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Weather Based Prediction Models for Forewarning Tobacco Caterpillar, Spodoptera Litura (Fabricius) Larval Population in soybean

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SUMMARY

The study is based on the daily village level data of tobacco caterpillar incidence and district level data on weather variables for Maharashtra collected from Crop Pest Surveillance and Advisory Project (CROPSAP). The Project conducted at Department of Agriculture, Govt. of Maharashtra for the period 2010-2015. The study was conducted to assess the influence of weather variables on tobacco Caterpillar (***Spodoptera litura)*** infestation in soybean. The correlations of insect population with weather variables pertaining to current, first and second lag weeks were worked out. Gregarious phase larvae was significantly positively correlated with relative humidity of first lag week (RH_{-1}) and significantly negatively correlated with rainfall of current and first lag weeks (RF_0, RF_{-1} respectively); and Solitary phase was significantly and negatively correlated with relative humidity of current and first lag week (RH_0 and RH_{-1}), and rainfall of first and second lag week (RF_{-1}, and RF_{-2}). Forewarning models were developed using training dataset and validated using validation dataset. Mean regression models explained 61.58%, 72.08% and 46.48% variability in the population of *S. litura* egg mass, gregarious and solitary larva, respectively. The pre-disposing conditions favouring the tobacco caterpillar infestation for maximum temperature, minimum temperature, relative humidity and rainfall were in the range of 27.10-32.83 ºC, 19.35-24.15 ºC, 84.21-93.38% and 14.77-92.95 mm with high or medium rainfall in previous weeks followed by low rainfall in current week (for *S. litura* egg mass); 27.29-31.94ºC, 20.28-25.63 ºC, 86.00-93.75% and 11.07-112.65 mm with low rainfall in previous weeks followed by higher rainfall in current week (for *S. litura* gregarious larva); and 27.06-32.45 ºC, 20.23-25.63 ºC, 82.96-94.28% and 15.03-119.18 mm with high rainfall in RF_{-2} and slowed in RF_{-1} followed by rise in RF_0 or continuously increasing pattern from RF_{-2} to RF_0 (for *S. litura* solitary larva) respectively. The models were validated by cross-validation and independent dataset methodologies. Two sample t-test, RMSE, and other validation statistics revealed no significance difference between observed and predicted values of insect population. Hence, the models could be utilized to disseminate the insect advisories to the farmers.

Keywords: S. litura, Soybean, Weather variables, Forewarning, Validation.

1. INTRODUCTION

Soybean [*Glycine max* (L.) Merrill] is a leading oilseed crop of India, containing 35-45% protein and 18-22% oil. There has been a rapid expansion of soybean in India on account of its comparative profitability over other *kharif* crops (Sharma *et al,* 2015). The crop has helped enhance the socio-economic status of the lakhs of small and marginal farmers in India (Dupare *et al.* 2009; Sharma *et al.* 2016a). Cultivation of crop is mainly concentrated in arid and semi-arid regions, particularly in Central India. Despite its unparallel growth in area and production over past four and half decades, the productivity of the crop hovers around 1.0 to 1.3 t/ha and the productivity growth is not impressive, and is nearly one-third compared to its climatic potential (Bhatia *et al.*, 2008). The low yield is due to the imbalance and sub-optimal use of resources (Sharma *et al.* 2016b); mono-cropping of soybean-wheat/chickpea continuously; and increased incidence of biotic and abiotic stresses (Bhatia *et al,* 2008).

