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# Prediction of girdle beetle (*Oberiopsis brevis*) infestation through pest-weather model in soybean

**Ram Manohar Patel, Purushottam Sharma and AN Sharma**

## Abstract
Girdle beetle happens to be a serious insect pest causing yield losses between 14 to 42 per cent in soybean. The incidence of this insect pest is related to the prevailing weather conditions. It is in this context, we intended to ascertain pertinent weather parameters that directly influence the girdle beetle incidence and the appropriate stage it infests and therefore necessary curative measures can be addressed to. Therefore, data survey was conducted on girdle beetle damage on soybean crop under Crop Pest Surveillance and Advisory Project (CROPSAP) in 20 districts of Maharashtra state during 2010-2015. The weekly data collected so were used for the analysis. The correlation analysis of girdle beetle damage with climatic variables showed the significant negative correlation with maximum temperature during current ($TMax_0$ =-0.44**) and previous two lag weeks ($TMax_{-1=}$ -0.61**; $TMax_{-2=}$-0.54**) and significant positive correlation with relative humidity in current ($RH_0$=0.24*) and first lag week ($RH_{-1}$=0.29*). Separate models pertaining to two peak weeks were developed using multiple regression and assessed for its prediction accuracy. The first peak (33rd SMW) model explained 54.2% variation in percent damage and the variables significantly influencing its infestation were $TMin_0$, $TMax_{-1}$, $TMin_{-1}$, and $TMin_{-2}$. The second peak model (36th SMW) could explain 53.52% variability and $TMax_{-1}$, $RF_{-2}$, and $TMin_{-2}$ were significantly influencing the infestation. The favorable pre-disposing conditions for peak damage were found to be related to maximum temperature (27.29-31.65 ºC), minimum temperature (19.73-24.74) ºC, relative humidity (82.96-93.75%), and weekly total rainfall (15.03-141.46 mm). Weather based prediction models were also validated satisfactorily using cross-validation approach using two years (2014 and 2015) independent dataset. Small RMSE value, standardized residuals between ±3 and insignificant value of t-test signifies that there was no significant difference between observed and predicted values of girdle beetle damage. In conclusion, maximum and minimum temperature, and rainfall determine the severity of girdle beetle incidence.

**Keywords:** Girdle beetle, soybean, weather variables, forewarning, validation

## Introduction
Soybean [*Glycine max* (L.) Merrill] the 'Golden bean' in recent years has occupied a vital place in Indian agriculture and established as a leading oilseed crops that had significantly contributed to yellow revolution in India. Soybean a nutritionally very important oilseed crop containing 40-42% protein and 20-22% oil and is a cheaper source of protein and oil and happens to be a source for mitigating protein-energy malnutrition. Soybean is a major *kharif* season oilseed crop of rainfed agro-ecological region of central and peninsular India. Presently, it is being grown between 15 ºN to 25 ºN longitude in India, which includes states such as Madhya Pradesh, Maharashtra, Rajasthan, Chhattisgarh, Andhra Pradesh (old), and Karnataka [4]. The suitability of cropping sequence, comparative profitability as compared to its competing crops [33, 32], and lower input cost in cultivation and management has led to its rapid expansion in area and production [29, 32, 30]. Moreover, the crop also helped the soybean growing farmers in improving their socio-economic status [8, 31]. The major states such as Madhya Pradesh, Maharashtra and Rajasthan contribute to more than 90 per cent of area and production and recently soybean has gained momentum in the states of Karnataka, Telangana, Chhatisgarh and Gujarat [1]. India ranks 4th position in terms of global area under soybean and 5th in terms of production of soybean. Countries like USA, Brazil, Argentina and China are major contributors to global soybean production [29]. Despite the unparallel growth in soybean area and production in India, the productivity though improved from 426 kg/ha during early 1970s to 1367 kg/ha during 2012-13 and still hovers around 1000-1200 kg/ha and has large

year-to-year variation due to lower adoption of improved technologies by farmers [7]; continuous mono-cropping of soybean-wheat/chickpea, and increased incidence of biotic and abiotic stresses [3].

