

Correlating the pheromone-trapped adults of *Spodoptera frugiperda* (J. E. Smith), with the weather parameters in maize fields of Assam, India

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ABSTRACT: Assam, a north-eastern Indian state, has experienced the invasion of fall armyworm (FAW) in recent years. The correlation study of weather factors with the adult population was undertaken with the adults caught in the pheromone traps installed in maize fields, of 3 districts of Assam during 2023-24. There was a positive correlation with the maximum temperature in 4 out of 9 occasions, and with minimum temperature in 7 out of 9 occasions of seasonal correlations across the districts, which led to a positive correlation ($r=0.331$ and $r=0.459$, respectively); however, the effects of minimum temperature on the adult population are more pronounced. Rainfall was positive, but insignificant. Three linear models were developed by the multiple linear regression analysis for weekly adults trapped against these weather parameters for two seasons, as well as their pooled data. All models are statistically significant, and the key factor contributing to variation in weekly trap catch was the temperature variable. The Durbin-Watson value of each season was near 2.0, which indicated that no serious autocorrelation in residuals occurred. These models will help in predicting the pests in the future.

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KEY WORDS: C-strain, adult catches, temperature, linear models, Durbin-Watson

INTRODUCTION

Maize (*Zea mays* L.), is an important staple food crop in India. Siddiqui and Marwaha (1993) reported 12 species as the serious pests of maize in India; however, the recent invasion of fall armyworm (FAW), *Spodoptera frugiperda* (J. E. Smith) (Lepidoptera, Noctuidae), is a great concern since the pest can cause damage to more than 180 crop species globally (Casmur *et al.*, 2010). FAW is native to America and has recently invaded the

different states of India (Sharanabasappa *et al.*, 2018; Ali *et al.*, 2018; Sisodiya *et al.*, 2018; Babu *et al.*, 2019; Chormule *et al.*, 2019; Maruthadurai and Ramesh, 2019; Meena *et al.*, 2019; Ankita *et al.*, 2020; Kerketta *et al.*, 2020; Patel *et al.*, 2020; Sharma and Sharma, 2020; Suby *et al.*, 2020; Vishwakarma *et al.*, 2020; Paschapur *et al.*, 2021; Soujanya *et al.*, 2024) including North Eastern States (Firake *et al.*, 2019; Sarma *et al.*, 2023). Because of its capability of high migration, FAW has now attained a global pest status (FAO, 2017;

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IPPC, 2021). The pest is predicted to cause up to 53 per cent annual loss in maize (Day *et al.*, 2017) but in India, yield reduction was reported up to 33 per cent (Aruna *et al.*, 2019) and 33-36 per cent (Jagdish *et al.*, 2019); with a predicted annual loss up to 75,000 tonnes (Suby *et al.*, 2020).

Since the long-distance dispersal of FAW mostly occur through winged adults (Garcia *et al.*, 2018), pheromone trap work is an effective tool for monitoring the adults (Akter *et al.*, 2025). FAW relies on the long-distance migration to move to more suitable climates (FAO, 2020), where temperature is a prime mover. North East Region of India is one of the least investigated regions, even after recommendation of pheromone trap for monitoring the FAW (Suby *et al.*, 2020; Nwanze *et al.*, 2021). The study on pheromone assisted trapping at farmers' field in scanty (Sarma *et al.*, 2024). The impacts of weather on FAW have been studied in different parts of India (Anandhi *et al.*, 2020; Ravi and Waghmare, 2021; Ratnam *et al.*, 2023; Prasad *et al.*, 2022; Haroli *et al.*, 2023). In this context, an attempt was made to study the adult population caught in the pheromone traps (installed in farmers' maize fields during 2023-24), based on the prevailing temperature (minimum and maximum) and rainfall in Assam.

