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Predictive zoning of rice stem borer damage in southern India through spatial interpolation of weather-based models

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Abstract

Rice stem borer is an important insect pest causing severe damage to rice crop in India. The relationship between weather parameters such as maximum (T_{max}) and minimum temperature (T_{min}), morning (RH_1) and afternoon relative humidity (RH_2) and the severity of stem borer damage (SB) were studied. Multiple linear regression analysis was used for formulating pest-weather models at three sites in southern India namely, Warangal, Coimbatore and Pattambi as SB = -66.849 + 2.102 T_{max} + 0.095 RH_1, SB = 156.518 – 3.509 T_{min} – 0.785 RH_1 and SB = 43.483 – 0.418 T_{min} – 0.283 RH_1 respectively. The pest damage predicted using the model at three sites did not significantly differ from the observed damage ($t = 0.442$; $p>0.05$). The range of weather parameters favourable for stem borer damage at each site were also predicted using the models. Geospatial interpolation (kriging) of the pest-weather models were carried out to predict the zones of stem borer damage in southern India. Maps showing areas with high, medium and low risk of stem borer damage were prepared using geographical information system. The risk maps of rice stem borer would be useful in devising management strategies for the pest in the region.

Key words

GIS, Predictive zoning, Rice stem borer, Spatial interpolation

Introduction

Rice production in India is adversely affected by the incidence of many insect pests and diseases. The rice stem borer is one of the most important pests of rice crop in the country. Apart from the yellow stem borer *Scirpophaga incertulas* , the crop is infested by striped borer, *Chilo suppressalis*; dark headed borer, *Chilo polychrysus*; pink borer, *Sesamia inferens* and white borer, *Scirpophaga innotata* (Nair, 1995). *S. incertulas* is the most damaging species of rice stem borer in tropical Asia (Cohen *et al*., 2000). The larvae of these species bore into the stem of rice plants causing 'deadhearts' or 'white earheads', which lead to severe yield losses.

Prediction of the buildup of pest population and the probable damage to agricultural crops can increase our preparedness towards better management of crop pests. Forecasting the occurrence of rice stem borer may help the farmers to adopt management practices well in advance thereby minimising the pest damage (Yang *et al*., 2009). There have been many attempts to develop weather-based forewarning models for rice stem borer (Samui *et al*., 2004). The attraction of yellow stem borer by light traps at Cuttack, India has shown positive correlation with maximum temperature, relative humidity, rainfall and wind speed, while showing negative correlation to minimum temperature and daily sunshine hours (Padhi and Saha, 2004). However, another study conducted at Jagdalpur, India showed that the attraction of moths by light traps was negatively correlated with minimum temperature, evening relative humidity and rainfall (Bhatnagar and Saxena, 1999). Maximum temperature and evening relative humidity were negatively correlated, whereas minimum temperature and morning relative humidity were positively correlated with the light trap catches of yellow stem borer at Raichur, India (Nandihalli *et al*., 1990). These results indicate that the relation between rice stem borer occurrence and meteorological parameters exhibit spatial variability across the country. Hence, predictions of pest occurrence using weather-based regression models are site specific.

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The predictions of pest occurrence can be applied to a larger geographical area with the help of Geographical Information System (GIS) techniques. Geospatial interpolation of pest occurrence and classification of the cropped area based on the predicted levels of pest occurrence is known as pest zoning (Teng and Savary, 1992). The pest zone maps thus prepared can be used for identifying the areas, which are highly favourable to pest occurrence. Surveillance of these pest hotspots may help to avoid or minimise crop loss due to pest outbreaks. The present studies were carried out to formulate weather-based regression models for the prediction of rice stem borer damage at Warangal, Coimbatore and Pattambi in southern India. Further, these models were geospatially interpolated to identify and map the predicted severity of rice stem borer damage in Southern India.

Materials and Methods

Study areas : The weather-based pest occurrence models were formulated for three sites namely, Warangal (18º00'N; 79º34'E, Andhra Pradesh), Coimbatore (11º00N; 76º58'E, Tamil Nadu) and Pattambi (10º49'N; 76º12'E, Kerala) in Southern India.

