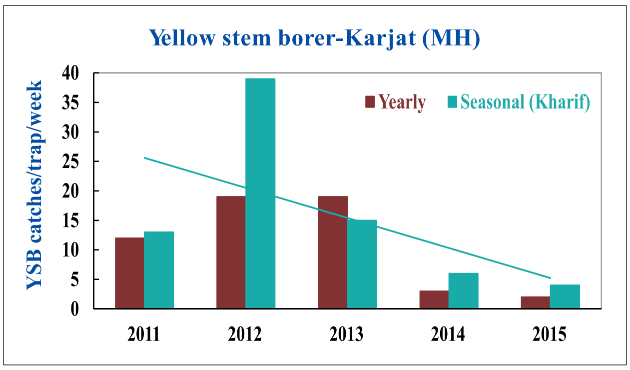


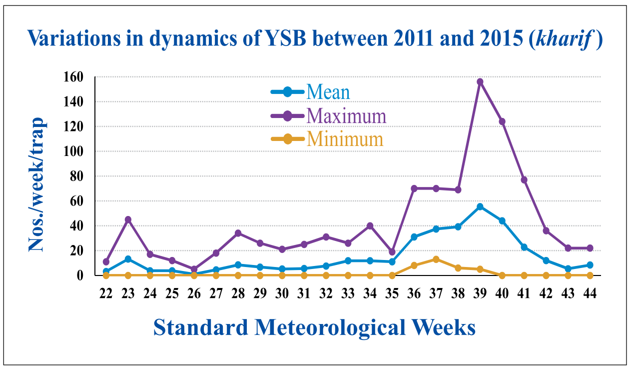
Raipur (CG)



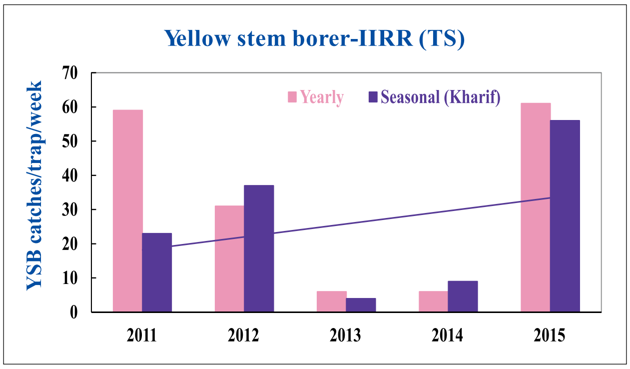


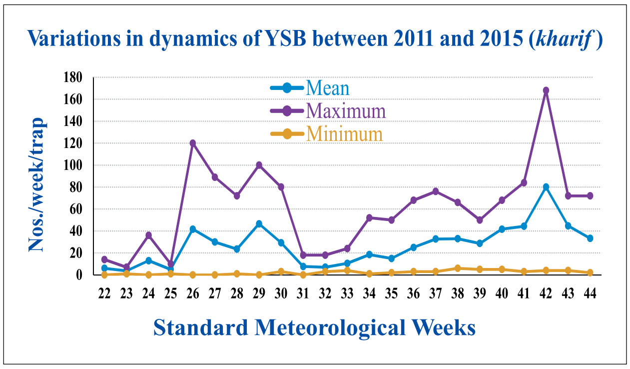
Karjat (MH)



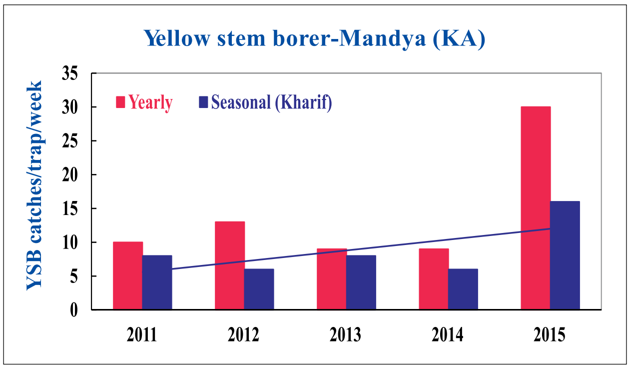


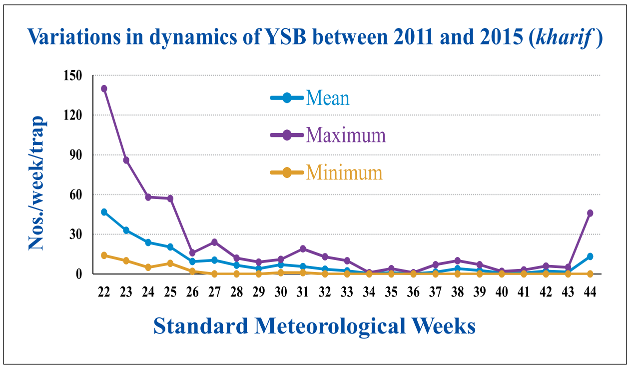
Hyderabad (TS)



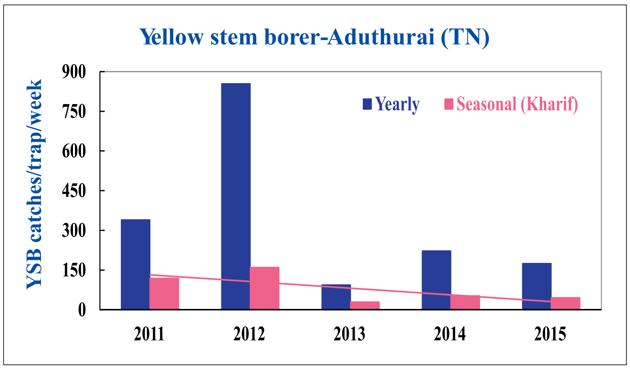


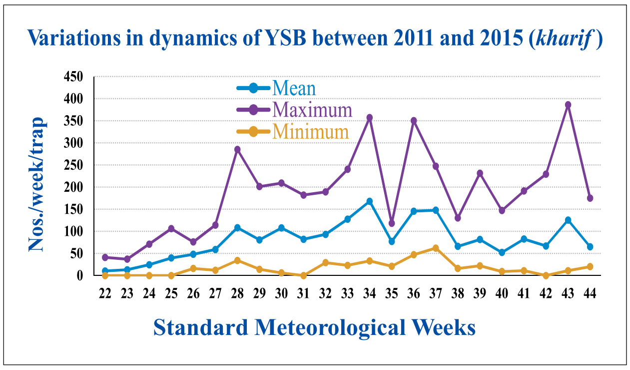
Mandya (KA)





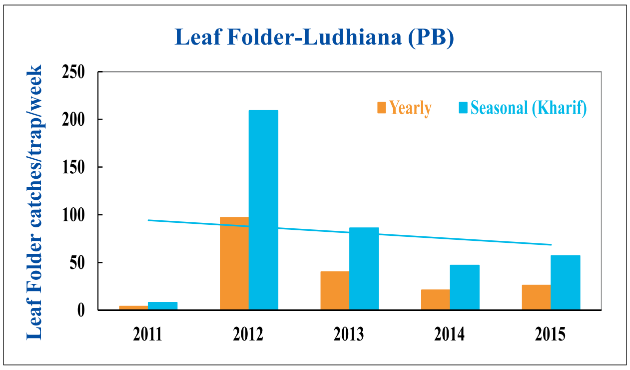
Aduthurai (TN)

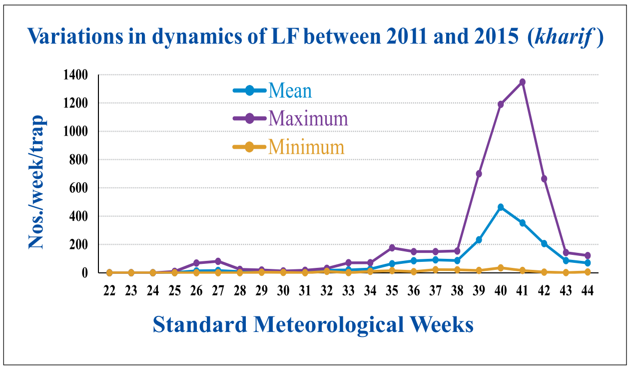




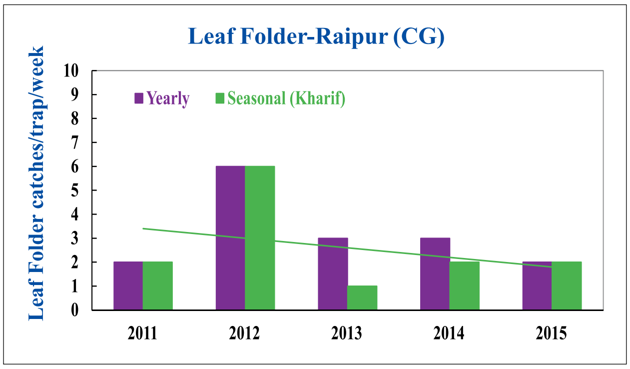
2. LEAF FOLDER

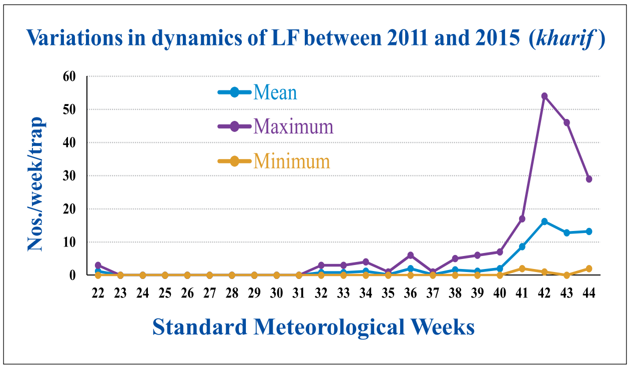
Ludhiana (PB)