MATERIALS AND METHODS

The experiments were conducted in 7-8 maize fields in each of the three districts of North Bank Plain Zone (NBPZ) of Assam, viz., Udalguri, Sonitpur and Biswanath Chariali. The fields of progressive farmers were selected as per the records of the concerned District Agricultural Office. Sonitpur district is located between other two districts and the average distance from the experimental plots of Sonitpur to that of Biswanath is about 43km (towards east) and to that of Udalguri is about 44 km towards west. The coordinates of the centrally located sites of each district are 26.768033°N; 92.098642°E (Udalguri), 26.69376°N; 92.55397°E (Sonitpur), and 26.79393°N; 92.97355°E (Biswanath). The crops were grown under the rainfed production systems and pest data were taken in the same standard meteorological weeks across the locations. The FAW adults were

monitored for 5 weeks a season by 5 pheromone traps installed in each maize field of about 1.5 bigha (0.2 ha) at a height of 1.5m, since trapping of more adults has been reported by Nwanze *et al.* (2021) at this height. Monitoring began at the early whorl stage of the crop, as this stage has been reported as the most preferred stage for oviposition (Harrison *et al.*, 2019) and the observation lasts for 5 weeks per season. The pheromone lures manufactured by Pheromone Chemicals, Hyderabad were used during 2023-24. Lures were changed only once after one month of first installation. The weekly trapped catch (WTC) adults in the traps was correlated with the corresponding week temperature (maximum and minimum), and rainfall. The weather data were collected from Ghogara Tea State, Sonitpur; Chandana Tea State, Udalguri; and Biswanath College of Agriculture, Assam Agricultural University, Biswanath Chariali. Pearson correlation was used for the correlation between the weather parameters and the number of adults captured. To come up with predictive models, different linear regressions were carried out, where trap catch was the dependent variable and three weather variables were used as independent variables in each of two cropping seasons, as well as pooled data. Multiple linear regression was performed using the generalized model ($Y = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_3 + \epsilon$). Statistical validity of each model was determined by R^2 , F-statistic, p-values, Durbin-Watson Statistic, Variance Inflation Factor (VIF), and the verification that model assumptions were true was done by Normal P-P plots of residuals. SPSS 26 version was used for all the analyses.

RESULTS AND DISCUSSION

The number of adults trapped in different districts and years varied. The mean weekly catches generated from 35-40 traps installed in 7-8 locations per district ranged from 1.2 - 6.6 in Udalguri, 0 - 5.6 in Sonitpur, and 0 - 3.2 in Biswanath Chariali during the entire observation period. The mean record of trap catches across the seasons, and places of the three districts was 2.31 adults per week. Diverse correlations of weather parameters with the adult population caught in pheromone traps

across the districts and seasons were noted. Even though the results of different districts were shown, the objective was to draw inferences on the zone as a whole, i.e., for the North Bank Plain Zone (NBPZ) of Assam, India. There was a positive correlation with maximum temperature in 4 out of 9 occasions of seasonal study across the 3 districts ($r=0.331$). Similarly, a positive correlation with minimum temperature was also observed in 7 out of 9 occasions of seasonal study across the 3 districts ($r=0.459$) in the zone as a whole. The correlation of minimum temperature with adult population was more pronounced than that of maximum temperature, which was reflected in 8 out of 10 Pearson's correlation values (Table 1).

Three regression models of the weekly trap catch (viz., number of adults caught weekly in pheromone traps) in relation to the weather parameters (minimum temperature, maximum temperature, and rainfall) were applied. The Normal P-P plots show that the residuals of the Season 1 model are near normal, whereas those of the Season 2 model have some deviations. However, the combined model (Season 1 + Season 2) showed a high level of correspondence with the normal distribution line, which proves that the assumption of normality is met (Table 2).

Interpretation for the season 1 regression model: The multiple linear regression analysis shows that the model has a significant impact in predicting the WTC ($F = 16.498$, $p < 0.001$), and the R^2 of the model is 0.529, which shows that the

given model explains the variance in WTC approximately with 52.9 percent. The adjusted R^2 of 0.509 indicates that the model still fits well even after the consideration of the number of predictors. Minimum temperature is significantly positively correlated with WTC ($p < 0.001$) compared to other predictors, but maximum temperature ($p = 0.843$) and rainfall ($p = 0.313$) fail to become significant predictors. The value of the Durbin-Watson test is 1.976, which is near 2, showing that no serious autocorrelation in residuals occurred. The issue of multicollinearity is to be ignored because the values of the Variance Inflation Factor (VIF) are less than 2, and the distribution of the residuals is normally distributed with a mean near zero (Fig. 1). Thus, it can be stated that the model is statistically significant, and the key factor contributing to variation in WTC among the explored variables is minimum temperature.