Data collection : The data on stem borer damage to rice crop recorded as percent 'deadhearts' in the insecticide evaluation trials conducted during 1990-2006 at Warangal, Coimbatore and Pattambi (DRR 1990-2006), were used for formulating and validating the models. The meteorological data for these locations were obtained from the Central Research Institute for Dryland Agriculture (CRIDA), Hyderabad, India. The weekly normal values (1951-1980) of temperature and relative humidity from weather stations across the states of Andhra Pradesh, Tamil Nadu and Kerala were obtained from the India Meteorological Department, New Delhi.

Data analysis : Stepwise, multiple linear regression analyses were carried out to establish the relationships between the pest damage and the weekly mean values of maximum temperature (T_{max}), minimum temperature (T_{min}), morning relative humidity (RH_1) and evening relative humidity (RH_2). The predicted and the observed stem borer damages during 2005 and 2006 at Warangal, Coimbatore and Pattambi were compared by 'student t' test.

Predictive zoning : The regression relationships developed for Warangal, Coimbatore and Pattambi were used for pest zoning of the states of Andhra Pradesh, Tamil Nadu and Kerala respectively, using ESRI ArcGIS 9. The range of weather parameters leading to low (< 5%), moderate (5-10%), high (10-15%) and severe (>15%) intensities of stem borer damage were derived, using regression models. The state boundaries were digitised and the study sites and weather stations were located on the state maps. Separate maps of temperature and humidity were prepared for each state using geostatistical interpolation technique (kriging). Masking was done to confine the interpolated variables within the state boundaries and raster calculations were done, based on the respective pest-weather models for the state, to prepare a combined map of temperature and humidity. The maps thus obtained were reclassified, based on the set of weather variables leading to low to high classes of stem borer damage.

Results and Discussion

Weather plays an important role in the incidence of crop pests and hence the models based on weather parameters are useful for forewarning of pest incidence (Agrawal and Mehta, 2007). In the present study, preliminary analyses indicated that the weather prevailed during 8-15 days prior to the rice stem borer damage (second lag week) was exhibiting better correlation with the intensity of damage. Stepwise linear regression methods were used to retain only two of the most important weather parameters in the pest-weather models.

The percent damage due to rice stem borer (SB) during the study period at Warangal was 8.5 ± 0.9, whereas the corresponding T_{max}, T_{min}, RH_1 and RH_2 were 32.1 ± 0.4 ºC , 22.1 ± 0.7 ºC , 84.3 ± 2.3 % and 60.9 ± 3 %, respectively. Correlation analysis indicated that T_{max} and RH_1 showed high correlation with stem borer damage at Warangal (Fig 1) and hence, the weather-based regression model was formulated as $SB = -66.849 + 2.102\ T_{max} + 0.095\ RH_1$ (R^2 = 0.673) (Table 1). The weather-based prediction of stem borer occurrence using regression model revealed that T_{max} > 35°C and RH_1 > 82% may lead to severe damage, whereas T_{max} < 31°C and RH_1 <78% may lead to low damage due to rice stem borer (Table 2).

The stem borer damage at Coimbatore was 13.7 ± 1.8 %, whereas T_{max}, T_{min} (ºC), RH_1, and RH_2 was 32.5 ± 0.6, 22 ± 0.5, 83.5 ± 1.5 and 46.2 ± 2.8, respectively. $T_{min}$and RH_1were highly correlated with stem borer damage (Fig. 1) and hence the regression model was formulated as $SB = 156.518 – 3.509\ T_{min} – 0.785\ RH_1$($R^2$= 0.622) (Table 1). Severe stem borer damage was predicted in areas with T_{min}< 22 °C and RH_1< 73%, whereas low damage was predicted in areas with T_{min}>27 °C and RH_1> 79% (Table 2).