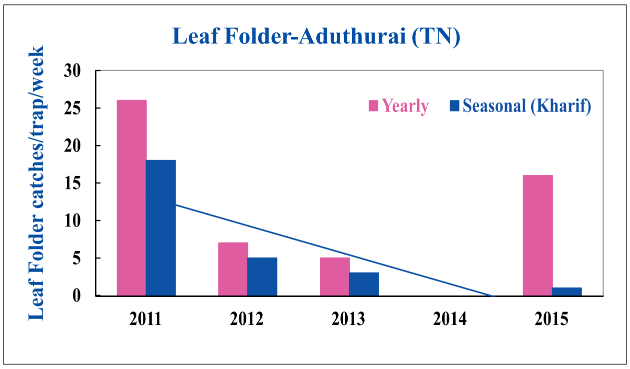


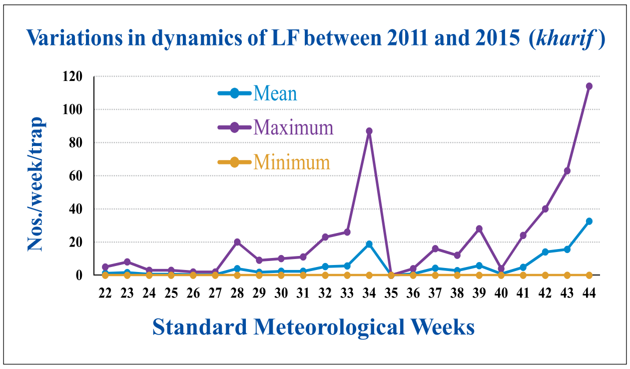
Raipur (CG)





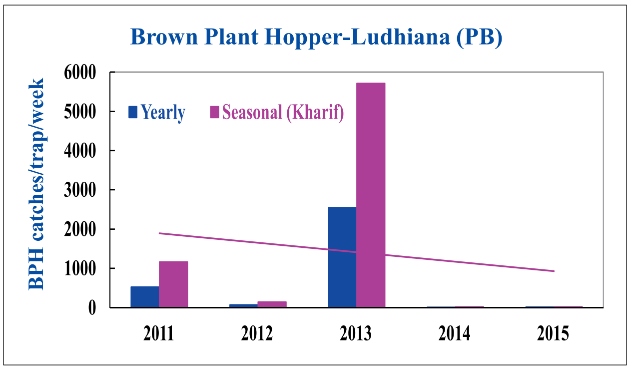
Aduthurai (TN)

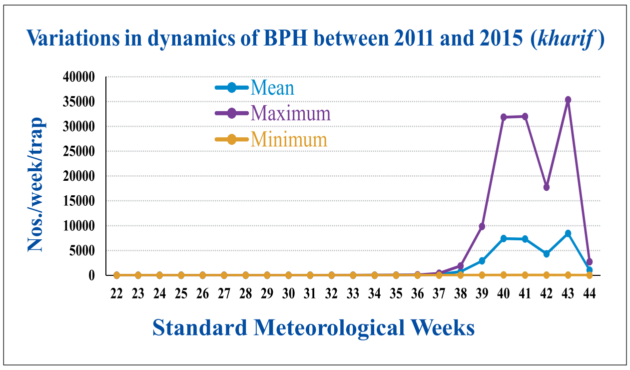




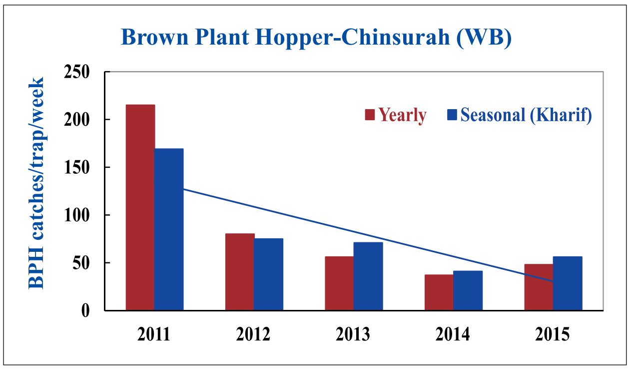
3. BPH

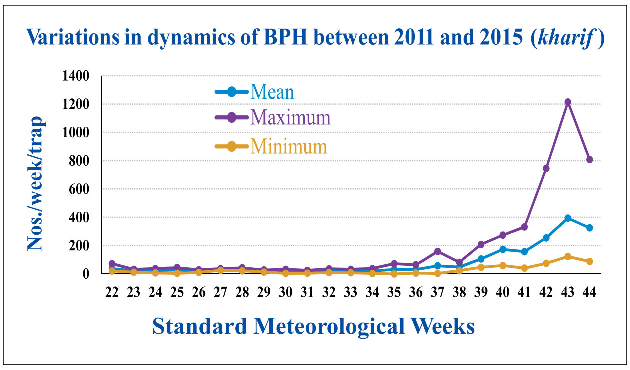
Ludhiana (PB)



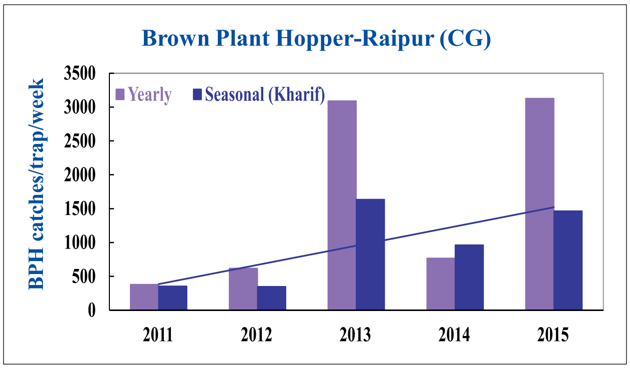


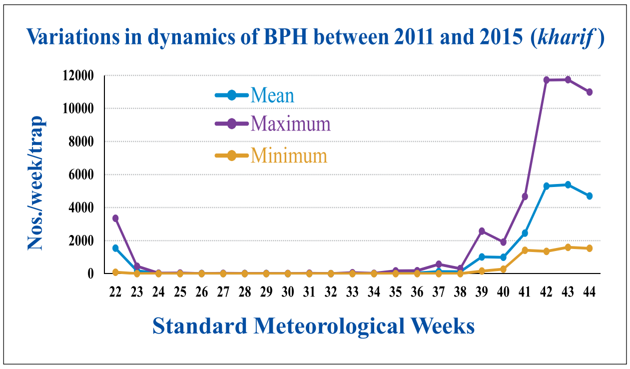
Chinsurah (WB)



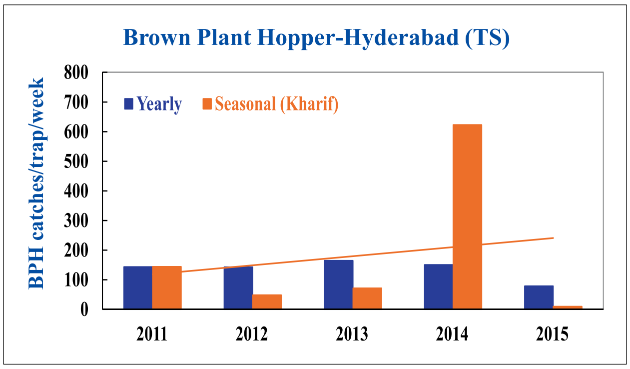


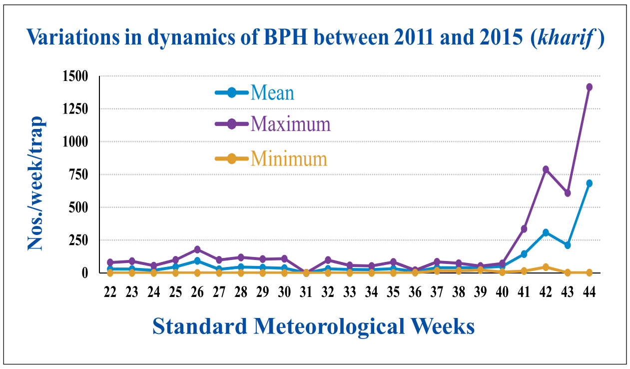
Raipur (CG)



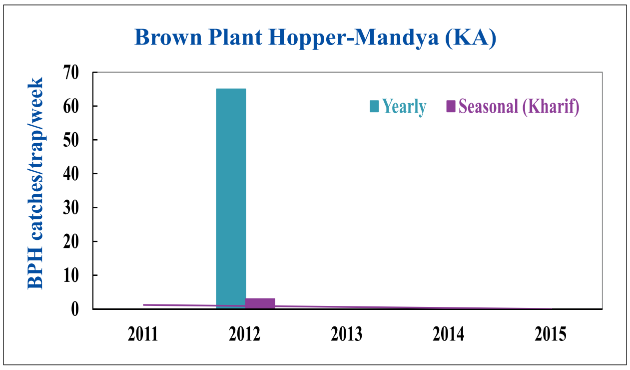


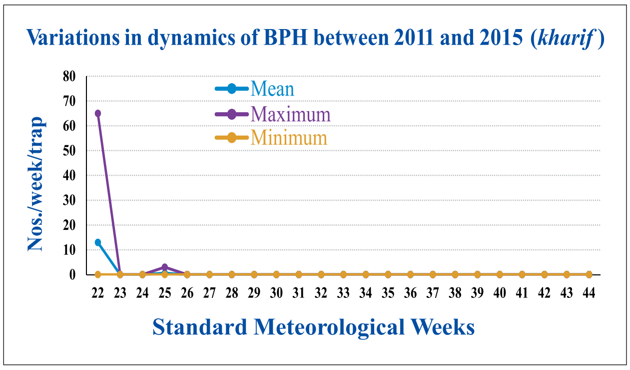
Hyderabad (TS)