Among biotic stresses, insect-pests play a significant role that hampers to achieve the realized yield of soybean (Punithavalli *et al.*, 2014 and Bhatia *et al.*, 2008). The losses due to biotic stresses in soybean are reported to the tune of 26.4% worldwide. The estimated yield losses caused by various insects in soybean have been reported to 26%-29% (Harish *et al.*, 2009; Oerke, 2006; Sharma and Shukla, 1997). In tropical Asia, common cutworm, *S. litura* is one among the most important polyphagous insects of soybean and of economical importance of agricultural crops worldwide (Punithavalli *et al.*, 2014; Armes *et al.*, 1997; Dhaliwal *et al.*, 2010; Feakin, 1973; Qin & Ye, 2007). Common cutworm hosts on at-least 120

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plant species; among the field crops groundnut, cotton, tobacco and short duration pulses and vegetables are the major hosts; and the most preferred host is soybean crop (Prasad *et al.*, 2013; Sharma, 1994). Severe outbreaks of the insect on soybean in India were reported in the years 1997, 2005, 2008 and 2009 (Prasad *et al.*, 2013). In soybean, *S. litura* larvae severely defoliates the leaves (Higuchi *et al.,* 1991) particularly at or after the bloom period causing reduction in number and weight of pods and grain per plant (Prasad *et al.*, 2013; Bhattacharjee and Ghude, 1985). In Maharashtra, during 2008-09 tobacco caterpillar (cutworm) together with pod borer (*H. armigera*) infested soybean area at around 1.46 m ha causing yield loss to the tune of 0.85 million tonnes and monitory loss of Rs. 1.39 billion (Singh, *et al.,* 2012). Tobacco caterpillar is a serious and regular insect in India that after defoliating the soybean plant start damaging the tender and younger parts consequently damaging to the tune of 30-50% of the pods (Sasvihalli *et al.*, 2017). The severe infestation of tobacco caterpillar was experienced when the sowing was delayed due to delay in monsoon along with fewer than normal rainy days and rainfall higher than 20 mm during June to mid-August (Prasad *et al.*, 2013).

Insect-pests density, dynamics, period and intensity of infestation are significantly influenced by the climatic variables. Protecting the crop well before the advent of insect infestation entails the understanding of favourable pre-disposed conditions for the growth and development of the insect. Hence, it is highly imperative to comprehend the key environmental variables responsible for the outbreak of the *S. litura* on soybean. The infestation of the insects in crops is a very complex phenomenon that happens spatially in an unstable and disorderly state and temporally in a regular and ordered state. The studies revealed that insect forewarning is a complex process with diversity, paroxysmal abnormality, randomness and heterogeneity in the dynamics of the insects (Yang, *et al.*, 2009; Zhang and Zhou, 1995). In soybean, the information corresponding to the influence of climatic variables on tobacco caterpillar is very scanty. The efficacy of any integrated pest management (IPM) strategy depends on the regular pest monitoring (Singh *et al.*, 2012; Grant *et al.* 2006), by which epidemic situations can be avoided. Hence, developing forewarning models for tobacco caterpillar incidence is of paramount importance in order to implement the management strategies to minimize the losses. Pest-Weather forewarning model is the scientific methodology that can thwart the impending infestation of *S. litura* through prediction and dissemination of agro-advisories to the soybean farmers to enable them to take timely management decisions. Hence, the study was carried out to investigate the effect of abiotic factors on tobacco caterpillar infestation in soybean and develop the prediction model based on the survey data to predict the severity of the infestation.

2. MATERIAL AND METHODS

The study uses daily village level data on number of egg mass, gregarious larva and solitary larva per meter row along with district level daily weather data (maximum, minimum temperature, relative humidity, and rainfall) collected under the CROPSAP (Crop Pest Surveillance and Advisory Project) of Department of Agriculture, Govt. of Maharashtra. The data collected from twenty districts of Maharashtra for *S. litura*-egg mass during 2010-14 (five years) and for *S. litura* – gregarious larva and *S. litura* – solitary larva during 2010-15 (six years) were covered in the analysis based on the availability of the data. The data were collected during the main soybean crop period (*kharif* season) from 27^{th} – 39^{th} standard meteorological weeks (SMW) i.e. from July – September period.