Insect-pests are among the major biotic factors that reduce soybean yield potential significantly [4, 5, 21, 23]. Globally, around 26.4% crop losses have been reported due to biotic factors in soybean [3]. In late sixties or early seventies, nearly 99 insects were reported to be infesting soybean crop in India [10], which has presently increased to about 275 insects [15]. It has been observed that about a dozen insects frequently infest soybean crop and are of economic importance and individually causing 20 - 100% yield losses [29]. Girdle beetle is a serious insect of soybean that causes the yield loss by 14 to 42% [14, 34]. Girdle beetle infests throughout rainy season and host includes mainly soybean, pigeonpea, cluster-bean, Indian bean and cowpea [11, 35]. Early developmental stage of soybean crop such as 31st August to 7th September (35th to 36th SMW) is highly susceptible to girdle beetle damage causing mortality to plants and also decreases number of pods per plant, seed number and seed weight [17]. Insect-pests population dynamics, distribution and period of infestation on crops are highly dependent on weather variables. The understanding of congenial pre-disposing weather conditions for multiplication and spread of insect are essential for timely, efficient and cost effective management. Hence, it is of paramount importance to assess the crucial weather factors responsible for the prevalence of girdle beetle. Temperature, relative humidity and rainfall were among the key abiotic factors which have influenced the girdle beetle infestation [13, 25]. In soybean, the information pertaining to the interaction of climatic variables and girdle beetle incidence is very scanty. The efficacy of any integrated pest management (IPM) strategies depends on the girdle beetle infestation pattern and damage. Thus, it was hypothesized to determine the crop growth stage (standard meteorological week) of occurrence of girdle beetle infestation and influencing weather parameters through prediction model so as implementation of best management strategies with a view to maximize soybean productivity and reduce the sprays required. Weather-based prediction model is the scientific tool that can help in assessing incidence of girdle beetle by forewarning and disseminating the agro-advisory to the soybean farmers well before its incidence and overcome economic loss to enable them to take timely management decisions [20]. Hence, the study was conducted with the aim to determine the relationship between abiotic factors and girdle beetle infestation in soybean through prediction model based on the survey data for the prediction of the severity of infestation.

## Material and Methods

### Survey of girdle beetle infestation and weather parameters

In the present study, village level daily survey data on girdle beetle percentage damage of soybean plants per meter row and district-wise daily weather data of maximum and minimum temperature, relative humidity and rainfall during the main soybean growing season from 27th to 39th standard meteorological week (SMW) was used for the analysis. The data were collected under the CROPSAP during 2010-2015 from 20 districts of Maharashtra state. The daily data on girdle beetle percent damage were transformed to district level weekly data according to standard meteorological week as the weather data were available only for the district level. The data from 2010-2015 were split into two sets as training dataset (2010-13) and validation or test dataset (2014-15). Training dataset was used to develop and train the model and test dataset was used to validate the accuracy of the model.

### Correlation and regression analysis

Correlation analysis and regression models were attempted to evaluate the relationship between weather variables on girdle beetle percentage damage. The data were analyzed using Panel regression model and Mean regression model as per standard methods [36]. In both the models, the data were taken from first emergence week to first and second peak incidence week (29th to 33rd SMW and 29th to 36th SMW) such as from flowering to reproductive stage of the soybean crop. The developed models have been fitted by using second degree polynomial equation for both the models, using step-wise multiple regressions approach [36].

### Validation of girdle beetle incidence with weather parameter data set

The outliers and leverage data points present in the data were cleansed using cook's D statistics and Student residuals. The model evaluation and testing was done based on $R^2$, $R^2_{Adj}$, RMSE, PRESS Statistics whereas Akaike Information Criteria (AIC), Root Mean Square Error (RMSE), were used to select the best fit model among the models. Validation of the model has been done using cross-validation methodology (LOOCV – Leave One Out Cross-Validation) that is $R^2_{Pred}$; and comparing observed validation datasets values to the predicted values using RMSE, standardized residual, and two sample 't-test'. The test of significance level at 5% was observed in both correlation and regression [18]. All the statistical analyses were done using SAS Enterprise Guide version 4.3 software [27].