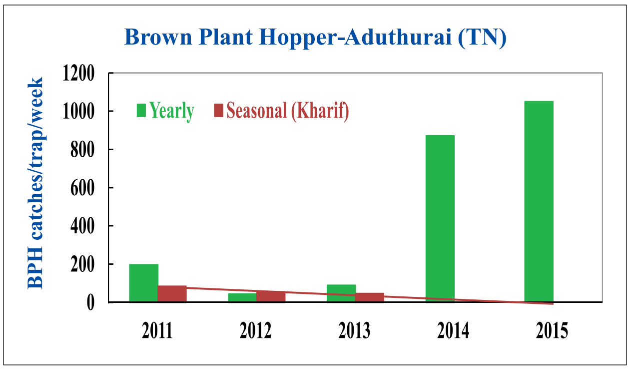


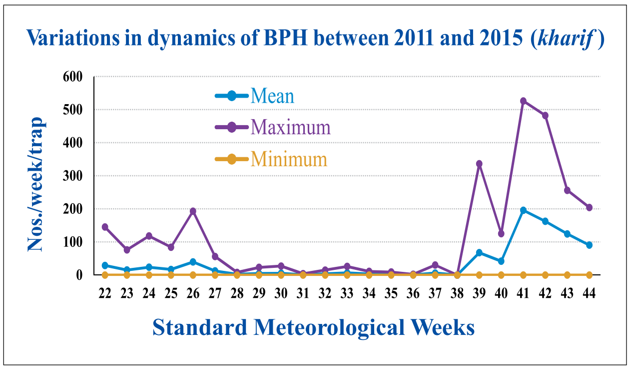
Mandya (KA)





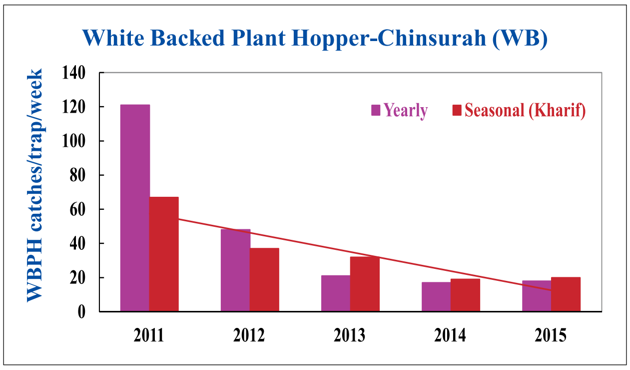
Aduthurai (TN)

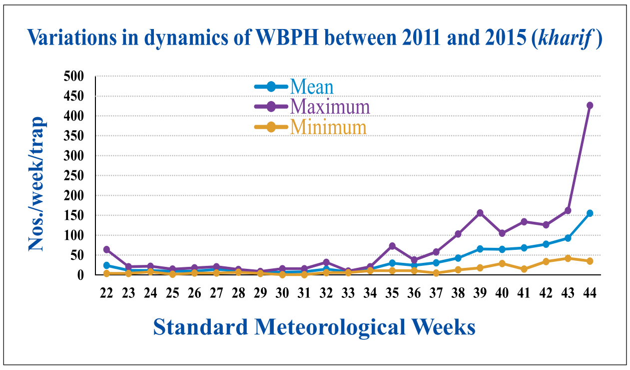




4. WBPH

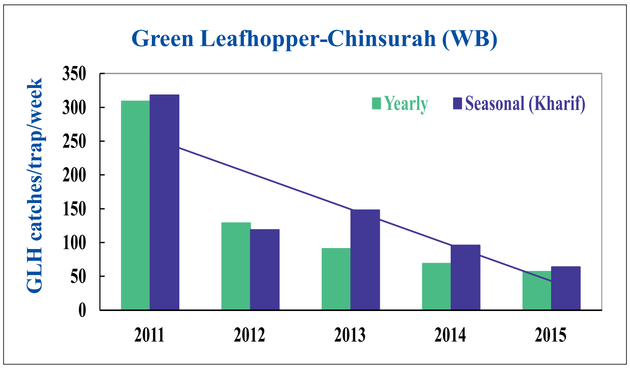
Chinsurah (WB)

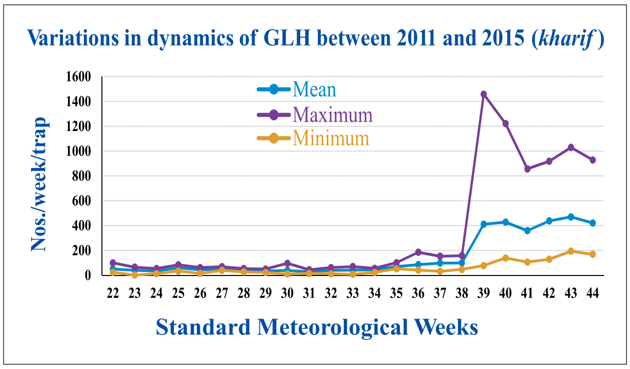




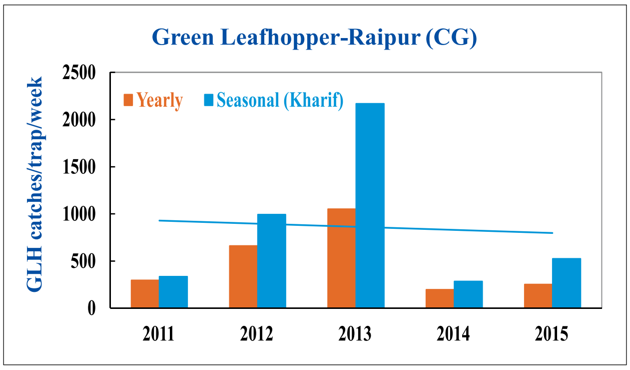
5. GLH

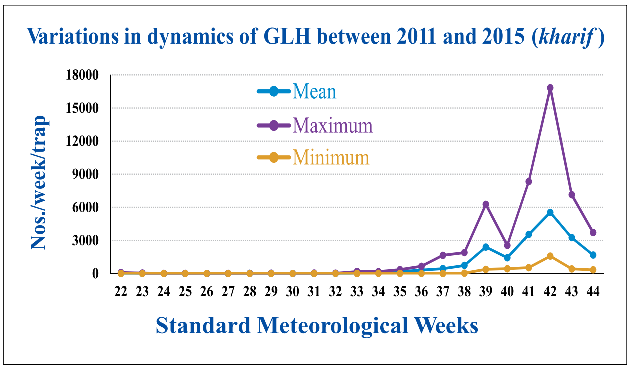
Chinsurah (WB)



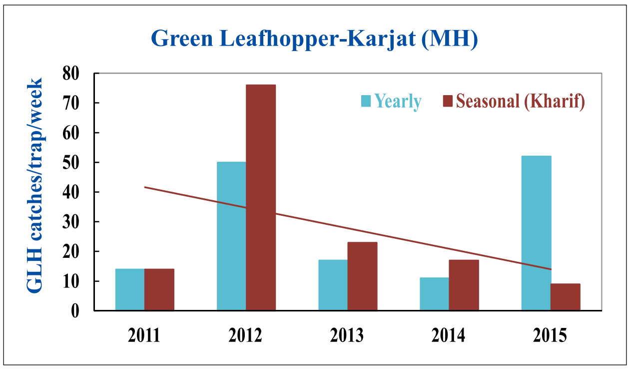


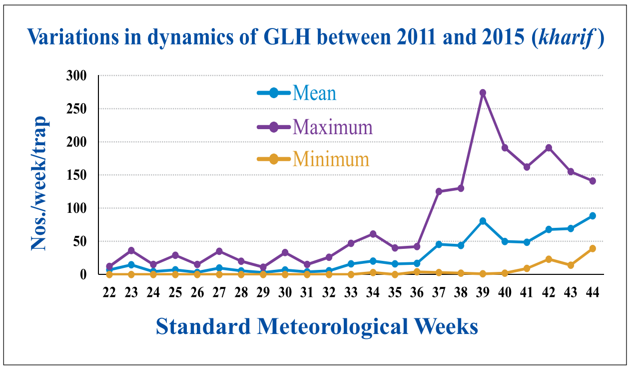
Raipur (CG)



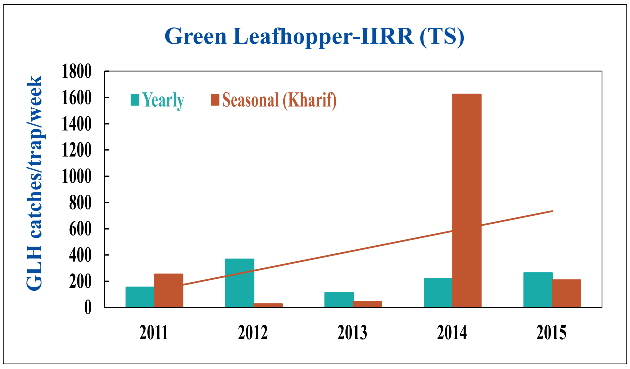


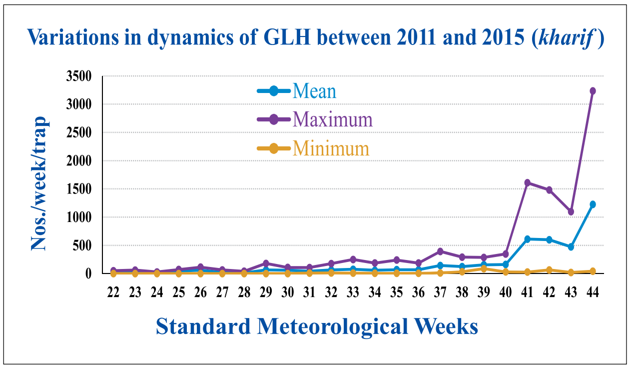
Karjat (MH)