The insects and weather survey data were transformed to district-wise weekly data pertaining to SMWs as per the district-wise availability of weather data by averaging the parameters and total of rainfall according to SMWs. The data transformation was attempted to improve the additivity and homoscedasticity of the time series data (Rao *et al.*, 2015). The data was split into two parts for training and developing the model as training dataset from 2010 to 2012 (egg mass) and 2010 to 2013 (gregarious larva and solitary larva); and for testing and validating the developed model, two years independent dataset from 2013 and 2014 (egg mass) and 2014 and 2015 (gregarious larva and solitary larva), were used.

In the analysis, two types of the models were developed and tested viz., panel data model and mean data model. In mean model, 20, 46 and 99 observations utilized for developing and 17, 17 and 66 observations for validating the developed models for *S. litura* – egg mass, greg. larvae and solitary lavae, respectively. In panel model, 31, 60 and 152 observations for developing and 18, 12 and 80 observations for validating the developed models for *S. litura* – egg mass, greg. larvae and solitary lavae, respectively. Weekly mean data over the years and for each district of insect larval population and weather variables were used in mean model whereas weekly data of each districts of all years were used in the panel model. In mean model, variability across the districts was retained while in panel model, variability is retained across years and the districts. The data used in the analysis for *S. litura* egg mass were from first emergence week to first peak week ($29^{th}–33^{rd}$ SMW), for *S. litura* gregarious larva from $29^{th}–35^{th}$ SMW and for *S. litura* solitary larva from $29^{th}–36^{th}$ week (Patel *et al.*, 2019). The correlation analysis was used to know the relationship of insect incidence with weather variables and regression analysis was used to assess the cause and effect relationship of insect with weather variables by formulating the prediction models. The models developed were second degree polynomial equation (to better fit the curvilinearity of the data and to get better R^2) fitted using multiple regression method for selecting the variables to predict the insect incidence. The models were developed by using insect incidence as response variables and weather variables (pertaining to current, 1^{st} and 2^{nd} lag week) as explanatory variables.

The survey data were processed and diagnosed to identify the leverage and outlier data points and then these points were removed using Cook's D statistic and studentized residuals to fit the model accurately. The observations (Table 1) having Cook's D statistic greater than unity or studentized residuals greater than ±3 were influential (outlier or leverage) points, hence removed from the dataset used for model development (Montgomery, *et al.*, 2011). The testing and evaluation of the developed models were done using R^2, RMSE, and RMSE values were selected as the best fit models among the models. Validation of the models were carried out using the cross-validation methodology (LOOCV – Leave One Out Cross-Validation) i.e. R^2_{Pred} which required no independent dataset for validation (Montgomery, *et al.*, 2011; Patel, *et al.*, 2019); and independent dataset for validating observed and predicted values. Two sample t-test, root mean square error (RMSE), standardized residuals and mean absolute error (MAE) were used to carry out validation of observed and predicted values. All the above statistical analyses were carried out using SAS Enterprise Guide version 4.3 (SAS Institute Inc., 2011).

3. RESULTS AND DISCUSSION

3.1 Correlation analysis

The linear relationship was worked out between *S. litura* infestation 'viz., egg mass (SEM), gregarious larva (SGL) and solitary larval stages (SSL) on soybean and weather variables and the results are depicted in Table 2. Correlation analysis revealed that in mean model, gregarious larva infestation was significantly and positively correlated with current and one lag week

Table 1. Influential observations removed from model development

Model	Insect	Deleted Observations	Insect Incidence	Studentized Residual	Cook's D Statistic
Mean Model	*S. litura* -Egg Mass	1	1.8	1.742	4.212
		2	2.2936	4.586	0.956
		3	0.4307	3.562	0.604
	S. litura –Greg. Larvae	1	1.8	4.243	10.366
		2	0.5	3.128	1.111
	S. litura – Soli. Larvae	1	4.875	4.589	1.29
		2	3.575	4.583	0.185
Panel Model	*S. litura* -Egg Mass	1	6.72	3.571	19.73
		2	1.2857	5.074	6.137
	S. litura –Greg. Larvae	1	1.8	5.337	4.801
		2	1	4.09	1.291
		3	0.65	4.124	0.107
		4	0.6	1.936	4.887
	S. litura – Soli. Larvae	1	9.6	9.829	1.59
		2	7.425	7.427	0.5
		3	3.575	3.411	0.031

