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GIS based pest-weather model to predict the incidence of Girdle beetle (*Oberiopsis brevis*) in Soybean crop

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ABSTRACT

Girdle beetle (*Oberiopsis brevis*) is an important insect of soybean that can cause up to 42.2% yield loss in severe infestation during flowering stage. The infestation of girdle beetle is prevailed by congenial environmental conditions, which leads girdle beetle to be the severe pest of soybean. The present study assesses the relevant weather variables that can cause the peak infestation. Crop Pest Surveillance and Advisory Project (CROPSAP) survey data of girdle beetle incidence were analyzed with weather variables using correlation and regression techniques. The girdle beetle infestation had significantly positive correlation with relative humidity of current and 2nd lag week (RH_0, RH_{-2}); and with rainfall of 2nd lag week (RF_{-2}) but significantly negative correlation with maximum temperature of 1st lag week ($TMax_{-1}$). The multiple regression technique was used to develop the forewarning models for three zones (Vidarbha, Madhya Maharashtra and Marathwada zones) and overall Maharashtra, the developed models could explain 80.30%, 94.62%, 73.56% and 79.56% variation in girdle beetle infestation, respectively. The congenial conditions for the peak infestation of girdle beetle on soybean have been worked out and validated, which were $TMax_0$, RH_0, RF_0, RH_{-1}, RF_{-1}, $TMax_{-2}$, and RF_{-2} ranged between 28.6-31.6 ºC, 85.2-91.8 %, 31.8-119.2 mm, 86.3-92.6 %, 38.1-76.4 mm, 27.7-30.8ºC, and 23.3-60.7 mm, respectively. The insect forewarning would be useful in devising the integrated management strategies for protecting the crop from insect in the incidence region.

Key words**:** Girdle beetle, soybean, weather variables, forewarning, validation, GIS

Soybean [*Glycine max* (L.) Merrill] occupied the prominent place in edible oil economy, accounting for about 40 per cent of total oilseeds production in India and contributing to nearly 25 per cent of domestic vegetable oil production in the country (Sharma, 2016). Longitudinally, it is being cultivated from about 15ºN to 25ºN (Bhatia *et al*., 2008) in India and 50ºN to 35ºS latitudinally worldwide (Gupta *et al*., 2017; Watanabe *et al*., 2012). The crop is highly suitable for varying agro-ecological regions covering Madhya Pradesh, Maharashtra, Rajasthan, Chhattisgarh, Telangana, and Karnataka states (Bhatia *et al*., 2008).Though, the rapid expansion of soybean in central Indian since last five decades in terms of area and production due to its low input cost and comparative profitability to other crops (Sharma *et al.*, 2015) was unparallel, however, its productivity hovers around 1 ton per ha (Patel *et al*., 2019b; Sharma *et al*., 2014). Continuous mono-cropping of soybean-wheat/gram sequence for long is one of the leading constraints for low productivity (Joshi and Bhatia, 2003)resulting in increased incidence of biotic and abiotic stresses (Bhatia *et al,* 2008).Of the biotic constraints, insect-pests are the major ones which potentially obstruct to attain the realized yield and production by increasing the input cost and impairing the quality of the produce (Baburao, 2012). Babu *et al*. (2017) reported about 26.4% loss of soybean crop due to biotic factors. At present, nearly 275 insects-pest species were infesting the soybean crop (Lokare *et al*., 2014) and about a dozen of them are infesting severely from sowing to harvesting (Chouhan, 2012).