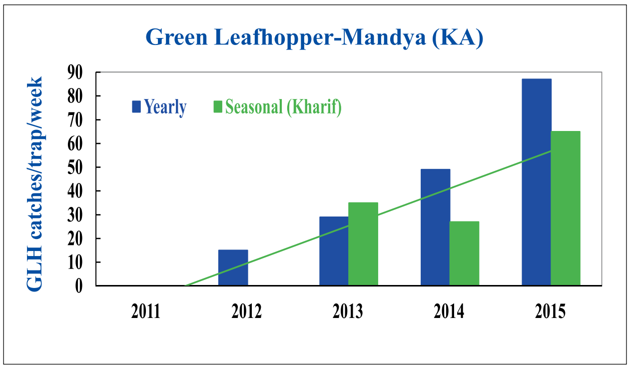


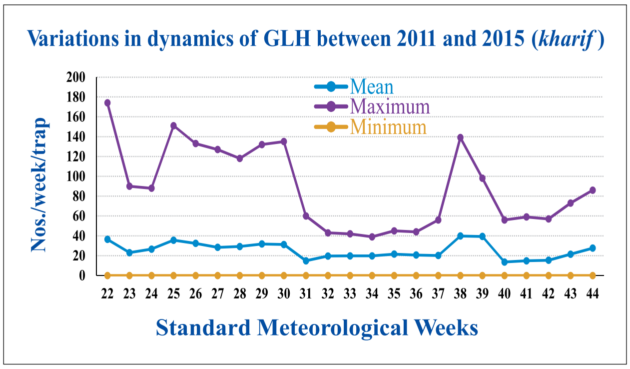
Hyderabad (TS)



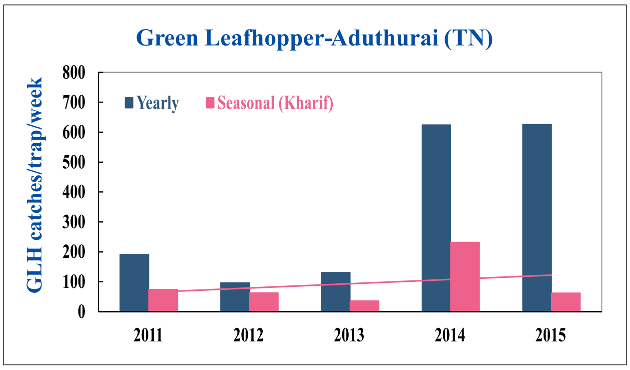


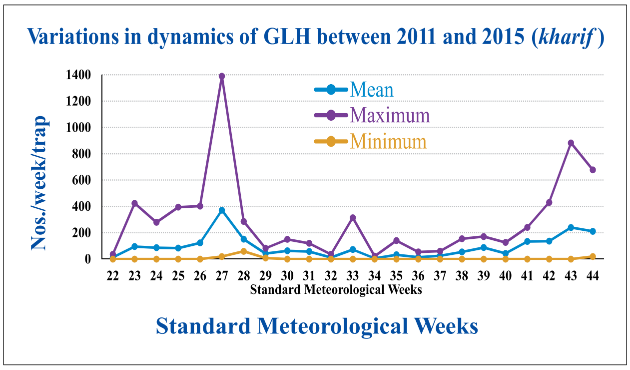
Mandya (KA)





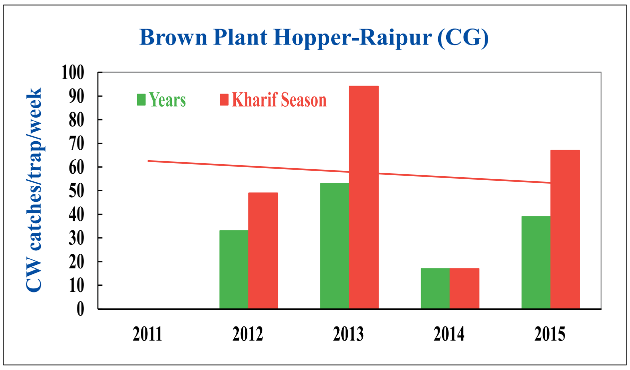
Aduthurai (TN)

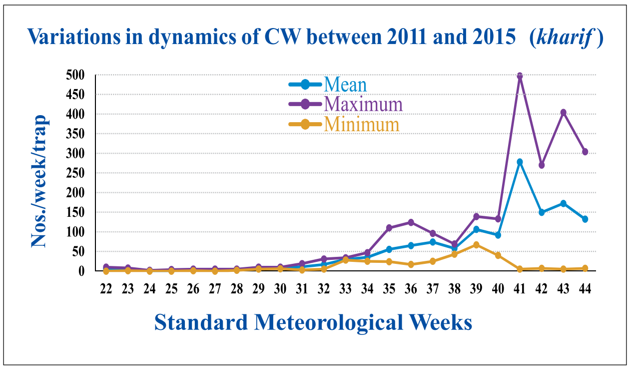




6. CASE WORM

Raipur (CG)

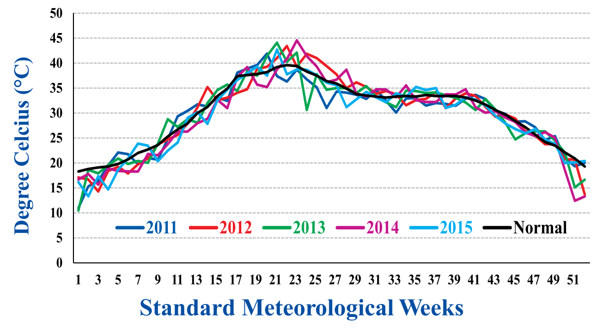




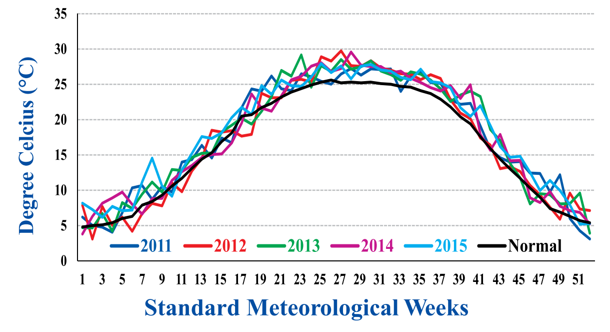
Annexure IV – Interannual climatic variations for study locations

1. LUDHIANA (PB)

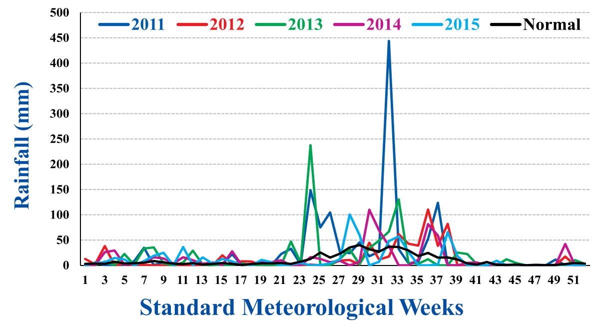
Maximum temperature (Ludhiana-PB)



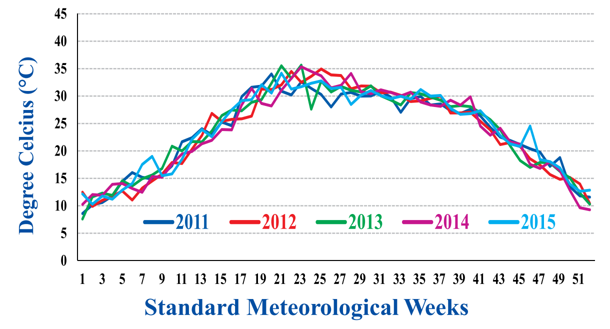
Minimum temperature (Ludhiana-PB)



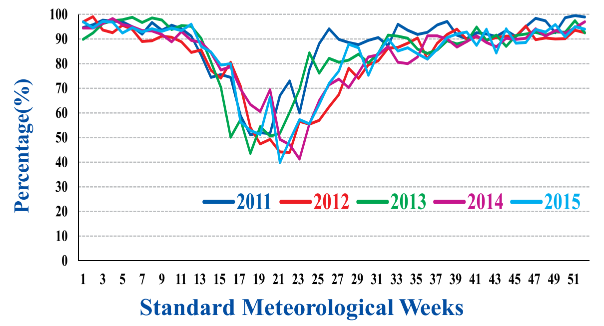
Rainfall (Ludhiana-PB)



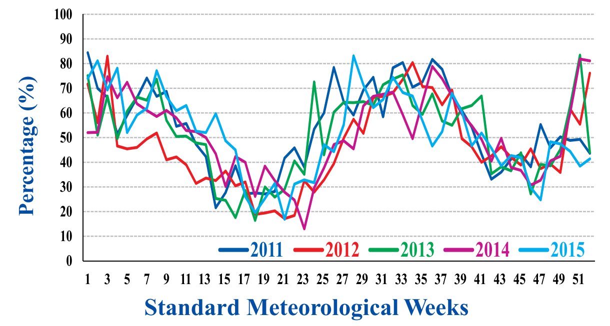
Mean temperature (Ludhiana-PB)



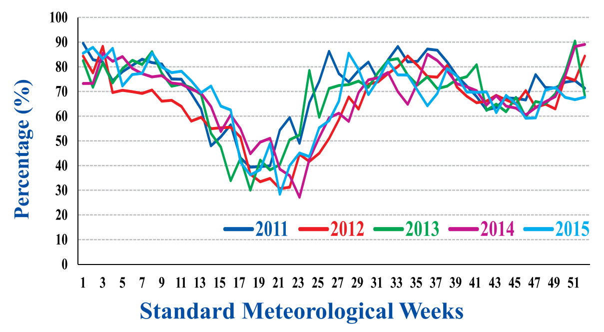
Morning relative humidity (Ludhiana-PB)



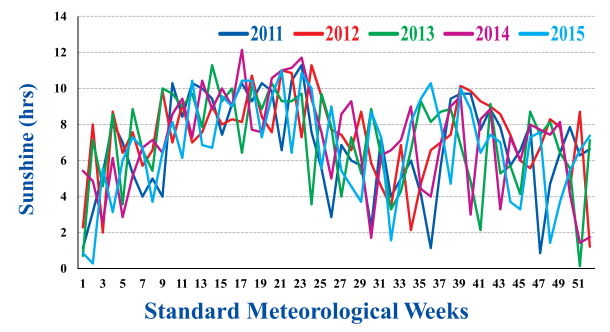
Evening relative humidity (Ludhiana-PB)