Table 2. Correlation coefficient of S. litura and weather variables on soybean (2010-13)

Variables	Mean model				Variables	Panel model		
	SEM	SGL	SSL			SEM	SGL	SSL
TMax0	-0.42	-0.15	0.02		**TMax0**	-0.16	**-0.42****	0.15
TMin0	-0.23	0.19	-0.15		**TMin0**	**-0.53****	-0.04	0.05
RH0	0.27	-0.09	**-0.28****		**RH0**	-0.18	0.13	0.02
RF0	0.38	**0.54****	-0.17		**RF0**	-0.13	0.17	**0.17***
TMax-1	-0.23	0.03	-0.05		**TMax-1**	-0.12	**-0.31***	0.08
TMin-1	-0.24	0.27	-0.11		**TMin-1**	**-0.37***	-0.08	0.02
RH-1	0.16	**-0.31***	**-0.29****		**RH-1**	-0.09	0.11	-0.08
RF-1	0.07	**0.45****	**-0.24***		**RF-1**	-0.18	0.11	-0.05
TMax-2	-0.06	0.10	-0.10		**TMax-2**	-0.22	-0.22	-0.03
TMin-2	-0.22	0.28	-0.14		**TMin-2**	**-0.49****	-0.05	-0.01
RH-2	-0.16	-0.27	-0.05		**RH-2**	0.03	0.07	-0.06
RF-2	-0.12	0.15	**-0.30***		**RF-2**	-0.29	0.04	**-0.27****

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.
SEM – Spodoptera Egg Mass; SGL – Spodoptera Gregarious Larvae; SSL – Spodoptera Solitary Larvae.

rainfall (RF_0 and RF_{-1}) and negatively with previous week relative humidity (RH_{-1}). Solitary larvae were having negatively significant correlation with current and previous week relative humidity (RH_0 and RH_{-1}) and one and two lag week rainfall (RF_{-1} and RF_{-2}). In panel model, egg mass were having negatively significant correlation with minimum temperature of all three weeks ($TMin_0$, $TMin_{-1}$, $TMin_{-2}$); gregarious larva had significantly negative correlation with maximum temperature of current and 1st lag weeks ($TMax_0$, $TMax_{-1}$); and solitary larva had negatively significant correlation with rainfall of current and 2nd lag weeks (RF_0, RF_{-2}).

3.2 Development and validation of prediction model

Two pest-weather models (Mean model and Panel model) were developed using step-wise multiple regressions method for *S. litura* egg mass, gregarious larva and solitary larva as response variable and weather variables corresponding to current (peak incidence week), 1st lag and 2nd lag week, as explanatory variables. In mean model (Table 3), the Egg mass (number per meter row length) was significantly affected by $TMin_0$, RF_0, RF_{-1}, $TMax_0^2$, $TMin_0^2$ at 5% and RH_{-1} at 10%. Gregarious larva (no. of infected plants per meter row length) was affected significantly by $TMax_0$, RF_{-1}, $TMax_0^2$ & RF_{-1}^2 at 5%. Solitary larva (no per meter row length) was significantly influenced by RH_0, RF_{-1}, RH_{-2}, RF_{-2}, RH_0^2, RF_0^2 & RF_{-2}^2 at 5% level of significance. In panel model (Table 4), the Egg mass was significantly affected by $TMin_0$, RF_{-1}^2 at 5% and RH_0 at 10%. Gregarious larva was affected significantly by $TMax_0$, $TMin_0$, $TMax_0^2$ at 5% and $TMin_0^2$ at 10%. Solitary larva was significantly influenced by $TMax_0$, RF_0, RF_{-2}, RF_0^2, & $TMax_{-2}^2$ at 5% level of significance. In mean model, the variables included in the models explained 61.58% (for egg mass); 72.08% (Gregarious larva) and 46.48% (solitary larva) whereas in panel model, 45.7% (for egg mass); 36.29% (Gregarious larva) and 26.5% (solitary larva) of the total variation in egg mass and larval population. The models (Mean Model and Panel Model) were evaluated statistically and it was found that Mean Model performed better than Panel model. Thus, the insects population and pre-disposing conditions were predicted based on the mean model. The models were validated by using two validation methodologies viz. cross-validation methodology (LOOCV – Leave One Out Cross-Validation) i.e. R^2_{Pred} and independent dataset (2013-14 for egg mass; 2014-15 for gregarious larva and solitary larva) methodology. In mean model, cross-validation R^2_{Pred} (Table 3 & 4) for egg mass, gregarious larva and solitary larva were 21%, 63.21% and 26.5% respectively; and comparison of observed values of independent dataset with predicted model values (Table 5) by two sample t-test P value were $p=0.085>0.05$ for egg mass, $p=0.535>0.05$ for gregarious larva and $p=0.064>0.05$ for solitary larva. In panel model, cross-validation R^2_{Pred} = 30.32% for