The percent stem borer damage at Pattambi was 9.4 ± 0.8 and the corresponding T_{max}, T_{min}, RH_1, and RH_2 were 31.2 ± 0.5 ºC, 22.1 ± 0.4 ºC, 87.7 ± 1.9 % and 55.6 ± 3.8 % respectively. Since T_{min} and RH_1 were highly correlated with the stem borer damage (Fig. 1), the pest-weather model was formulated as $SB = 43.483 – 0.418\ T_{min} – 0.283\ RH_1$($R^2$= 0.515) (Table 1). The weather conditions predicted to be highly favourable for stem borer damage were T_{min} < 11°C and RH_1 < 90%, whereas T_{min}> 24 °C and RH_1 > 90% were predicted to be least favourable (Table 2). The stem borer damage at Warangal, Coimbatore and Pattambi, during 2005 and 2006, predicted using the regression models were not significantly different from the actual damage recorded (t = 0.442; p > 0.05) (Fig. 2).

The relationship between the level of pest damage and weather parameters was found to vary among Warangal, Coimbatore and Pattambi. The stem borer damage was correlated with T_{max} at Warangal, whereas with T_{min} at Coimbatore and Pattambi. RH_1 was established to have significant correlation with stem borer damage at all three sites. The pest damage was positively correlated with T_{max} and RH_1 at Warangal, while negatively correlated with T_{min} and RH_1 at Coimbatore and Pattambi. This clearly indicates that the pest damage-weather models were site specific. Among the three regression models formulated, the models for Warangal (R^2= 0.673) and Coimbatore (R^2= 0.622) were more reliable in their predictive value in comparison with the model for Pattambi (R^2= 0.515).

The growth and survival of insect species may get adversely affected beyond the favourable range of temperature and humidity. Studies on the attraction of stem borer moths to light traps indicated that minimum temperature played an important role in the population buildup and the pest incidence was negatively correlated to minimum temperature, evening relative humidity and rainfall (Bhatnagar and Saxena, 1999; Sarkar and Gayen, 1992). The predictions on the influence of temperature on