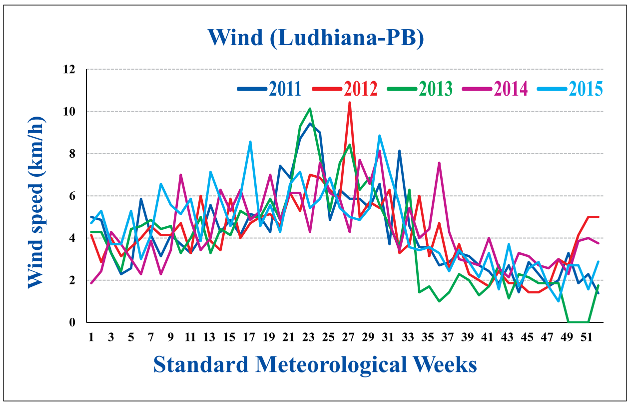


Mean relative humidity (Ludhiana-PB)

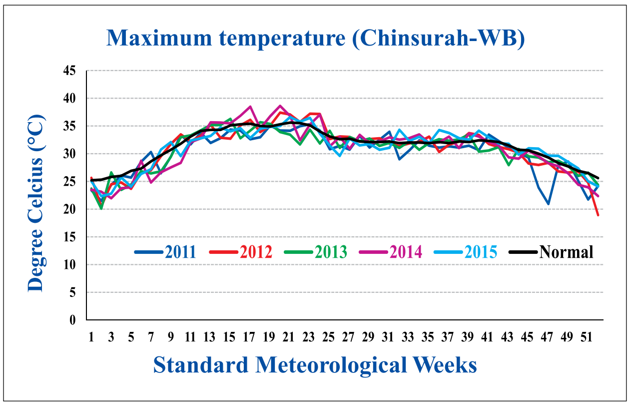


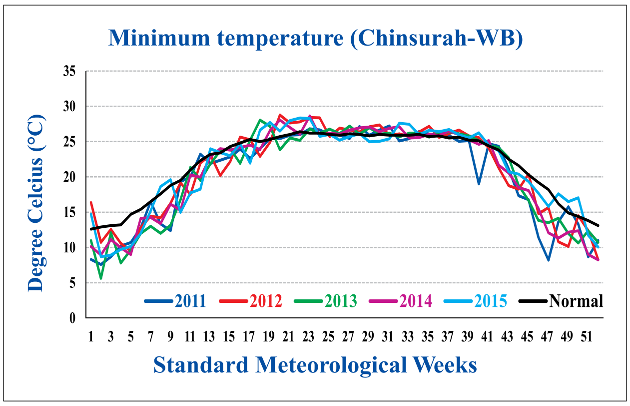
Sunshine (Ludhiana-PB)

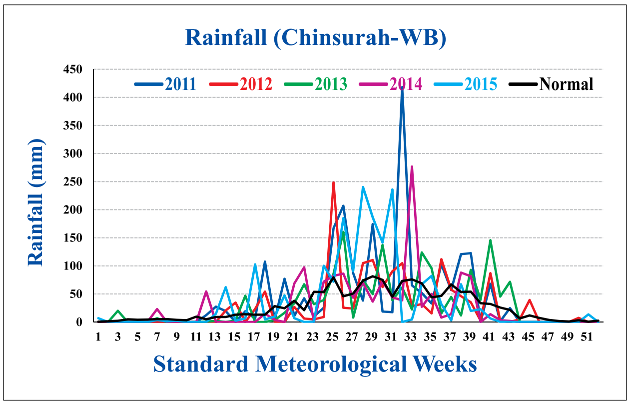


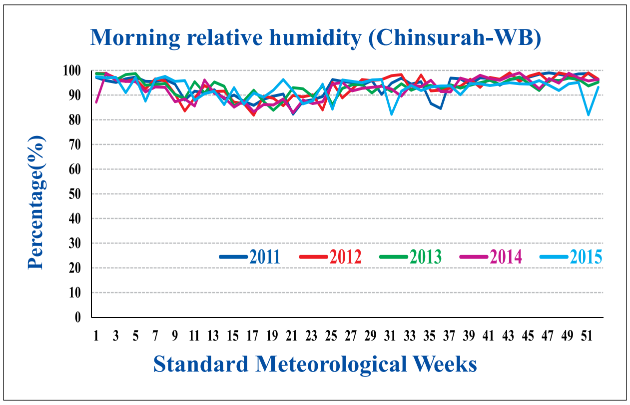


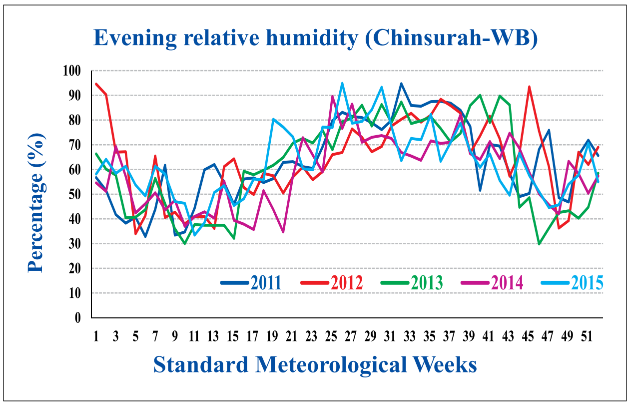
2. CHINSURAH (WB)

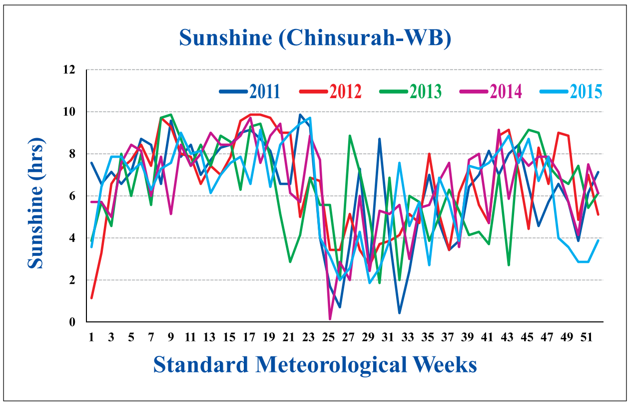




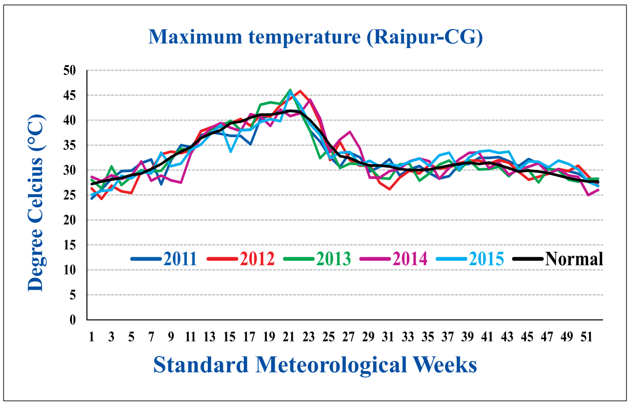


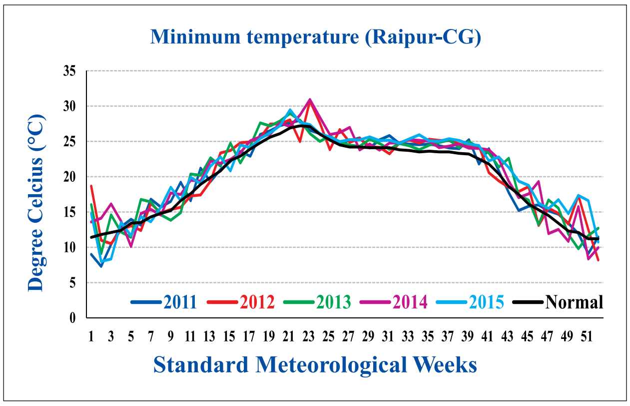


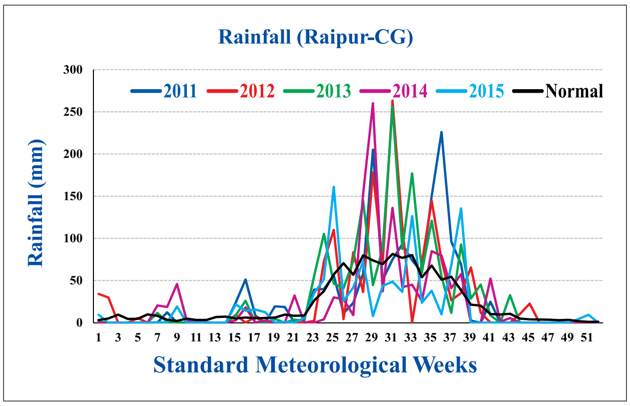


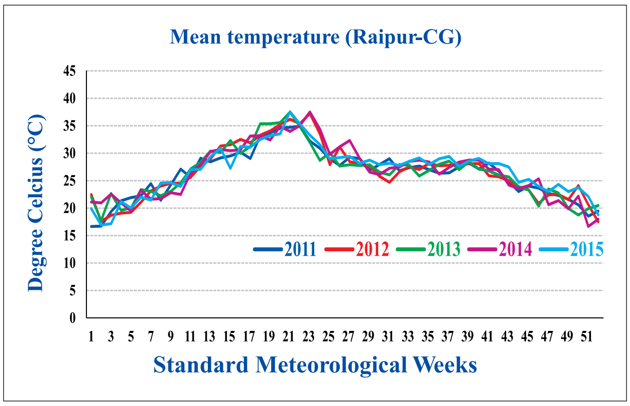


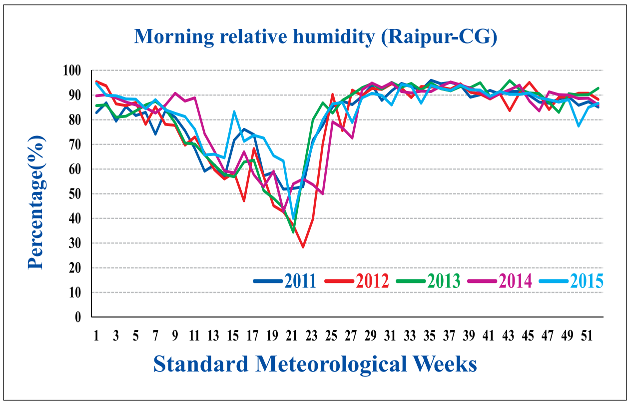
3. RAIPUR (CG)