Table 3. Forewarning Mean Model for Spodoptera litura incidence

SEM	SEM = 6.58 – (0.67 X $TMin_0$) + (0.002 X RF_0) + (0.009 X RH_{-1}) - (0.001 X RF_{-1}) - (0.0005 X $TMax_0^2$) + (0.016 X $TMin_0^2$)	R^2 = 61.58%, $R^2_{(Adj)}$ = 43.84%, $R^2_{(Pred)}$ = 21%, SE = 0.038
SGL	SGL = 18.26 - (1.21 X $TMax_0$) - (0.0043 X RF_{-1}) + (0.02 X $TMax_0^2$) + (0.00004 X RF_{-1}^2)	R^2 = 72.08%, $R^2_{(Adj)}$ = 69.36%, $R^2_{(Pred)}$ = 63.21%, SE = 0.072
SSL	SSL = 163.22 – (3.63 X RH_0) - (0.02 X RF_1) + (0.053 X RH_{-2}) - (0.031 X RF_{-2}) + (0.02 X RH_0^2) + (0.00014 X RF_0^2) + (0.0002 X RF_{-2}^2)	R^2 = 46.48%, $R^2_{(adj)}$ = 42.37%, $R^2_{(pred)}$ = 26.5%, SE = 0.53

Table 4. Forewarning Panel Model for Spodoptera litura incidence

SEM	SEM = 1.14 - (0.03 X $TMin_0$) - (0.005 X RH_0) -(0.000004 X RF_{-1}^2)	R^2 = 45.7%, $R^2_{(Adj)}$ = 39.66%, $R^2_{(Pred)}$ = 30.32%, SE = 0.06
SGL	SGL=8.51 - (0.78 X $TMax_0$) + (0.31 X $TMin_0$) + (0.013 X $TMax_0^2$) - (0.007 X $TMin_0^2$)	R^2 = 36.29%, $R^2_{(Adj)}$ = 31.66%, $R^2_{(Pred)}$ = 25.71%, SE = 0.095
SSL	SSL= - 0.24 + (0.04 X $TMax_0$) + (0.006 X RF_0) - (0.002 X RF_{-2}) - (0.00003 X RF_0^2) - (0.0007 X $TMax_{-2}^2$)	R^2 = 26.5%, $R^2_{(Adj)}$ = 23.99%, $R^2_{(Pred)}$ = 21.13%, SE = 0.19

egg mass, R^2_{Pred} = 25.71% for gregarious larva and R^2_{Pred} = 21.13% for solitary larva; and comparison of observed values of independent dataset with predicted values by two sample t-test were p=0.06>0.05 for egg mass, p=0.86>0.05 for gregarious larva and p=0.98>0.05 for solitary larva. Also the estimated standardized residuals also were in between -3 to +3 (Table 5) indicated the suitability of the models for predicting the *Spodoptera litura* infestation (Akashe *et al.*, 2016). Other validation statistics are shown in Table 5. The validation by t-test, standardized residual, RMSE and MAE showed no significant difference between observed and predicted values. Hence, the models were validated satisfactorily. By the results it is evident that mean models are better than panel models and can be used for agro-advisories to the soybean farmers.

