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Prediction of *Helicoverpa armigera* (Hubner) larval population using weather based forewarning model in soybean

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ABSTRACT

Weekly larval populations of pod borer, *Helicoverpa armigera* (Hubner) collected from 20 districts of Maharashtra under Crop Pest Surveillance and Advisory Project (CROPSAP) during 2010-2015 were analyzed to work out the effect of weather variables on the incidence of this insect on soybean. The appearance of larva was observed throughout the soybean growing season, and the peak incidence was observed during third week of August to first week of September (34-35 SMW). The correlation analysis of the data revealed that larval population was significantly and positively influenced by the minimum temperature and rainfall of current week as well as previous two weeks. For the development of forewarning model, data for the period from 2010 to 2013 were used as training dataset and two year (2014-2015) data as validation dataset. The mean model used for forewarning the incidence of pod borer larval population was developed by using step-wise multiple regression analysis in polynomial form. The results of mean model revealed that the significant variables affecting the pod borer larval population in soybean were maximum temperature (current and 1st lag week), and rainfall (current week) and the model explained 48.93% variation. The pre-disposing conditions for the incidence of larvae have been worked out as maximum temperature ranging from 26.1 to 31.47 ºC and rainfall ranging from 6.63 to 141.46 mm with low or medium rainfall in previous weeks followed by high in current week. The model was validated with 2014-15 independent dataset with predicted R^2 (R^2_{Pred}) value 28.13%. Two sample t-test showed no significant difference between observed and predicted values ($p = 0.3691 > 0.05$).

Key words: *Helicoverpa armigera*, soybean, weather variables, forewarning, validation.

Soybean [*Glycine max* (L.) Merrill], popularly known as golden bean, has established as a leading oilseed crops in India. It is a very important oilseed crop in terms of its nutritional value with 40-45 % protein and 18-22% oil (Devi *et al.*, 2014; Javor *et al.*, 2001) and is a cheaper source of protein. Soybean is mainly cultivated as a rainfed crop in India. The crop is sown, with the onset of monsoon, from 2nd week of June to 2nd week of July but the optimum sowing time is from 3rd week of June to 1st week of July (Jain *et al.*, 2014). It requires lower input cost in cultivation and comparative profitability than other *kharif* crops, which led to rapid expansion of the crop in area as well as in production (Sharma *et al.*, 2014).

There are many biotic and abiotic factors which hinder to achieve the realization of the yield potential. Among the biotic factors, insect-pests infestation reduces the yield potential of the soybean crop (Punithavalli *et al*., 2014). Presently, nearly a dozen major insect-pests are infesting the soybean crop regularly in one or the other soybean growing states. These insects individually can cause 20 - 100 % yield losses in soybean crop (Sharma *et al.*, 2014). *Helicoverpa armigera* (Hubner) is among the major insects which cause damage to soybean crop. It is voracious in nature and a polyphagous pest which survive on large number of hosts all over the year (Aheer *et al.*, 2009). In India, soybean is cultivated in rainy season and weather conditions during crop growth, management practices like date of sowing, deep summer ploughing, seed treatment, *etc*. affects the insect pest development (Vannila *et al.*, 2011) on the crop. The most congenial environmental condition to the insect is when the soybean is in flowering and vegetative growth period but it can be seen till maturity or harvest of the crop.

Timely and effective management of insect incidence entails better understanding of the favourable environmental conditions for growth and spread of the insect population. Hence, there is a need to understand and study the key weather factors such as temperature, rainfall and relative humidity, which are responsible for higher incidence of *H. armigera* on soybean crop. The information on interaction of weather variable (s) and the *H. armigera* attack on soybean are very scanty. For the effective and timely pest management and to develop the integrated pest management (IPM) strategy, the need of the hour is to develop the forewarning model of *H. armigera* incidence on soybean and disseminate this to the farming community before the spread of insect to the level of causing economic loss. Forewarning of insect infestation will empower the farmers to take appropriate management practices and reduce the yield loss. Looking at the importance of the subject, an attempt has been made to determine the association and effect of weather variables on *H. armigera* incidence on soybean and develop the survey data based forewarning model.