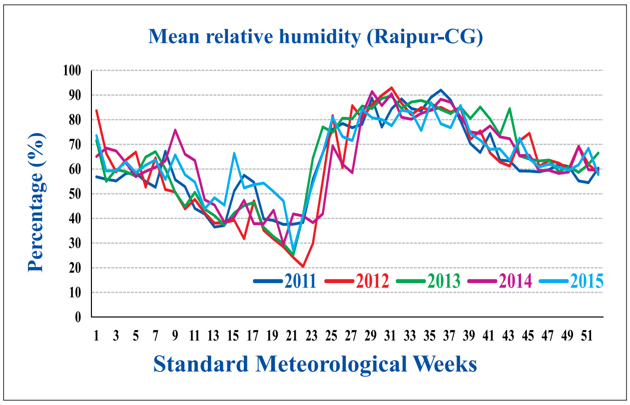

Maximum temperature (Raipur-CG)
Degree Celcius (°C)
2011 2012 2013 2014 2015 Normal
Standard Meteorological Weeks

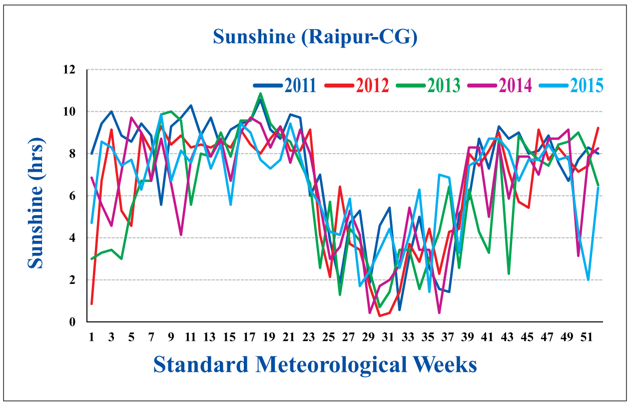

Minimum temperature (Raipur-CG)
Degree Celcius (°C)
2011 2012 2013 2014 2015 Normal
Standard Meteorological Weeks

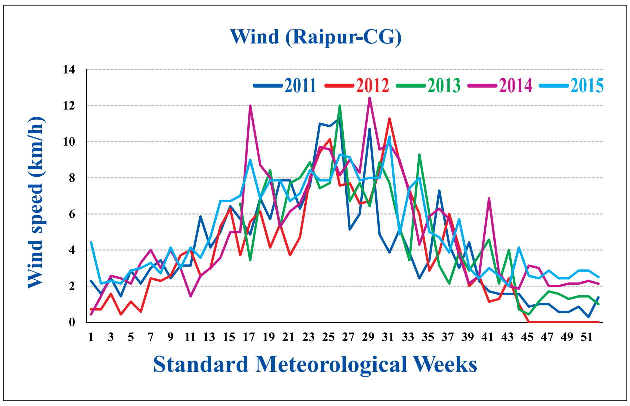

Rainfall (Raipur-CG)
Rainfall (mm)
2011 2012 2013 2014 2015 Normal
Standard Meteorological Weeks


Mean temperature (Raipur-CG)
Degree Celcius (°C)
2011 2012 2013 2014 2015
Standard Meteorological Weeks

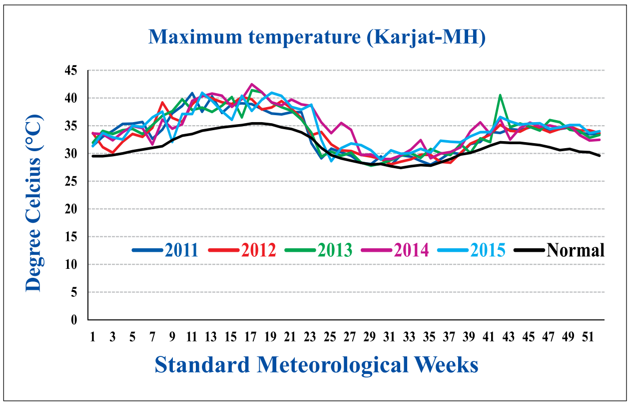

Morning relative humidity (Raipur-CG)
Percentage(%)
2011 2012 2013 2014 2015
Standard Meteorological Weeks

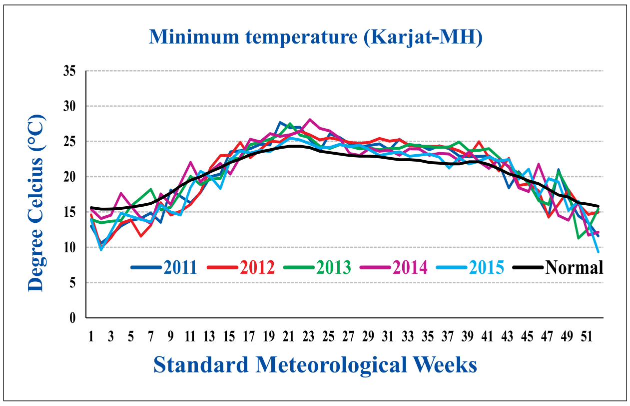

Mean relative humidity (Raipur-CG)
Percentage (%)
2011 2012 2013 2014 2015
Standard Meteorological Weeks

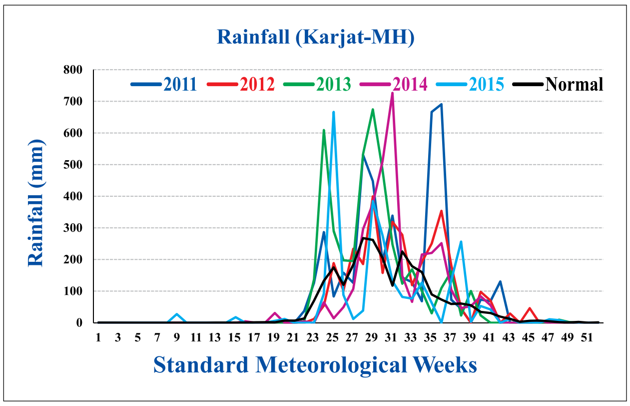

Sunshine (Raipur-CG)
Sunshine (hrs)
2011 2012 2013 2014 2015
Standard Meteorological Weeks

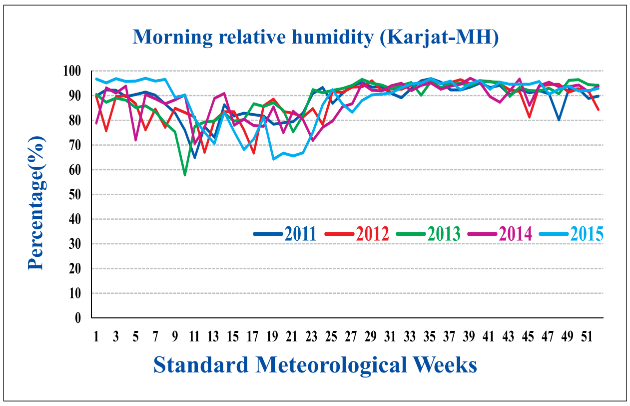

Wind (Raipur-CG)
Wind speed (km/h)
2011 2012 2013 2014 2015
Standard Meteorological Weeks

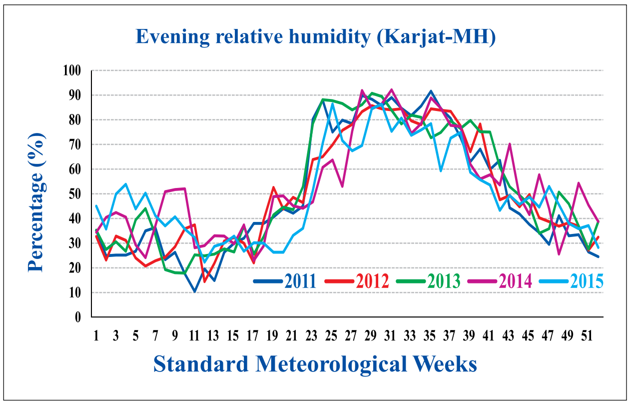
4. KARJAT (MH)

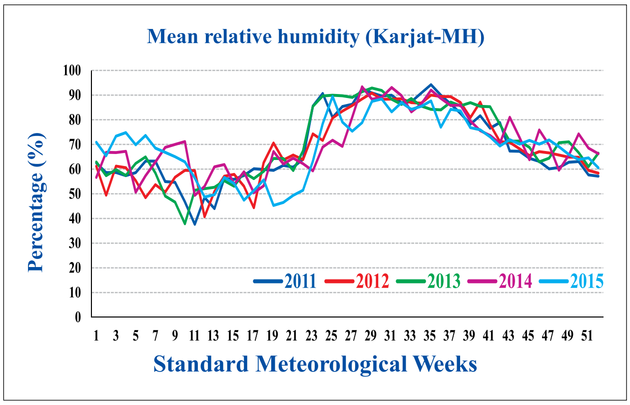

Maximum temperature (Karjat-MH)
Degree Celcius (°C)
2011 2012 2013 2014 2015 Normal
Standard Meteorological Weeks

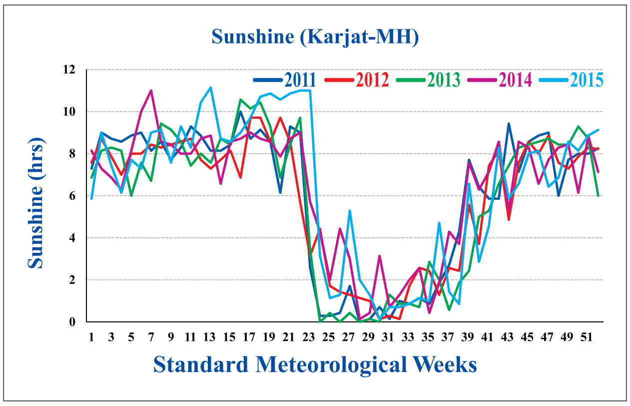

Minimum temperature (Karjat-MH)
Degree Celcius (°C)
2011 2012 2013 2014 2015 Normal
Standard Meteorological Weeks