Seed quality and yield of soybean are affected adversely due to various major insect *viz.*, girdle beetle (*Obereopsis brevis)*, gram pod borer (*H. armigera*), tobacco caterpillar (*S. litura*), green semilooper, jassids and white fly. Every year around 15 - 20 per cent of total soybean production is lost due to the infestation of insect-pests (Bhosle *et al.*, 2014). More *et al*., (2014) reported that girdle beetle (*Obereopsis brevis*), stem fly (*Melangromyza sojae*) and green semilooper (*Gesonia gemma*) infestation is increasing recently whereas leaf miner (*Aproaerema modicella*) incidence is decreasing year by year. Thus, girdle beetle is the growing menace for soybean production in the country. Girdle beetle a major soybean insect that can cause about 19.5 to 26.5% loss reported by Kumawat *et al*., (2010); however, Shrivastava *et al*. (1972) reported about 13.7-42.2% loss of soybean. Girdle beetle is a polyphagous insect (Tagde, 2015; Garg*et al.,* 2014) and infestation may start as early as from 6-8 days after sowing till maturity (Chouhan, 2012). Initial crop stage i.e. nearly 31stAugust to 7th September (35th to 36th SMW) is highly prone to girdle beetle infestation and consequently reduces the yield around 16.72% to 18.97% (Malgaya, 2013) and approximately 75% soybean plants were damaged before maturity consequent upon early infestation by girdle beetle (Tirole,2015).The pod and seed yield loss of about 84.4 and 47.2 kg ha^{-1} respectively has been observed due to infestation of girdle beetle (More *et al.*, 2014a). The change of weather variables significantly affecting the agriculture productivity in many aspects, one among them is changing the insect-pest biology (Shamim *et al.*, 2009; Dhaliwal *et al.,* 2004) which consequently affect the dynamics, distribution and infestation period.

For protecting the soybean crop from insect-pests well before the incidence, it's extremely important to understand and investigate the crucial weather parameters which cause the girdle beetle infestation. The information about girdle beetle infestation with changing weather in soybean is very meager. The effectiveness of integrated pest management (IPM) measures depends on how best and timely it has been implemented. Development and use the forewarning model as an insect-advisory (Chattopadhyay *et al.*, 2019; Patel *et al.*, 2020) along with spatial distribution using geo-spatial technology is needed to control and avoid the infestation well in advance.

The insect forewarning in conjunction with geographical information system (GIS) are the measure which are being implemented to thwart the impending incidence, maximize the efficacy and reduce the input cost needed for controlling the insect by spraying the insecticide in the incidence specific location. Rao and Prasad (2020), have mapped the spatial pest risk indices using the DIVA-GIS (an open source geographic information system, downloadable at http://www.diva-gis.org).GIS is the scientific tool which allows the location specific control of the insect and prediction models are used for disseminating insect-advisory to the soybean growers well in advance before causing economic loss. The present study was carried out to comprehend the effect of climate variables on girdle beetle infestation in soybean and develop pest forewarning model.

MATERIALS AND METHODS

Study area and Data Collection

Daily village level survey data on girdle beetle incidence on soybean and district level daily meteorological data of twenty districts of Maharashtra, i.e. from 16.71° N, 74.24° Eto 21.15°N, 79.09° E (Fig. 1), were collected under Crop Pest Surveillance and Advisory Project (CROPSAP) sponsored by department of agriculture, Maharashtra for the period 2010 to 2015.

Vidarbha Zone was having high incidence due to continuous infestation and with high intensity over the years followed by Madhya Maharashtra Zone had less incidence compared to Vidarbha zone and irregular infestation over the years having larger districts with medium infestation. Marathwada Zone had least and irregular infestation with less number of districts in different weeks over the years.

Pre-processing of data

Girdle beetle infestation (% damage per meter row length) data of first emergence week to the peak incidence week, along with the current and previous two weeks' data of meteorological parameters of maximum temperature (°C), minimum temperature (°C), average relative humidity (%) and rainfall (mm) of soybean season were used in the analysis. The variables are of different order of magnitude; hence the variable's transformed weekly data were standardized so that all the variables should have zero mean and one standard deviation using the equation (1) as

$$z_i = \frac{(x_i - \mu)}{\sigma} \tag{1}$$

Where Z_i is ith standard normal variate x_i, is ith variables, μ is mean of ith variables and σ is standard deviation. The data were cleansed from outliers and leverage points using cook's D statistics and Student residuals.