Table 5. Observed vs Predicted values of Spodoptera litura incidence validation statistics

Mean	**MAE**	**RMSE**	**t-test *P* value**
SEM	0.164	0.0204	0.085
SGL	0.21	0.30	0.535
SSL	0.74	0.88	0.064
Panel	**MAE**	**RMSE**	**t-test *P* value**
SEM	0.33	0.54	0.06
SGL	0.21	0.3	0.86
SSL	0.26	0.33	0.98

SEM – *S.litura* – Egg Mass, SGL – *S.litura* – Gregarious larva, SSL – *S.litura* – Solitary larva; MAE – Mean Absolute Error; RMSE – Root Mean Standard Error

3.3 Pre-disposing Conditions

The pre-disposing weather conditions for the higher incidence of the tobacco caterpillar (*S. litura*) has been worked out and presented in Table 6. The analysis results revealed that favourable weather conditions for egg mass are; average maximum temperature ranging from 27.10-32.83 ºC, average minimum temperature ranging from 19.35-24.15 ºC, average relative humidity ranging from 84.21-93.38 % and the weekly average of total rainfall ranging from 14.77-92.95 mm (Table 6). High or medium rainfall in previous weeks followed by low rainfall in current week causes the high incidence of the insect (Duraimurugan, 2018). The most favourable conditions for *S. litura* gregarious larva worked out to be; average maximum temperature ranging from 27.29-31.94ºC, average minimum temperature ranging from 20.28-25.63 ºC, average relative humidity ranging from 86.00-93.75 % and the weekly average of total rainfall ranging from 11.07-112.65 mm (Table 7). Besides the rainfall range, generally the pattern of rainfall in gregarious larva was low in previous weeks followed by higher rainfall in current week was observed. For *S. litura* solitary larva, the favourable weather conditions were; average maximum temperature was ranging from 27.06-32.45 ºC, average minimum temperature ranging from 20.23-25.63 ºC, average relative humidity ranging from 82.96-94.28 % and the weekly average of total rainfall ranging from 15.03-119.18 mm (Table 8). Usually two trends of rainfall were observed in solitary larva, one was high rainfall in RF_{-2} and slowed in RF_{-1} followed

Table 6. Pre-disposing conditions for Spodoptera litura - egg mass

Current Week		1st Previous Week		2nd Previous Week	
Weather Factors	**Range**	**Weather Factors**	**Range**	**Weather Factors**	**Range**
$TMax_0$ (^0C)	27.10-30.50	$TMax_{-1}$ (^0C)	27.10-31.37	$TMax_{-2}$ (^0C)	28.02-32.83
$TMin_0$ (^0C)	19.35-23.41	$TMin_{-1}$ (^0C)	20.38-24.12	$TMin_{-2}$ (^0C)	20.38-24.15
RH_0 (%)	86.95-93.38	RH_{-1} (%)	84.90-92.43	RH_{-2} (%)	84.21-91.21
RF_0 (mm)	28.73-92.95	RF_{-1} (mm)	23.68-92.95	RF_{-2} (mm)	14.77-92.95

Table 7. Pre-disposing conditions for Spodoptera litura – Gregarious Larva

Current Week		1st Previous Week		2nd Previous Week	
Weather Factors	**Range**	**Weather Factors**	**Range**	**Weather Factors**	**Range**
$TMax_0$ (^0C)	27.29-31.47	$TMax_{-1}$ (^0C)	27.52-31.67	$TMax_{-2}$ (^0C)	27.50-31.94
$TMin_0$ (^0C)	20.28-24.97	$TMin_{-1}$ (^0C)	20.49-25.01	$TMin_{-2}$ (^0C)	20.72-25.63
RH_0 (%)	86.68-93.61	RH_{-1} (%)	86.18-93.61	RH_{-2} (%)	86.00-93.75
RF_0 (mm)	15.03-102.19	RF_{-1} (mm)	11.07-109.01	RF_{-2} (mm)	11.07-112.65