Rainfall (Karjat-MH)
Rainfall (mm)
2011 2012 2013 2014 2015 Normal
Standard Meteorological Weeks

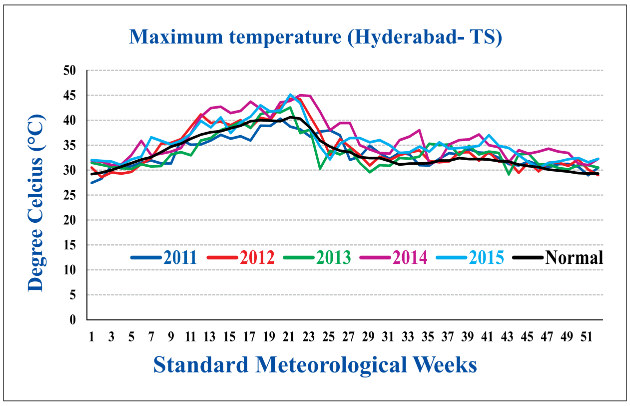

Morning relative humidity (Karjat-MH)
Percentage(%)
2011 2012 2013 2014 2015
Standard Meteorological Weeks

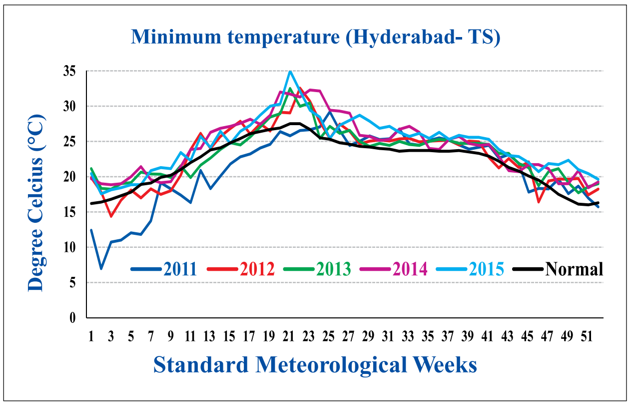

Evening relative humidity (Karjat-MH)
Percentage (%)
2011 2012 2013 2014 2015
Standard Meteorological Weeks

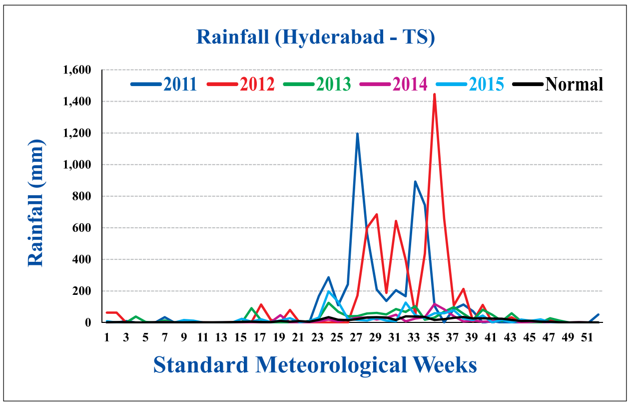

Mean relative humidity (Karjat-MH)
Percentage (%)
2011 2012 2013 2014 2015
Standard Meteorological Weeks

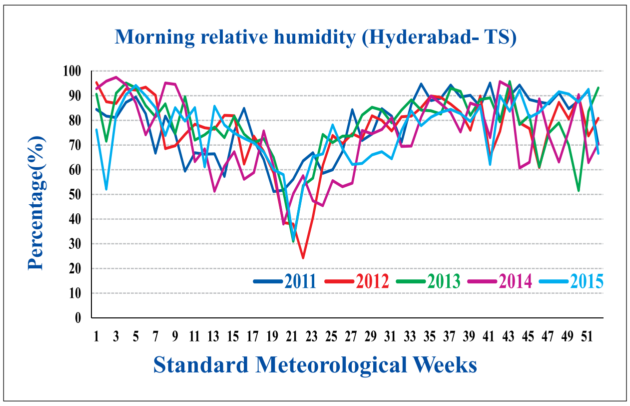

Sunshine (Karjat-MH)
Sunshine (hrs)
2011 2012 2013 2014 2015
Standard Meteorological Weeks

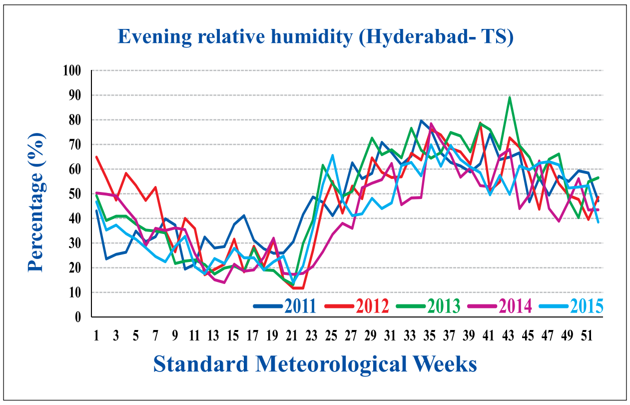
5. HYDERABAD (TS)



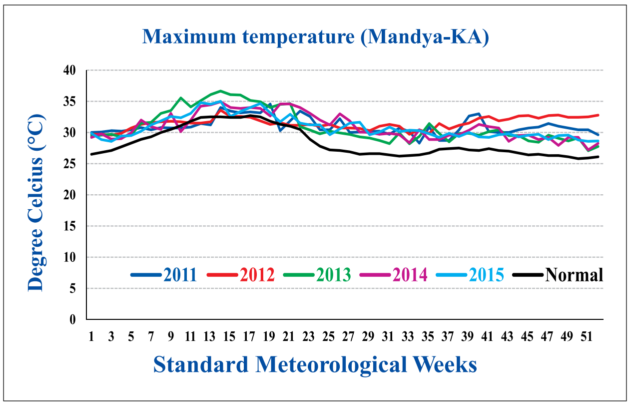


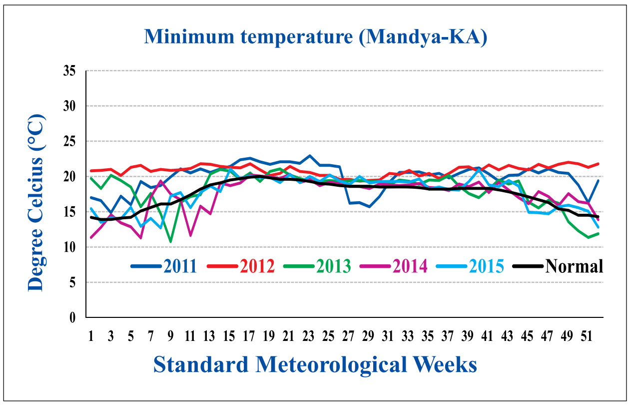


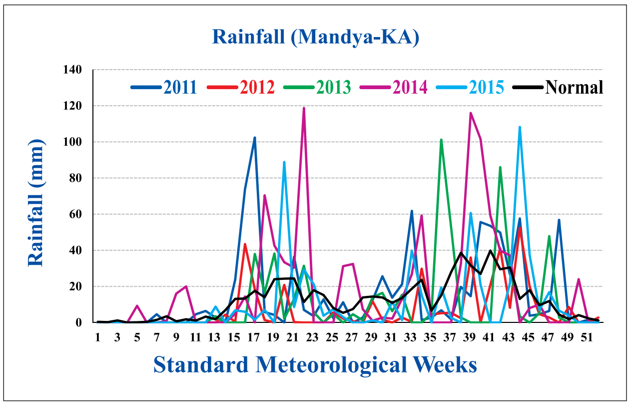


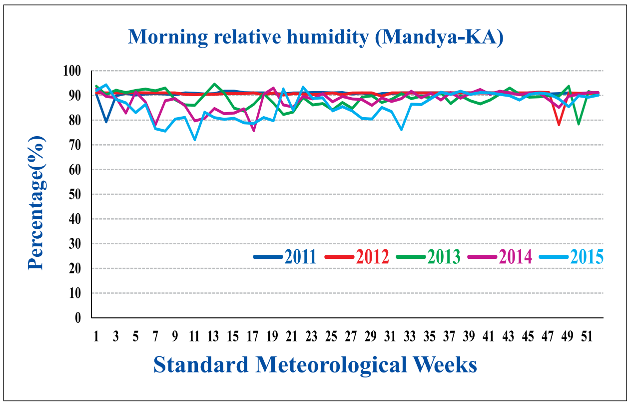


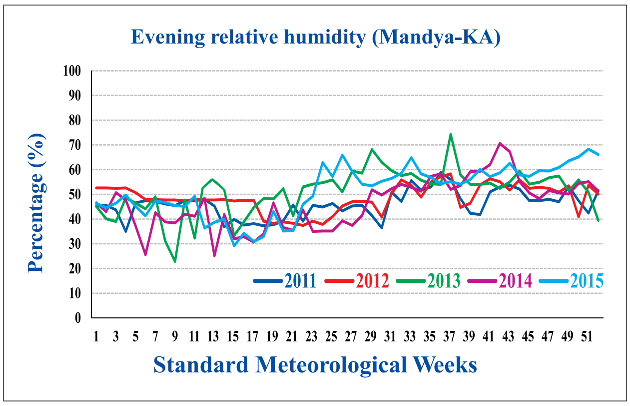
6. MANDYA (KA)