Analysis

The collected datasets were split into training dataset (2010-13) and test dataset (2014-15). Multiple regression methodology (Eq. 2) was used to develop forewarning models for Vidarbha, Madhya Maharashtra and Marathwada zones and overall for Maharashtra; and the models were tested and validated using test dataset for accuracy.

$$y = \alpha + \sum_{i=1}^{n}(\beta_i z_i) + \sum_{j=1}^{n}(\beta_j z_j^2) + \varepsilon \tag{2}$$

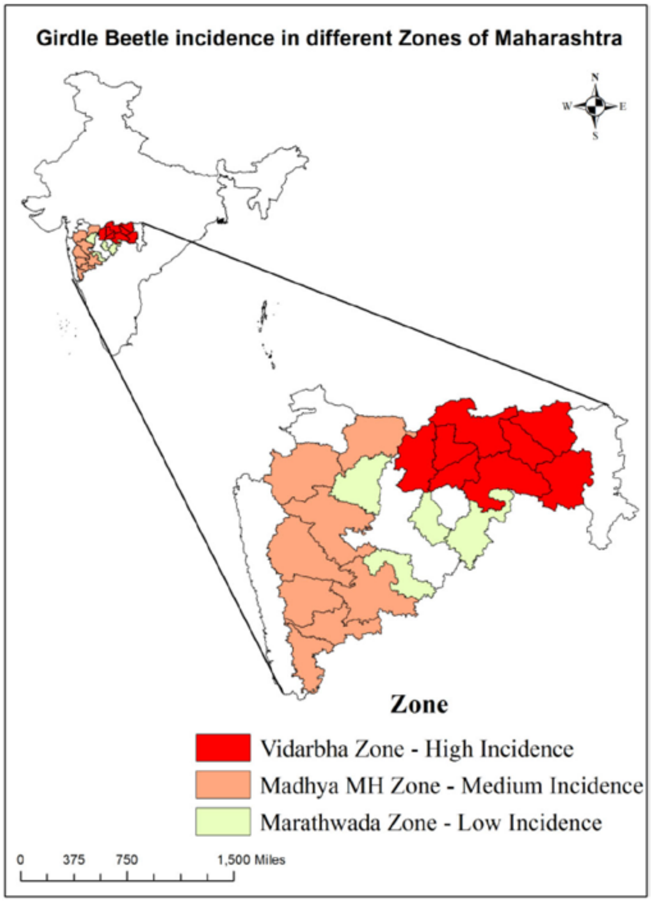

Fig. 1: Girdle beetle incidence zones

where y and Z_i are the standard normal variates; β_i and β_j are the regression coefficients.

The models were formulated by using the peak incidence week (peak model) value (Ghosh *et al.*, 2014) of five year mean of different districts to work out the relationship and effect of weather on girdle beetle infestation for Maharashtra (all zones). However, in mean model, weekly mean data over the years of each district from first emergence week to first peak week used for Zonal models (Vidarbha, Madhya Maharashtra and Marathwada zones). The models were fitted by second degree polynomial equation taking percent damage per meter row length due to girdle beetle as dependent variable and maximum temperature (TMax), minimum temperature (TMin), relative humidity (RH) and rainfall (RF) pertaining to current, 1st and 2nd lag week as independent variables (Vannila *et al.*, 2011; Kamakshi *et al.*, 2018).

Model evaluation and validation

The models were developed to evaluate the relative significance of different meteorological variables on the basis of coefficient of determination, R^2 (Kamakshi *et al.*, 2018), RMSE, PRESS statistics. Accuracy of the models were validated using cross-validation approach (LOOCV – Leave One Out Cross-Validation) that is R^2_{Pred} (Patel *et al.*, 2019b; Montgomery, *et al.*, 2011);comparison of observed and predicted values using RMSE, standardized residual, and two samples 't-test' have been used. SAS Enterprise Guide version 4.3 software (SAS Institute Inc., 2011) was used to carry out all the analyses (Patel *et al*., 2019a).