Table 8. Pre-disposing conditions for Spodoptera litura – Solitary Larva

Current Week		1st Previous Week		2nd Previous Week	
Weather Factors	**Range**	**Weather Factors**	**Range**	**Weather Factors**	**Range**
$TMax_0$ (^0C)	27.17-31.69	$TMax_{-1}$ (^0C)	27.06-32.33	$TMax_{-2}$ (^0C)	27.39-32.45
$TMin_0$ (^0C)	20.23-24.97	$TMin_{-1}$ (^0C)	20.28-25.01	$TMin_{-2}$ (^0C)	20.49-25.63
RH_0 (%)	86.04-93.75	RH_{-1} (%)	84.38-94.28	RH_{-2} (%)	82.96-93.75
RF_0 (mm)	19.02-119.18	RF_{-1} (mm)	16.45-112.65	RF_{-2} (mm)	15.03-112.65

by rise in RF_0 and other was continuously increasing pattern from RF_{-2} to RF_0 was observed.

4. CONCLUSIONS

In the present study, it was found that the tobacco caterpillar (*S. litura*) started infecting the soybean crop in most of the fields from 29th standard meteorological week (SMW) i.e. 3rd week of July. The peak infestation of *S. litura* egg mass, gregarious larva and solitary larva was found to be 33rd, 35th and 36th SMW respectively. In case of *S. litura* gregarious larva, RH_{-1} had significantly negative correlation and RF_0, RF_{-1} had significantly positive correlation. In case of *S. litura* solitary larva, except $TMax_0$, all other variables were negatively and significantly correlated with RH_0, RH_{-1}, RF_{-1}, and RF_{-2}. Regression analysis revealed that models of *S. litura* egg mass, gregarious larva and solitary larva could explain 61.58%, 65.28% and 29.51% variation in their population respectively. The variables significantly affecting egg mass population were $TMin_0$, RF_0, RF_{-1}, $TMax_0^2$ and $TMin_0^2$ at 5% and RH_{-1} at 10% level of significant; gregarious larva population were $TMax_0$, RH_{-1}, RF_{-1}, $TMax_0^2$ and RF_{-1}^2 at 5% level of significance; and solitary larva were RH_0, RF_{-2}, RH_{-2}^2 and RF_{-2}^2 at 5% and RH_0^2 at 10% level of significance. The validation mean model was done by cross validation; and independent dataset of 2013 and 2014 (for egg mass) and 2014 and 2015 (for gregarious and solitary larva). Two sample t-test and other statistics in all the models signified no significant difference between observed and predicted values of the insects. The congenial conditions that favoured the insect incidence were found for *S. litura* egg mass to be TMax ranging from 27.10-32.83 ºC, TMin from 19.35-24.15 ºC, RH from 84.21-93.38 % and RF from 14.77-92.95 mm with high or medium rainfall in previous weeks followed by low rainfall in current week; for gregarious larva TMax from 27.29-31.94ºC, TMin from 20.28-25.63 ºC, RH from 86.00-93.75 % and RF from 11.07-112.65 mm with low rainfall in previous weeks followed by higher rainfall in current week; and for solitary larva TMax ranging from 27.06-32.45 ºC, TMin from 20.23-25.63 ºC, RH from 82.96-94.28 % and RF from 15.03-119.18 mm with high rainfall in RF_{-2} and slowed in RF_{-1} followed by rise in RF_0 or continuously increasing pattern from RF_{-2}

to RF_0. Based on the above information, the models would be utilized to disseminate the insect advisories to forewarn the soybean growers on the incidence of the tobacco caterpillar to take timely management measures to protect the crop from yield losses.

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