## Results and Discussion

### Correlation studies

The perusal of the data for the year-wise percentage damage due to girdle beetle infestation on soybean crop in Maharashtra indicated that the infestation/ damage was higher in the year 2010 as compared to other years. Reports indicate that pest incidence especially *Spodoptera litura* in the soybean growing districts of Maharashtra to be higher in 2010 may be due to higher rainfall events as compared to other years of study [22]. The first peak infestation/ damage of girdle beetle on soybean crop was observed at 33rd SMW, that is, 3rd week of August and second peak infestation was observed at 36th - 37th SMW, that is, near 1st-2nd week of September, in most districts however the infestation was seen throughout the crop season. Similarly, it was found that the damage due to girdle beetle on stem and petiole was higher during 33rd SMW and reproductive stage of soybean crop such as, during 31st August to 7th September (35th to 36th SMW) is highly susceptible to girdle beetle damage [17].This is in consonance with earlier reports of girdle beetle infestation from 30 days after sowing to 55 days after sowing as was observed in the present study [6, 19, 17].

The association of girdle beetle damage to soybean crop (*Oberiopsis brevis*) with weather parameters (in relation to current, first and second lag weeks) was analyzed and presented in Table 1. The agro-meteorological conditions plays an important role on affecting the migration, reproduction and growth of girdle beetle leading to infestation in soybean and the temporal and spatial variation in percentage damage. The correlation was worked out for the period 2010-2013 from $29^{th}$ – $36^{th}$ SMW using mean and panel data. Girdle beetle percentage damage had a significantly negative correlation with maximum temperature during current and previous two weeks (Table 1) whereas, it was found to be significantly and positively correlated with relative humidity of current and previous week. Rainfall of $2^{nd}$ lag week was found to be positively correlated with the percentage damage by girdle beetle in soybean only in panel data model. This is in accordance with the findings of earlier studies [16].

**Table 1:** Correlation coefficient between Girdle Beetle and Weather variables on soybean (2010-13)

| Year (2010-13) | Mean Model | Panel Model |
|---|---|---|
| $TMax_0$ | -0.44** | -0.26** |
| $TMin_0$ | -0.18 | -0.03 |
| $RH_0$ | 0.24* | 0.34** |
| $RF_0$ | -0.09 | 0.08 |
| $TMax_{-1}$ | -0.61** | -0.30** |
| $TMin_{-1}$ | -0.17 | -0.03 |
| $RH_{-1}$ | 0.29* | 0.35** |
| $RF_{-1}$ | 0.075 | 0.12 |
| $TMax_{-2}$ | -0.54** | -0.43** |
| $TMin_{-2}$ | -0.14 | -0.01 |
| $RH_{-2}$ | 0.17 | 0.24** |
| $RF_{-2}$ | 0.084 | 0.16* |