RESULTS AND DISCUSSION

Correlation studies

On the perusal of data on girdle beetle incidence on soybean, it has been found that the peak infestation in different districts were mainly during 36-37th standard meteorological week (SMW). However, there were deviations in girdle beetle incidencedue to spatial and temporal variation in climate variables. Earlier studies also reported the peak activity of girdle beetle during 35-36th SWM (Netam *et al.,* 2013; Malgaya *et al*., 2013).

The correlation coefficient has been calculated between girdle beetle infestation and climatic variables of the Whole area pertaining to current, 1st lag and 2nd lag week of peak incidence in soybean. The agro-climatic factors played significant role to influence the dynamics of insect-pest migration, reproduction and other activities which led to cause the incidence in soybean. Time and place variation were primarily due to the discrepancy in congenial weather conditions. The insects-pestsalter their dynamics and developmental rates that can vary from place and/or time to cope with environmental conditions (Rao *et al*., 2015).

The analysis showed significantly positive correlation of girdle beetle infestation with relative humidity of current and 2nd lag week (RH_0: r= 0.48*,RH_{-2}: r= 0.47*); and with rainfall of 2nd lag week (RF_{-2}: r= 0.52**) but significantly negative correlation with maximum temperature of 1st lag week ($TMax_{-1}$: r= -0.45*). Moreover, other weather variables were insignificantly correlated were $TMax_0$,$TMin_0$, RF_0, $TMin_{-1}$, RH_{-1}, RF_{-1}, $TMax_{-2}$ and $TMin_{-2}$ with r values -0.28, -0.01, 0.10, -0.12, 0.37, 0.28, -0.40 and -0.06, respectively.

Development and validation of prediction model

Multiple regression analysis has been employed to formulate the prediction models of Vidarbha Zone, Madhya Maharashtra Zone, Marathwada Zone using mean model

Table 1: Predicting Model for Girdle Beetle infestationat peak incidence

$GB_{Maharashtra}$=1.97 X $ZTMax_0$ + 0.68 X ZRF_0 - 2.03 X ZRH_{-1} -1.43 X ZRF_{-2} + 2.94 X ZRH_0^2 + 0.53 X ZRF_{-1}^2 - 1.03 X $ZTMax_{-2}^2$	R^2= 79.56%, R^2_{Adj} = 65.26% R^2_{Pred} = 27.55%, SE = 0.57
$GB_{Vidarbh}$=0.66 X ZRH_0 - 21.14 X $ZTMax_{-1}$+82.25 X ZRH_{-1} + 21.72 X $ZTMax_{-1}^2$ - 82.47 X ZRH_{-1}^2	R^2=80.30%, R^2_{Adj} =73.3%, R^2_{Pred} =63.12%, SE=0.503
GB_{Madhya}= 0.36 X ZRF_0 + 1.86 X ZRF_{-2} + 1.2 X $ZTMax_{-1}^2$+0.91 X ZRF_{-1}^2- 2.48 X $ZTMin_{-2}^2$	R^2=94.62%, R^2_{Adj}=90.14%, R^2_{Pred} =84.54%, SE=0.30
$GB_{Marathwada}$ = - 0.996 X ZRH_0 - 0.488 X ZRF_{-1} + 0.866 X ZRH_{-1}^2	R^2 = 73.56%, R^2_{Adj} = 63.64% R^2_{Pred} = 60.46%, SE = 0.554