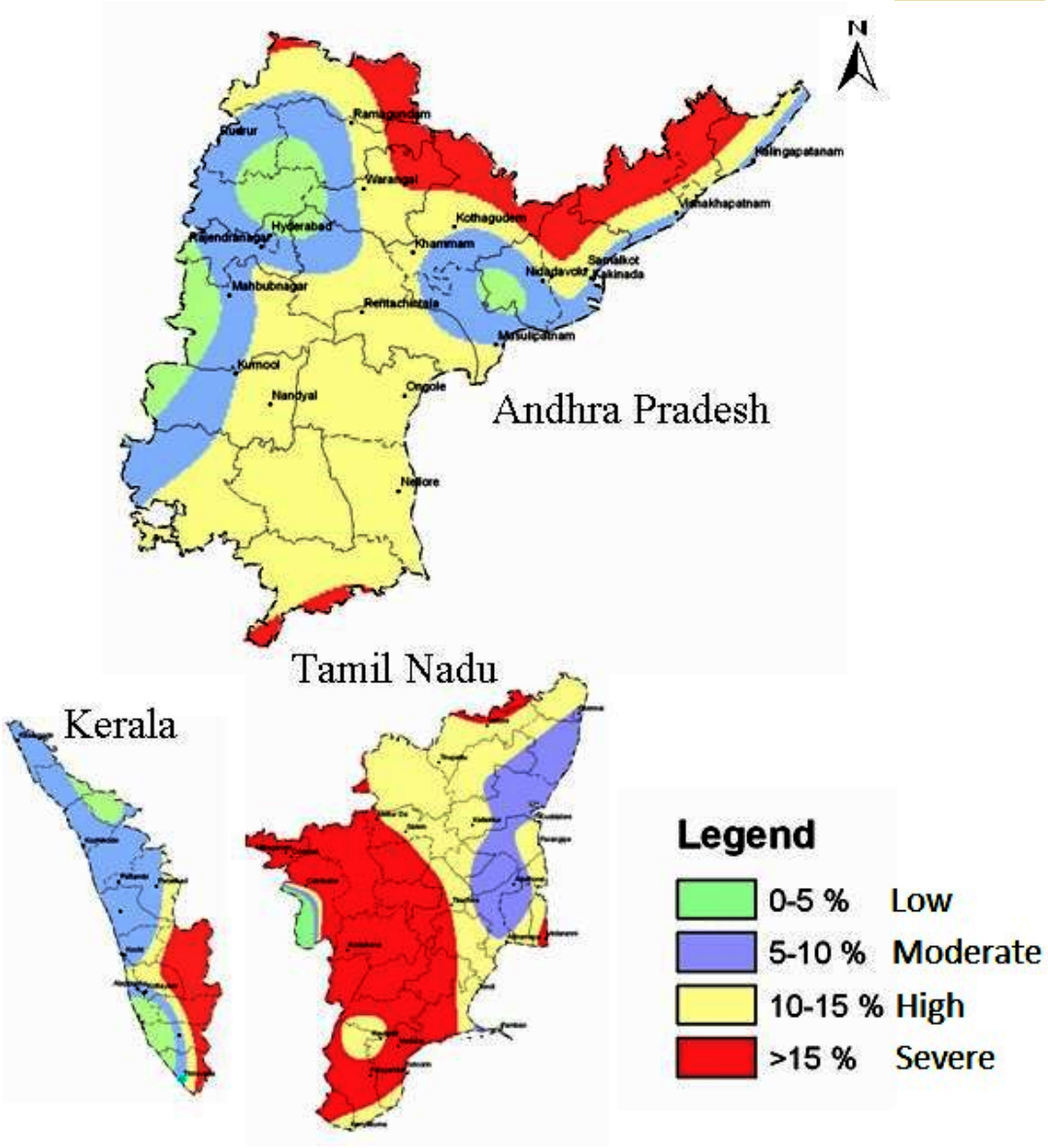

Fig. 3 : The predicted zones of severe (>15%) to low (0-5%) rice stem borer damage in Andhra Pradesh, Tamil Nadu and Kerala states of India

Table 1 : Multiple linear regression between the percent stem borer damage and the weather factors at Warangal, Coimbatore and Pattambi

Locations	Predictors	Coefficients	SE_{mean}	R^2	t	*p*
Warangal	Constant	-66.849	14.675	0.673	4.555	.000
	Tmax	2.102	0.379		5.549	.000
	RH1	0.095	0.061		1.554	.141
Coimbatore	Constant	156.518	31.330	0.622	4.996	.000
	Tmin	-3.509	0.753		4.663	.000
	RH1	-0.785	0.232		3.388	.004
Pattambi	Constant	43.483	9.907	0.515	4.389	.000
	Tmin	-0.418	0.396		1.056	.307
	RH1	-0.283	0.077		3.682	.002

Tmax = Weekly mean maximum temperature (ºC); Tmin = weekly mean minimum temperature (ºC); RH1 = Weekly mean morning relative humidity (%); RH2 = Weekly mean afternoon relative humidity (%)

Table 2 : Range of weather parameters predicted to be favourable for severe-to-low levels of stem borer damage at Warangal, Coimbatore and Pattambi

Predicted zones of stem borer damage	Warangal		Coimbatore		Pattambi	
	T_{max} (ºC)	RH_1 (%)	T_{min} (ºC)	RH_1 (%)	T_{min} (ºC)	RH_1 (%)
Severe(>15%)	>35	>82	<22	<73	<11	<90
High(10 – 15%)	33-35	78-82	22-25	73-79	11-18	<90
Moderate(5 – 10%)	31-33	78-82	25-27	73-79	18-24	>90
Low(<5%)	<31	<78	>27	>79	>24	>90

the stem borer damage at Coimbatore and Pattambi were in agreement with an earlier study, which showed that temperature above 33°C was lethal to rice stem borer (Suwongwan and Catling, 1987). The weather-based multiple regression models for the major pests of rice were validated at Pattambi during 2000 and 2001 with 67% population variation (Samui *et al*., 2004). However, variation between the predicted and observed pest damage in the present study was lower (5.6-44.3%) in comparison.