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

**Pre-disposed Conditions**

The pre-disposing conditions that were favoring the maximum incidence of girdle beetle during their peak infestation using data for weather parameters pertaining to current week and previous two weeks were worked out. The pre-disposing conditions at two peak weeks ($33^{rd}$ and $36^{th}$ week) has been worked out based on the regression models analyzed and presented in Table 2. The pre-disposing factors were worked out as a range of weather variables at the time of 1st peak damage to its two previous weeks ($33^{th}$-$31^{st}$ week); and $2^{nd}$ peak week to its previous two weeks ($36^{th}$ -$34^{th}$ week). The favorable weather conditions for higher damage due to girdle beetle infestation in soybean during $1^{st}$ peak ($33^{rd}$ – $31^{st}$ week) worked out to be average maximum temperature in the range from 27.29-31.21 ºC, average minimum temperature from 19.73-24.74 ºC, average relative humidity in the range of 82.96-93.75%, and weekly total rainfall ranging between 15.03-141.46 mm with high rainfall in $2^{nd}$ previous week than moderate to low in $1^{st}$ previous week followed by low rainfall in current (peak incidence) week (Table 2). Whereas, the most crucial weather conditions for the $2^{nd}$ peak ($36^{th}$ – $34^{th}$ week) of girdle beetle infestation were; average maximum temperature was ranging from 27.68-31.65 ºC, average minimum temperature from 19.81-23.49 ºC, average relative humidity from 85.18-92.62%, and weekly total rainfall in the range of 23.28-111.91 mm with low rainfall in $2^{nd}$ previous week followed by moderate to high rainfall in $1^{st}$ previous week and current week. This coincides with the earlier findings [9, 12, 24].

**Table 2:** Range of pre-disposed conditions of weather variables

| Current Week | | | $1^{st}$ Previous Week | | | $2^{nd}$ Previous Week | | |
|---|---|---|---|---|---|---|---|---|
| Weather Factors | Range ($33^{rd}$ Week) | Range ($36^{th}$ Week) | Weather Factors | Range ($32^{nd}$ Week) | Range ($35^{th}$ Week) | Weather Factors | Range ($31^{st}$ Week) | Range ($34^{th}$ Week) |
| $TMax_0$ | 28.94-31.21 | 28.57-31.65 | $TMax_{-1}$ | 27.29-30.38 | 28.36-30.93 | $TMax_{-2}$ | 27.67-30.14 | 27.68-30.19 |
| $TMin_0$ | 20.46-24.07 | 19.95-23.45 | $TMin_{-1}$ | 19.73-23.82 | 19.81-23.49 | $TMin_{-2}$ | 21.16-24.74 | 20.23-23.36 |
| $RH_0$ | 85.54-93.61 | 85.18-91.76 | $RH_{-1}$ | 82.96-91.36 | 86.31-92.62 | $RH_{-2}$ | 87.36-93.75 | 86.68-91.71 |
| $RF_0$ | 25.58-80.87 | 31.38-111.91 | $RF_{-1}$ | 15.03-72.70 | 40.29-76.38 | $RF_{-2}$ | 52.04-141.46 | 23.28-78.27 |

**Development and validation of prediction model**

The effect of weather variables on girdle beetle incidence has been worked out using step-wise multiple regressions and prediction model, developed to predict the percentage damage caused by girdle beetle based on the weather parameters of current and two leg weeks. The coefficients of weather factors delineated from the weekly data for the period 2010 to 2013 (training dataset) using panel model and mean model developed and evaluated for prediction accuracy, and the best fit model has been selected based on methodology discussed above.

In soybean crop season, generally two major peaks of girdle beetle incidence were observed, first during $33^{rd}$ week and second during $36^{th}$ – $37^{th}$ week (overlapping weeks, thus for analysis of $2^{nd}$ peak incidence data were taken from $29^{th}$ – 36 week). The regression analysis was performed separately for two peaks in order to assess the factors responsible for peak incidence of girdle beetle in soybean and to predict the damage, and the results are depicted on Table 4 and 5. The result of first peak model ($33^{rd}$ week) revealed that all the variables included in the model turned out to be significant at 5% level. The $2^{nd}$ degree polynomial equation was fitted and the variables included in the model explained 54.2% variation in girdle beetle percentage damage. The $2^{nd}$ peak model ($36^{th}$ week) fitted was also curvilinear and all variables turned out to be significant at 5% level of significance and the model could capture 53.52% variation in the damage by girdle beetle in soybean.