Interpretation for season 2: The multiple linear regression reveals that the model is significantly useful in predicting the WTC ($F = 5.139$, $p = 0.002$). The R^2 of 0.527 shows that the amount of variance in WTC explained by the predictors, viz., temperature (max and min) and rainfall, is about 52.7 per cent with adjusted R^2 as 0.502, which is an indication of good model fit when adjusted to account for the number of predictors. The temperature (max) ($p = 0.023$) and temperature (min) ($p = 0.021$) are statistically significant and positively correlated with WTC. However, the factor rainfall is not a statistically significant predictor ($p = 0.908$) in this particular model. The

Table 1. Correlations of weather parameters with weekly trapped catch of FAW during two seasons

Parameters	Udalguri district			Sonitpur district			Biswanath district			NBPZ
	Season 1	Season 2	Pooled	Season 1	Season 2	Pooled	Season 1	Season 2	Pooled	#Pooled
Max - Temp (17.4 - 34°C)	+ve (0.093)	-ve* (-0.388)	-ve (-0.122)	+ve* (0.358)	-ve** (-0.486)	-ve (-0.115)	-ve (-0.024)	+ve (0.072)	+ve (0.062)	+ve** (0.331)
Min - Temp (7.38 - 25°C)	+ve* (0.337)	+ve* (0.376)	+ve* (0.265)	-ve (-0.221)	+ve** (0.661)	+ve (0.232)	-ve (-0.003)	+ve (0.123)	+ve (0.100)	+ve** (0.459)
Rainfall (0 - 70.2mm)	+ve (0.249)	-ve (-0.067)	-ve (-0.006)	+ve (0.009)	+ve (0.236)	+ve* (0.268)	+ve (0.275)	-ve (-0.051)	+ve (.094)	+ve (0.071)

+ve: Insignificantly positive; +ve*: Significantly positive; +ve**: Highly significantly positive.

-ve: Insignificantly negative; -ve*: Significantly negative; -ve**: Highly significantly negative. NBPZ: North Bank Plain Zone (n): The values within parentheses are Pearson Correlation Values. #Pooled across the seasons and districts.

Regression models

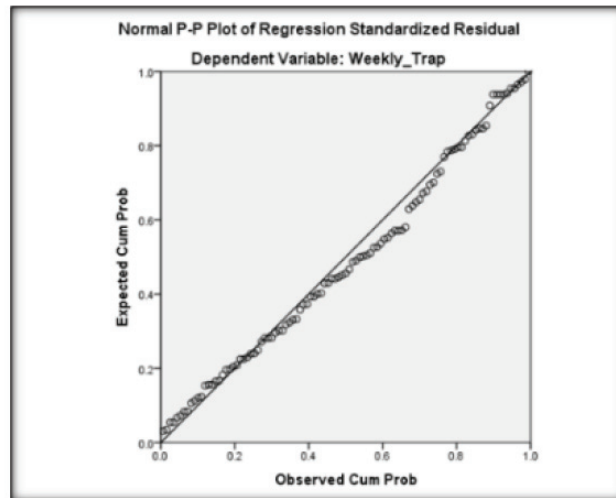
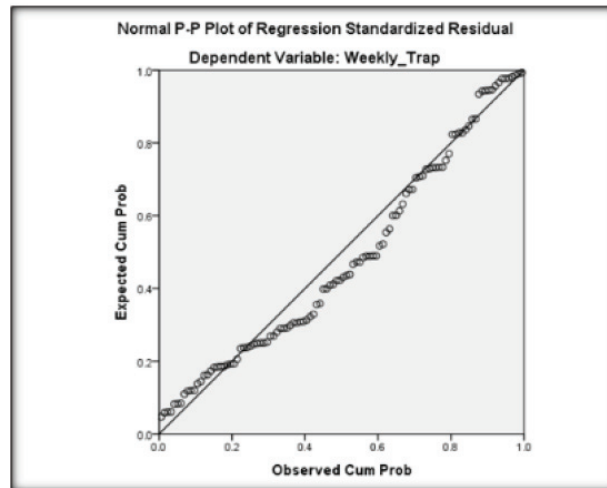
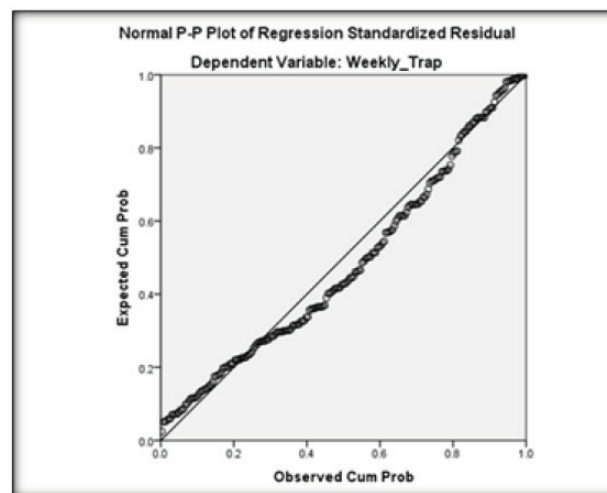
**Fig. 1** Normal P-P Plot for the season 1;**Fig. 2** Normal P-P Plot for the season 2**Fig. 3** Normal P-P Plot for the overall