Note: $ZTMax_0$, $ZTMax_{-1}$ and $ZTMax_{-2}$are the standardized maximum temperature at current week, 1st and 2nd lag week, similarly for other variables

and using peak model for overall Maharashtra. Models were developed to assess the relationship between girdle beetle infestation with meteorological parameters of current, 1st lag and 2nd lag weeks using training dataset. The analysis revealed that all the weather variables of three zones and Maharashtra are significant at 5% level of significance except ZRF_{-1}^2 for Maharashtra which is significant at 10% level. The developed models are curvilinear (Table 1) and explained 79.56% (Maharashtra), 80.30% (Vidarbh Zone), 94.62% (Madhya Zone) and 73.56% (Marathwada Zone) variation (R^2) of girdle beetle infestation by weather parameters. Current and previous week rainfall, relative humidity, and maximum temperature were found to be significant variables impacting the girdle beetle infestation in Maharashtra. Rainfall of previous week was common significant factor impacting the girdle beetle infestation in all the zones, lag week maximum temperature in Vidarbha and Madhya Maharashtra zones and relative humidity of previous week in Marathwada and Vidarbha zones.

The regression model for Maharashtra was used for forewarning model to work out congenial conditions of girdle beetle incidence on soybean, as the model explained about 80% variations in the data. The cross-validation technique (LOOCV) result of the modelsrevealed the predicted R^2 (R^2_{Pred}) variation of 27.55%, 63.12%, 84.54% and 60.46% for Maharashtra, Vidarbha, Madhya Maharashtra and Marathwada zones, respectively. Validation using test dataset has been carried out for comparing thepredicted and observed values of girdle beetle infestation during 2014 to 2015. The root mean square error (RMSE) were1.058, 1.00, 3.37 and 0.82 and two sample t-test **p** values were 0.087, 0.317, 0.156 and 0.914 > 0.05for Maharashtra, Vidarbha Zone, Madhya Maharashtra Zone and Marathwada Zone, respectively (Patel *et.al*, 2020). This signified the model predicted with higher accuracy and minimum errors. Also the estimated standardized residuals also were in between -3 to +3 indicated the suitability of the models for predicting the girdle beetle percentage infestation (Akashe *et.al*, 2016).

The reports revealed that the peak infestation occur between 34th to 37th SWM this variation is due to location and time. Our analysis revealed that the peak incidence in most of the districts were during 36-37th SWM, hence the pre-disposed conditions of whole area were worked out based on 36-37th SWM to previous two weeks. The congenial conditions of key meteorological parameters which played significant role in girdle beetle incidence are maximum temperature of current week ($TMax_0$) ranged between 28.6-31.6 ºC, current week average relative humidity (RH_0) ranged from 85.2-91.8 %, current week rainfall (RF_0) ranged from 31.8-119.2 mm, average relative humidity of 1st lag week (RH_{-1}) ranged from 86.3-92.6 %, 1st lag week rainfall (RF_{-1}) ranged from 38.1-76.4 mm, maximum temperature of 2nd lag week ($TMax-_2$) ranged between 27.7-30.8 ºC, and rainfall of 2nd lag week (RF_{-2}) ranged from 23.3-60.7 mm.

CONCLUSION

In the present study, results revealed that the peak infestation of girdle beetle was in 36th-37th SMW in most of the districts. The correlation study revealed significantly positive correlation with RH_0,RH_{-2}, and RF_{-2} but significantly negative correlation with $TMax_{-1}$.The congenial weather conditions for the peak infestation of girdle beetle on soybean were observed to be $TMax_0$ in the range of 28.6 to 31.6 ºC, RH_0 85.2 to 91.8 %, RF_0 31.8 to 119.2 mm, RH_{-1}86.3 to 92.6 %, RF_{-1} 38.1 to 76.4 mm, $TMax-_2$27.7 to 30.8 ºC, and RF_{-2} 23.3 to 60.7 mm. respectively. Thus, satisfactorily validated whole area model can be utilized to forewarn the farmers two weeks prior to the infestation and disseminate the weather based insect-advisory of girdle beetle incidence on soybean to take precautionary measures. The combination of statistical model with geographical information system can be used to protect the crop from the insect damage by resorting to suitable management practices in the specified locations and to reduce the input cost.

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