Predictive pest zoning involves the spatial interpolation of the probable levels of pest occurrence or damage in an area predicted with the help of a model. The predictive zoning maps for Southern India indicated the areas predicted to be having severe, high, moderate and low levels of stem borer damage (Fig. 3). The normal range of T_{max} and RH_1in Andhra Pradesh were 31-35.1°C and 71.2-89.8% respectively. The zoning map of Andhra Pradesh predicted severe stem borer damage in the northern parts of state and high damage for most of the remaining areas. The normal range of T_{min} and RH_1in Tamil Nadu were 10.5-26.2°C and 64.6-86.6% respectively. The predictive zoning indicated severe stem borer damage in the southwestern part, whereas high damage in most of the other areas of the state. The normal $T_{min}$and RH_1ranges in Kerala were 22.5-23.8°C and 86.6-95.2% respectively. The stem borer damage was predicted to be severe in the southeastern region, whereas moderate in the rest of the state.

Geographical Information System tools can be used for linking models with georeferenced temperature data for forecasting pest occurrence in areas where the temperature data is not available (Jarvis *et al*., 2003). Kriging is a spatial interpolation method for predicting a continuous variable distributed in space or in time at unsampled locations based on the data from the sampled locations (Vinatier *et al*., 2011). The site predictions are interpolated to a large area with the help of Geographical Information System wherein geostatistical techniques are used for carving out zones of equal epidemic potential (Teng and Savary, 1992). Agro-ecological zoning of rice leaf folder (Chander *et al*., 2004) and brown plant hopper (Yadav *et al*., 2010) occurrence were carried out in the states of Haryana and Andhra Pradesh (India) respectively. The geographical distribution of the sugarcane woolly aphid in India was predicted by Genetic Algorithm for Rule set Prediction (GARP) and DIVA GIS (Ganeshiah *et al*., 2003). Similarly, airborne imagery and GIS technology were integrated to map and compare the citrus black fly infestations occurring in different years in Texas, United States (Fletcher *et al*. 2004).

Forecasting of pest incidence in agricultural crops may help in taking appropriate control measures so as to reduce the yield losses. Weather factors have a significant influence on the abundance and distribution of crop pests and hence weather-based pest forecasting models have been developed and are being used across the world (Olatinwo *et al*., 2011; Way and Emden, 2000). Pest occurrence in many crops can be forecasted with the help of weather-based regression models. However, regression models need to be formulated separately for each location due to their site specificity. The predictive zoning by geospatial interpolation of such models using GIS helps to make