MATERIALS AND METHODS

The study is based on village level daily data on number of larva per square meter of pod borer (*H. armigera*) for soybean growing period from 27^{th} to 39^{th} standard meteorological weeks (SMW) i.e. from July to September along with district-wise daily data of weather variables (maximum and minimum temperature, average relative humidity and rainfall). The data were collected from twenty districts of Maharashtra (Ahmednagar, Akola, Amravati, Aurangabad, Buldhana, Chandrapur, Jalgaon, Kolhapur, Nagpur, Nanded, Nasik Osmanabad, Parbhani, Pune, Sangli, Satara, Solapur, Wardha, Washim, Yeotmal) under Crop Pest Surveillance and Advisory Project (CROPSAP) project from 2010 to 2015 (six years). Daily data on larval population and weather variables were averaged to standard meteorological week level (total of rainfall) and district level as the availability of weather data was at district level. The data sets of insect incidence and weather variables for the period 2010 to 2013 were used for the development of forewarning model as training dataset, and the data sets for 2014 and 2015 were used for the validation of the developed forewarning model.

In the present study correlation of insect incidence and weather variables and regression models on weekly panel data (panel model) and district level weekly mean data (mean model) were tested and validated for the model prediction accuracy. The statistically best model has been selected for working-out pre-disposing weather factors for insect incidence forewarning. In the mean model, weekly mean data over years of larval population of pod borer of each district from first emergence week to first peak incidence week (29^{th} to 35^{th} SMW) of *kharif* soybean season were used. In the panel model, all individual observations of different years and districts were used for the analysis to retain the variability over the years and across the districts. Second degree polynomial equation using step-wise multiple regressions has been fitted for the selection of variables to develop the forewarning models using SAS Enterprise Guide version 4.3 (SAS Institute Inc., 2011). The pre-disposing factors were worked out using training datasets (2010 to 2013) of larval population as dependent variable and four weather factors pertaining to current, first and second lag weeks as independent variables.

The data used for model development has been cleansed from outliers and leverage points based on the cook's D statistics. The model developed has been tested and evaluated using R^2, R^2_{Adj}, RMSE, PRESS Statistics and among the models, the model which has the minimum AIC, and RMSE is selected as the best fit model. Models were validated using the cross-validation methodology (LOOCV – Leave One Out Cross-Validation) *i.e.*, R^2_{Pred} (Montgomery, *et al.,* 2011); and by comparing the week-wise mean values of observed validation datasets of future values from 2014 to 2015 with predicted larval populations by two sample 't-test' (Patel et al., 2019). The test of significance level of 5 per cent was observed in both correlation and regression. All the statistical analyses were done using SAS Enterprise Guide version 4.3 (SAS Institute Inc., 2011).

RESULTS AND DISCUSSION

Correlation studies

The larval population of soybean pod borer, *H. armigera* for different years was plotted on Fig. 1, which indicated that the pod borer infestation was high in the year 2010 (high incidence year) as compared to other years. The high incidence and normal year standard meteorological week (SMW) level data graph (Fig 2) revealed that the insect incidence started from mid-July and continued till maturity of soybean but first peak of incidence was shown in 34-35^{th} SMW. The insect incidence and weather factors was computed by taking the four year (2010-2013) standard meteorological week-wise means of variables (Vannila *et al*., 2011).

The correlation between *H. armigera* larval population on soybean crop and weather variables (in relation to current, first and second lag weeks) has been worked out and presented in Table 1. The correlation results revealed that the larva populations were greatly affected by agro-meteorological conditions. The variation in larval population was due to the variation in the weather in different districts during the crop season in different years. The overall correlation analysis during 2010-2013 (29^{th} – 35^{th} SMW) indicated that larva population was mainly influenced by the minimum temperature of the current week as well previous two weeks, and rainfall of current and 1^{st} lag weeks. Among these weather variables *H. armigera* larva had positive significant