**Table 4:** Mean model for predicting Girdle Beetle percentage damage till peak incidence

| | | |
|---|---|---|
| $1^{st}$ Peak ($33^{th}$ Week) | $GB = 141.15 - 26.18 \times TMin_0 - 0.87 \times TMax_{-1} + 15.73 \times TMin_{-1} + 0.59 \times TMin_0^2 - 0.37 \times TMin_{-1}^2 + 0.027 \times TMin_{-2}^2$ | $R^2$= 54.2%, $R^2_{Adj}$= 46.11%, $R^2_{Pred}$ = 34.57%, SE = 1.39, N=41 |
| $2^{nd}$ Peak (36th Week) | $GB = 30.18 - 1.015 \times TMax_1 - 0.08 \times RF_2 + 0.0094 \times TMin_2^2 + 0.0005 \times RF_2^2$ | $R^2$= 53.52%, $R^2_{Adj}$ = 50.47%, $R^2_{Pred}$ = 44.91%, SE = 1.16, N=66 |

In the panel data model, individual weekly data points for all the years and districts were used to develop and validate the model for forecast accuracy. Thus, the spatial and temporal variability was retained while developing the panel model. Similar to the mean data model, regression analysis was attempted separately for two peaks of girdle beetle incidence ($33^{rd}$ and $36^{th}$ week) and presented on the Table 5. Second order polynomial equation or curvilinear models were fitted and all the variables included in both the models (first peak and second peak models) were significant at 5% level of significance. The variables included in the first peak model could explain 28.58% variation and the second peak model explained 44.85% variability in percentage damage by girdle beetle in soybean.

**Table 5:** Panel Model for predicting Girdle Beetle percentage damage till peak incidence

| | | |
|---|---|---|
| 1st Peak (33th Week) | $GB = -41.45 + 0.22 \times RH_0 - 9.3 \times TMin_{-1} - 0.42 \times TMax_{-2} + 12.28 \times TMin_{-2} + 0.20 \times TMin_{-1}^2 - 0.26 \times TMin_{-2}^2$ | $R^2$=28.58%, $R^2_{Adj}$ =24.42%, $R^2_{Pred}$ =19.52%, SE =1.99, CV=54.99, N=110 |
| 2nd Peak (36th Week) | $GB = -20.15 + 0.14 \times RH_0 + 0.92 \times TMin_{-2} - 0.009 \times TMin_0^2 + 0.0007 \times RH_{-1}^2 - 0.013 \times TMax_{-2}^2$ | $R^2$= 44.85%, $R^2_{Adj}$= 43.24% $R^2_{Pred}$ = 41.53%, SE = 1.59, N=178, CV=49.69 |

The model fit statistics of mean data model and panel data model revealed that the mean data model turned out to be best fit (Table 4 and 5) as the model explained higher variation in the dependent variable. Therefore, the mean model (Table 4) is used for predicting the girdle beetle percentage damage and work-out the pre-disposed conditions for the insect. The validation results of the fitted mean models by cross-validation methodology (LOOCV) revealed that the predicted $R^2$ ($R^2_{Pred}$) for 33rd and 36th SMW models were 34.57% and 44.91% respectively. The validation by independent validation dataset (for the year 2014 and 2015), to compare the predicted and observed values of girdle beetle percentage damage for first peak (33rd SMW) and second peak (36th SMW) models, was performed (Figures 1 and 2) and the results indicated the root mean square errors were $RMSE_{33}$ = 3.51 and $RMSE_{36}$ = 1.03; two sample t-test results for 33rd and 36th SMW were $p = 0.122 > 0.05$ and $p = 0.1752 > 0.05$, respectively and the estimated standardized residuals also were in between -3 to +3 for both the models. Earlier studies also reported two peaks of damage by girdle beetle infestation [26, 28]. The t-test results signify non-significance differences between predicted and observed values and standardized residuals specified the suitability of the models for prediction of girdle beetle damage. The results are in consonance with earlier studies [2].