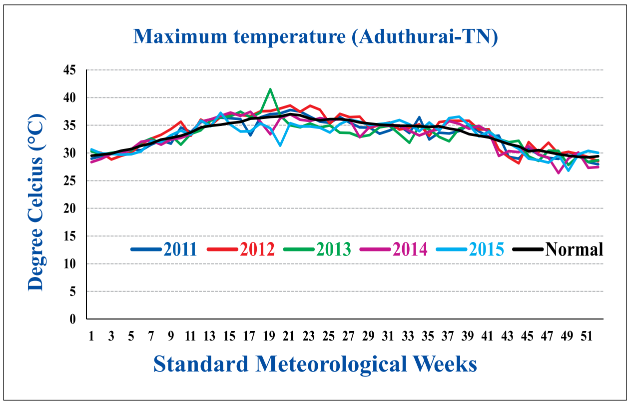


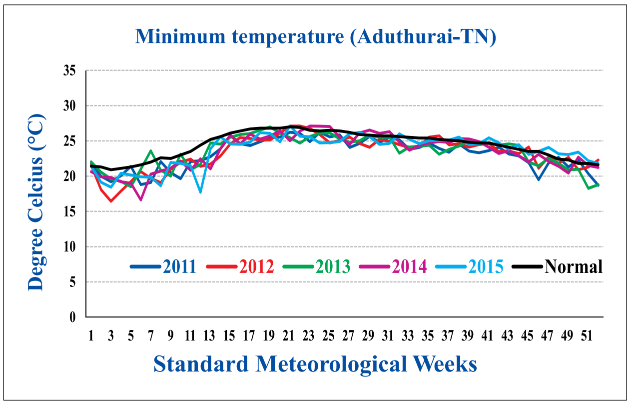


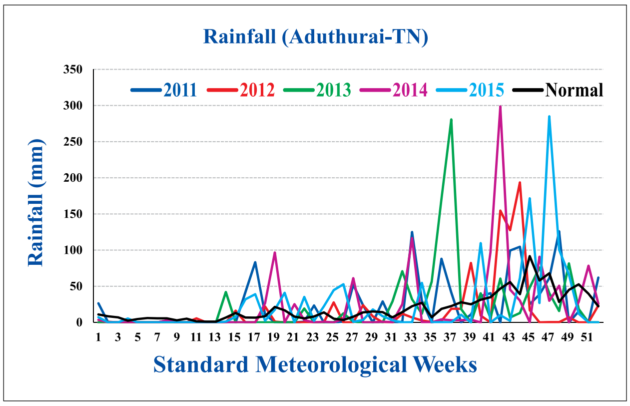


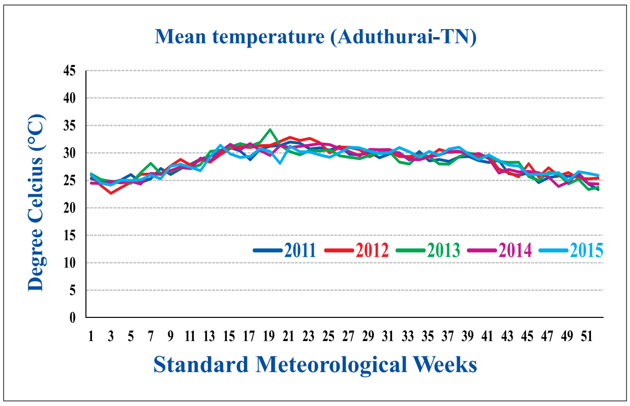


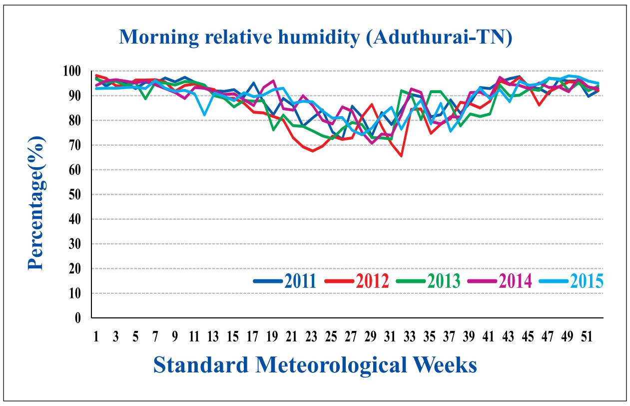
7. ADUTHURAI (TN)

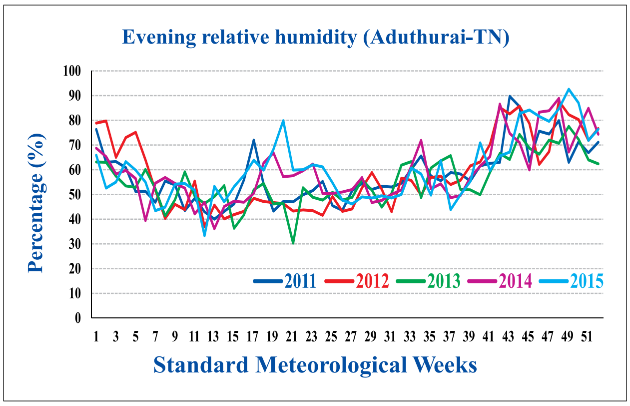


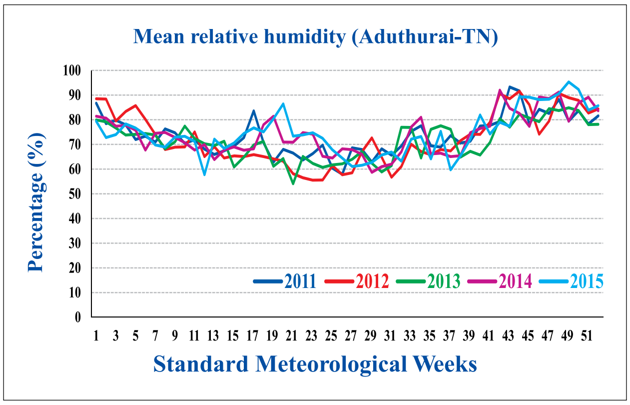


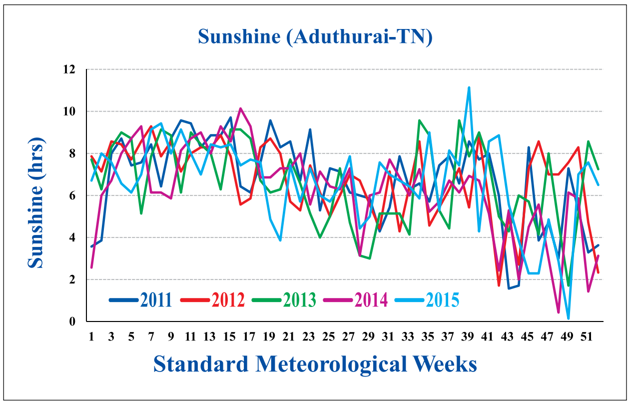


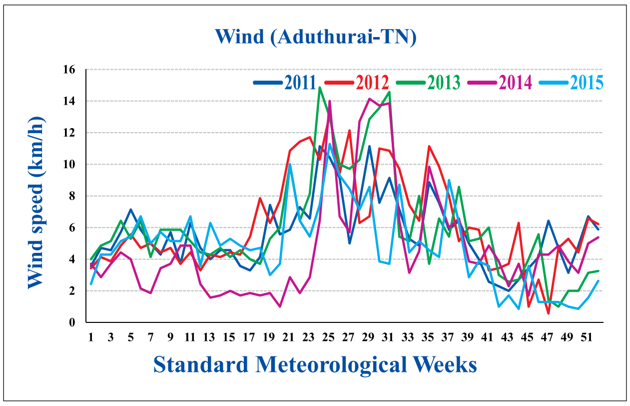



Morning relative humidity (Aduthurai-TN)
Percentage(%)
2011 2012 2013 2014 2015
Standard Meteorological Weeks


Evening relative humidity (Aduthurai-TN)
Percentage (%)
2011 2012 2013 2014 2015
Standard Meteorological Weeks


Mean relative humidity (Aduthurai-TN)
Percentage (%)
2011 2012 2013 2014 2015
Standard Meteorological Weeks


Sunshine (Aduthurai-TN)
Sunshine (hrs)
2011 2012 2013 2014 2015
Standard Meteorological Weeks


Wind (Aduthurai-TN)
Wind speed (km/h)
2011 2012 2013 2014 2015
Standard Meteorological Weeks

Annexure V – Prediction accuracies of weather based models (calendar year based)

LOCATION	Calendar year				
	2011	2012	2013	2014	2015
YSB					
Ludhiana (PB)	96.15	96.15	92.31	92.31	98.08
Chinsurah (WB)	50	40.38	50	48.08	51.92
Raipur (CG)	84.62	75	67.31	65.38	61.54
Karjat (MH)	90.38	88.46	82.69	94.23	94.23
Hyderabad (TS)	73.08	62.50	90.38	80	26.09
Mandya (KA)	26.92	11.54	75	88.46	65.38
Aduthurai (TN)	38.89	38.46	76	51.92	78.85
Leaf Folder					
Ludhiana (PB)	82.69	71.15	75	75	78.85
Raipur (CG)	80.77	78.85	84.62	78.85	69.23
Aduthurai (TN)	86.11	84.62	80	80.77	75
BPH					
Ludhiana (PB)	69.23	55.77	51.92	67.31	67.31
Chinsurah (WB)	65.38	75	82.69	86.54	80.77
Raipur (CG)	61.54	65.38	51.92	53.85	50
Hyderabad (TS)	57.69	75	40.38	40	67.39
Mandya (KA)	38.46	28.85	90.38	92.31	86.54
Aduthurai (TN)	75	57.69	60	59.62	59.62
WBPH					
Chinsurah (WB)	65.38	82.69	100	92.31	92.31
GLH					
Chinsurah (WB)	82.69	94.23	100	94.23	92.31
Raipur (CG)	82.69	82.69	71.15	86.54	80.77
Karjat (MH)	98.08	76.92	96.15	96.15	80.77
Hyderabad (TS)	76.92	93.75	73.08	76.67	80.43
Mandya (KA)	61.54	57.69	32.69	53.85	40.38
Aduthurai (TN)	86.11	84.62	80	76.92	82.69
Gall Midge					
Raipur (CG)	80.77	90.38	82.69	88.46	76.92
Caseworm					
Raipur (CG)	-	90.38	82.69	88.46	76.92