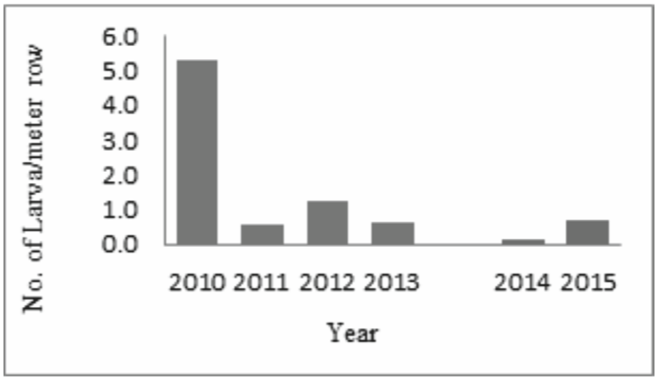

Fig. 1: Normal and high incidence year

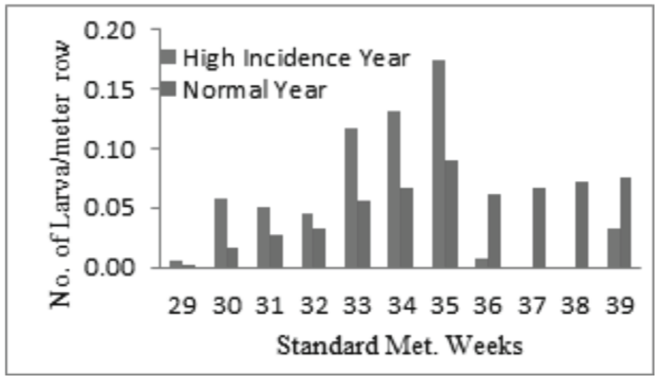

Fig. 2: Larva incidence in normal & high incidence year

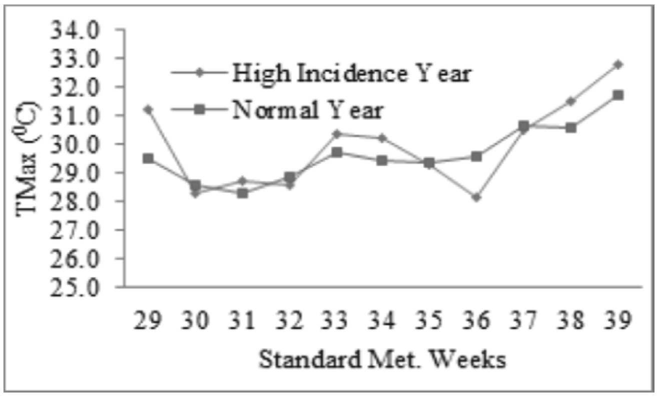

Fig. 3: Max. temp. of high incidence and normal year

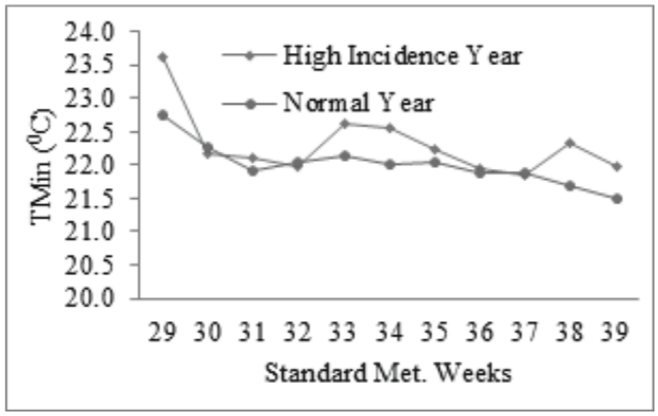

Fig. 4: Min. temp. of high incidence and normal year

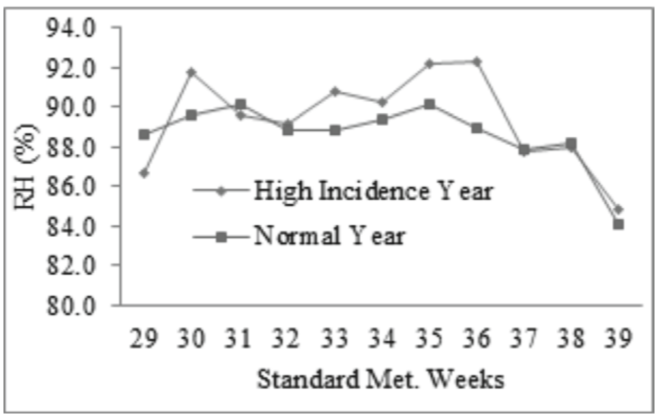

Fig. 5: Relative humidity of high incidence and normal year

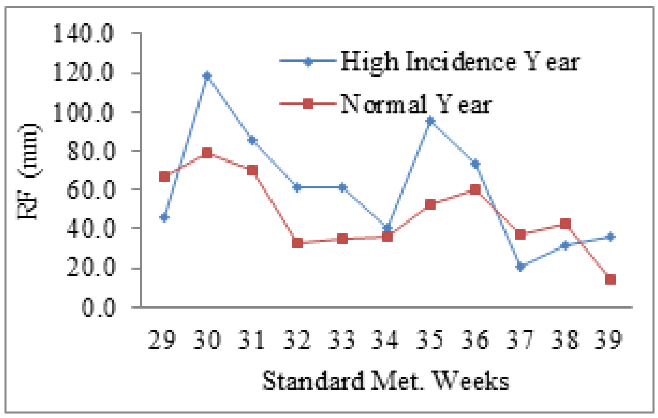

Fig. 6: Max. temp. of high incidence and normal year

correlation with RF_0 & $TMin_{-1}$ (r=0.41 and 0.38 respectively) at 1% level of significance and positive significant correlation with $TMin_0$, RF_{-1} & $TMin_{-2}$ (r=0.32, 0.29 and 0.33 respectively) at 5% level of significance. Earlier studies also reported the significant correlation of temperature, rainfall and relative humidity with *H. armigera* population on cotton and pulse crops (Jat *et al*., 2017; Meena and Bhatia, 2014; Mukherjee and Bhowmik, 2009 and Sagar *et al.*, 2017). Other weather factors showed non-significant correlations. This implied that the larval population of soybean pod borer increases with the increase in rainfall and minimum temperature of current as well as previous two weeks.

Development and validation of prediction model

Step-wise multiple regressions was used to develop forewarning model for pod borer larval population and weather variables (pertaining to current, 1st and 2nd lag week) over years (2010-13). Two models (mean model and panel model) were tested and evaluated for prediction accuracy. The results of analysis indicated that mean model was found to be statistically best fit as compared to the panel model (Table 2) based on the parameters listed in the methodology section. Hence, mean model was used to predict *H. armigera* larval population and pre-disposed condition. The results of

Table 1: Correlation coefficient between population of, *H. armigera* larva and weather variables (2010-13)

Weather variables	Correlation coefficients
$TMax_0$	-0.14
$TMin_0$	0.32*
RH_0	-0.08
RF_0	0.41**
$TMax_{-1}$	0.10
$TMin_{-1}$	0.38**
RH_{-1}	-0.26
RF_{-1}	0.29*
$TMax_{-2}$	0.01
$TMin_{-2}$	0.33*
RH_{-2}	-0.17
RF_{-2}	0.24

Note: **, * significant @ 1% and 5% respectively. $TMax_0$, $TMax_{-1}$, $TMax_{-2}$ represents Maximum temperature for current week, 1st and 2nd lag week respectively and similarly for other weather variables.