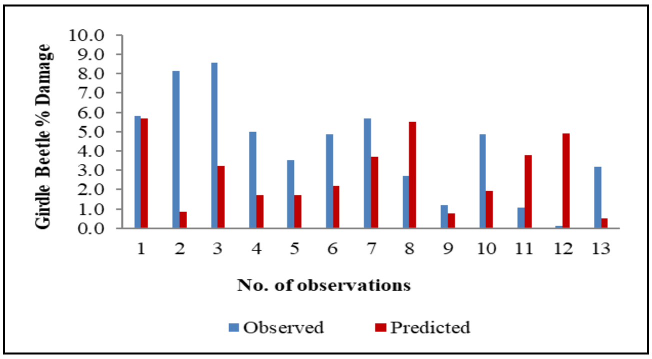


**Fig 1:** Validation of mean model for 33rd SMW predicting Girdle Beetle percentage damage

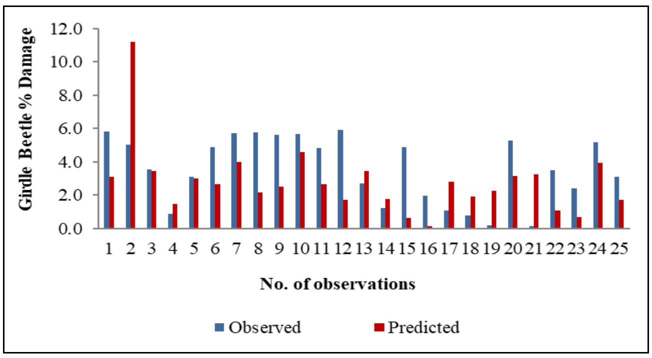


**Fig 2:** Validation of mean model for 36rd SMW predicting Girdle Beetle percentage damage

## Conclusion

The girdle beetle infestation pattern observed from the data for the period 2010 to 2015 indicated that the insect starts infesting the crop from 3rd week of July and continued till the September end. Two peaks of infestation were observed (1st near 33rd SMW and 2nd during 36th SMW) in Girdle beetle infestation in soybean. Girdle beetle infestation had significantly positive correlation with $RH_0$ and $RH_{-1}$ but significantly negative correlation with TMax (all three weeks). Two models (panel data model and mean data model) corresponding to two peak weeks were developed using multiple regression approach and evaluated, and results indicated the mean model as the best fit. Mean model for the 1st peak (33rd SMW) could explain 54.2% variability in Girdle beetle percent damage and the variables significantly influencing its infestation were $TMin_0$, $TMax_{-1}$, $TMin_{-1}$, and $TMin_{-2}$, whereas the 2nd peak model (36th SMW) could explain 53.52% variability and factors significantly influencing the infestation were $TMax_{-1}$, $RF_{-2}$, and $TMin_{-2}$. Both the fitted models were of second order curvilinear. The pest-weather models were validated satisfactorily using cross-validation (LOOCV – Leave One Out Cross-Validation) approach i.e. $R^2_{Pred}$; and two years (2014-15) independent dataset. RMSE, standardized residuals and t-test results revealed no significant difference between observed and predicted values of girdle beetle percent damage. The environmental conditions that are congenial for peak girdle beetle damage in soybean for the first peak (33rd week) were observed to be maximum temperature ranging from 27.29-31.21 ºC, minimum temperature from 19.73-24.74 ºC, relative humidity in the range of 82.96-93.75%, and weekly total rainfall ranging between 15.03-141.46 mm with high rainfall in 2nd lag week then moderate to low in 1st lag week followed by low in current (peak incidence) week. Whereas, for the 2nd peak (36th week) maximum temperature ranging from 27.68-31.65 ºC, minimum temperature from 19.81-23.49 ºC, relative humidity from 85.18-92.62%, and weekly total rainfall in the range of 23.28-111.91 mm with low rainfall in 2nd lag week followed by moderate to high rainfall in 1st lag week and current week. Thus, based on the developed pest-weather model farmers can be forewarned by disseminating the insect advisory of girdle beetle incidence well before two weeks of peak infestation to take timely decision and control measure to protect the crop from insect damage.

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