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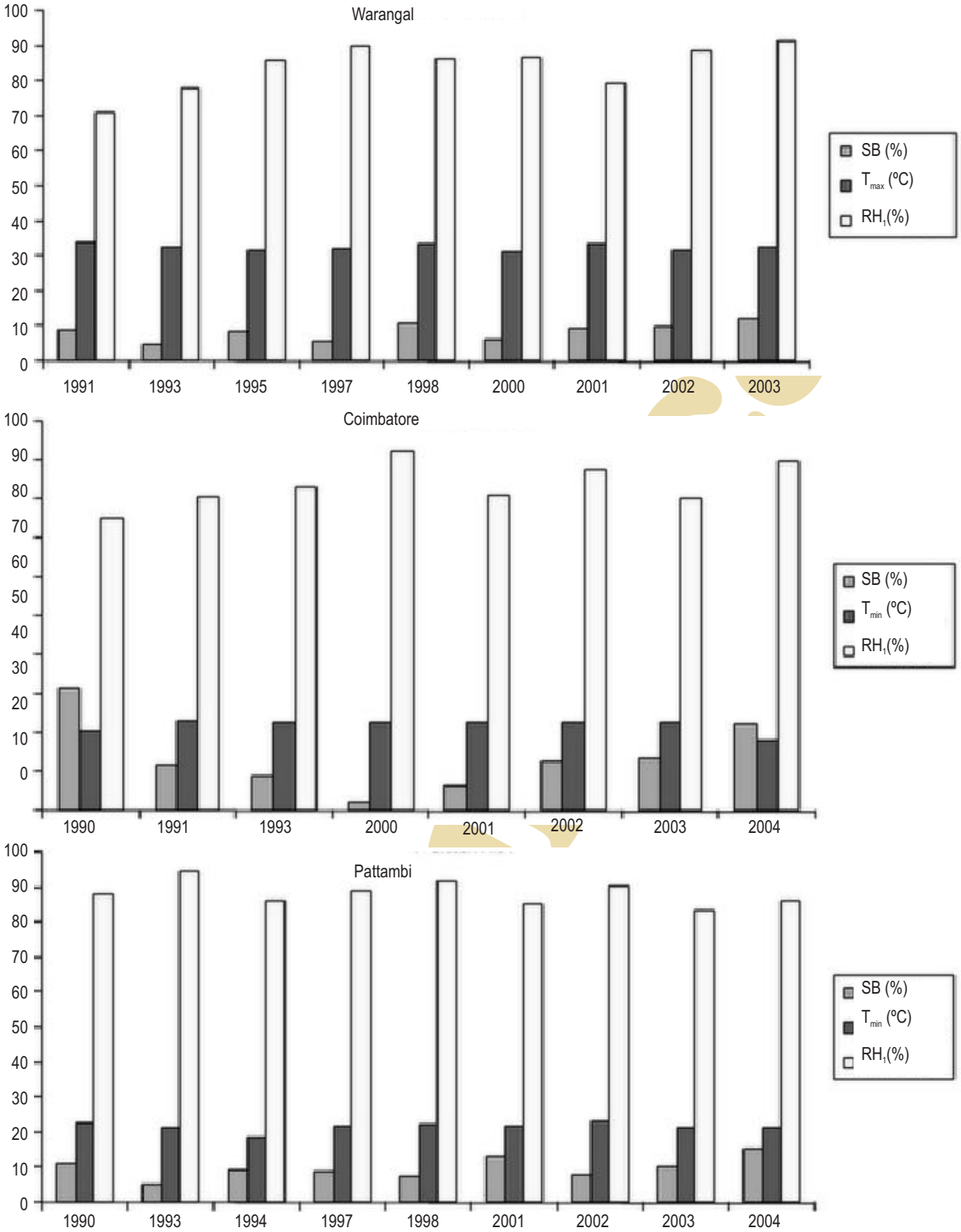

Fig. 1 : Rice stem borer damage and the weather parameters during the second lag week at Warangal, Coimbatore and Pattambi in Southern India

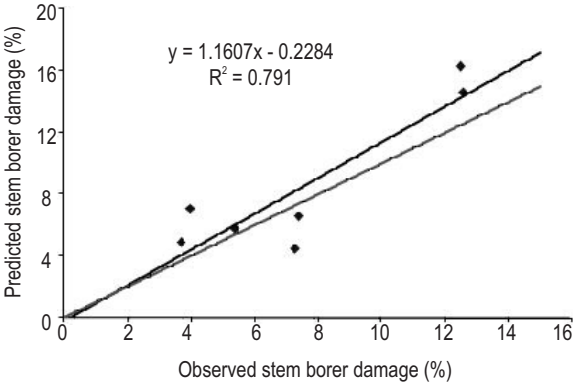

Fig. 2 : Comparison of predicted and observed stem borer damage at Warangal, Coimbatore and Pattambi in Southern India (t = 0.442; p> 0.05)

these models applicable for the prediction of pest damage in a large geographical area. Hence, the use of geospatial interpolation techniques would avoid the need to develop regression models for each location within the selected geographical area separately. The delineation of pest zones in rice as well as in other major agricultural crops in the region would help in identifying the hotspots of pest infestation and to prevent pest outbreaks. The combination of mathematical models with geographical information system as in the present study would be useful in developing decision support systems for crop pest management.

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