regression model (mean model) revealed that, the pod borer larval population was significantly affected by the maximum temperature of current and 1st lag week ($TMax_0$ and $TMax_{-1}$, respectively), rainfall of 1st lag week (RF_{-1}) and second order maximum temperature of current week (Table 2). Whereas the results of panel model revealed that larval population was significantly influenced by maximum temperature of 1st and 2nd lag weeks and second degree minimum temperature of current and 2nd lag week. The variables included in the model explained 48.93% (mean model) and 18.92% (panel model) of the total variation in larval population. All the weather variables used were significant at 5% level of significance. In mean model, the effect of $TMax_0$ and RF_{-1} was found to be negative and significant, while the $TMax_{-1}$ affecting the larva incidence positively and significantly. This signifies (by mean model) that the high rainfall reduced larval population in the following week while lower maximum temperature increases the incidence in the following week. The larval population washed out with the high rainfall and thus, the incidence was reduced in the following week. In panel model, the effect of $TMax_{-1}$ and $TMin_{-2}$ was positively significant while $TMin_0$ and $TMin_{-2}$ were significantly negative to the larval population of pod borer. The developed forewarning model was validated using the cross-validation methodology (LOOCV – Leave One Out Cross-Validation) *i.e.* R^2_{Pred} = 28.13% (mean model) and R^2_{Pred} = 9.26% (panel model); independent dataset of 2014 and 2015, comparison of mean of observed values from 2014 to 2015 of the study areas with predicted larval populations was carried out by two sample t-test and found no significant difference between observed and predicted values (mean model: $p = 0.3691 > 0.05$; panel model: $p = 0.0685 > 0.05$).

Pre-disposing conditions

The analysis was carried out to work out the pre-disposing conditions favorable for peak incidence of pod borer larva as affected by weather variables during two weeks prior to current (peak incidence) week. Analysis of dataset and comparing the high incidence and weather variables of normal year (Fig. 3-6) revealed that the favourable weather conditions for the peak incidence of pod borer larva were found to be; average maximum temperature ranging from 26.1 to 31.47 ºC,

Table 2: Forewarning model for H. armigera larval incidence

Mean model	$HA = 15.83 - 1.1 \times TMax_0 + 0.04 \times TMax_{-1} - 0.002 \times RF_{-1} + 0.018 \times TMax_0^2$	R^2=48.93%, R^2_{Adj}=43.56% R^2_{Pred}=28.13%, SE=0.079, N=43
Panel model	$HA = -3.16 + 0.013 \times TMax_{-1} + 0.27 \times TMin_{-2} - 0.0004 \times TMin_0^2 - 0.006 \times TMin_{2}^{2}$	R^2=18.92%, R^2_{Adj}=13.52% R^2_{Pred}=9.26%, SE= 0.056, N=65

Table 3: Range of weather variables

Current week		1st Previous week		2nd Previous week	
Weather factors	Range	Weather factors	Range	Weather factors	Range
$TMax_0$	26.74 - 31.47	$TMax_{-1}$	26.6 - 31.21	$TMax_{-2}$	26.1 - 31.21
$TMin_0$	19.81 - 24.07	$TMin_{-1}$	19.73 - 23.82	$TMin_{-2}$	19.54 - 24.07
RH_0	82.77 - 93.61	RH_{-1}	81.86 - 93.29	RH_{-2}	81.86 - 93.75
RF_0	6.63 - 63.19	RF_{-1}	7.39 - 72.7	RF_{-2}	11.07 - 141.46

average minimum temperature ranging from 19.54 to 24.07 ºC, average relative humidity ranging from 81.86 to 93.75 % and the weekly average of total rainfall ranging from 6.63 to 141.46 mm (Table 3). But after removing outlier values, the favourable weather conditions for peak incidence of larval population on soybean crop, in more than 90 percent of the cases, were maximum temperature ranging from 27.48-31.44 ºC, minimum temperature ranging from 19.73-23.91 ºC, relative humidity 86.18-93.61% and rainfall ranging of 11.07-94.33 mm with low or medium rainfall in previous weeks followed by high rainfall in current week as shown in Table 2 (Duraimurugan, 2018). Pratheepa *et al*. (2010) reported that the incidence of *H. armigera* was high when maximum temperature ranged from 29.9ºC to 34ºC.

CONCLUSION

The results of analysis revealed that the favourable weather conditions for the peak incidence of pod borer larva on soybean were observed to be maximum temperature ranging from 27.48-31.44 ºC, minimum temperature ranging from 19.73-23.91 ºC, average relative humidity ranging from 86.18 - 93.61 % and the weekly average of total rainfall ranging from 11.07-94.33 mm with low or medium rainfall in previous weeks followed by high in current weeks. The model developed can be utilized to forewarn the farmers and disseminate the agro-advisory of incidence of pod borer larval population well in advance to take precautionary measure and protect the crop from insect damage by optimizing management practices.

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