Table 2. Regression equations for the three models Weekly Trapped Catches (WTC) of FAW adults

Regression models	R ²	SE	F	p-value
Season 1: $WTC = 0.491 + (-0.005) \times \text{Temp_Max} + 0.108 \times \text{Temp_Min} + 0.018 \times \text{Rainfall}$	0.529	0.92827	16.498	< 0.001
Season 2: $WTC = -1.030 + (0.090) \times \text{Temp_Max} + 0.054 \times \text{Temp_Min} + (-0.001) \times \text{Rainfall}$	0.527	1.23678	5.139	0.002
Overall: $WTC = -0.376 + (0.045) \times \text{Temp_Max} + 0.082 \times \text{Temp_Min} + 0.003 \times \text{Rainfall}$	0.626	1.11433	20.536	< 0.001

value of the Durbin Watson test is found to be 1.905. VIF statistics indicate that there is no issue of multicollinearity among predictors because they are as close to 1 as possible (Fig. 2). The developed model is statistically significant and moderately strong, and temperature variables are determinants contributing most to forecasting the WTC.

Interpretation for the overall regression model (Season 1 + Season 2): Multiple linear regression analysis indicates that the model has a significant amount of predictive value for WTC ($F = 20.536$, $p < 0.001$). The model describes 62.6 percent of changes in WTC ($R^2 = 0.626$), the adjusted $R^2 = 0.615$, demonstrating that there is a very strong fit of the model once the number of predictors is considered. When it comes to the independent variables, the maximum temperature and minimum temperature are significant predictors of temperature (maximum) ($p = 0.045$) and temperature (minimum) ($p < 0.001$). The coefficients are positive in both cases. On the other hand, rainfall ($p = 0.595$) is not a significant predictor. The proposed variable (Durbin-Watson test value = 1.863) does not suggest an important autocorrelation of residuals. The value of VIF of all predictors is less than 1.4, which verifies the insignificance of multicollinearity (Fig. 3). In general, the model indicates a statistically significant and relatively strong association of temperature variables with WTC.

The overall mean weekly adult catch record across the locations and seasons is 2.31 per trap. Different sowing dates of maize to varied levels of infestation of FAW in Nagaland (Longkumer *et al.*, 2023), which is also an indication of the differential impact of prevailing weather. Differential seasonal effect of rainfall has also been reported by Haroli *et al.* (2023) in commensuration with our result; their

study conducted in Coimbatore revealed that the rainfall exhibited a positive relation and a negative correlation during summer and rainy season, respectively. Negative correlation of larval population of FAW with rainfall has been reported from other parts of India (Anandhi *et al.*, 2020; Gowda *et al.*, 2024). Ratnam *et al.* (2023) have also reported that the rainfall, temperature, and humidity significantly influenced the emergence of the FAW and its infestation on maize crop under East Coast agro-climatic conditions of Andhra Pradesh. Likewise, the weather parameters had a profound impact on the infestation of FAW in Pakistan (Ahmad and Ibrahim, 2021). By a simulated study, Prasad *et al.* (2022) also predicted a greater number of generations and potential threat of FAW under the changing climate.

Highly variable trap catches (number of males per trap per night) have been recorded across countries such as Argentina (Bratovich *et al.*, 2019), Mexico (Malo *et al.*, 2001), the USA (Meagher *et al.*, 2013), Costa Rica (Andrade *et al.*, 2000), and India (Bhanu *et al.*, 2020). Such variation may be attributed to ecological factors associated with the maize ecosystem, e.g., crop acreage, abundance of predatory birds, light sources in and around the cropped area, and the history of FAW invasion in the locality. The role insectivorous predatory bird in suppressing the infestation of FAW has been emphasised in Assam (Sarma *et al.*, 2023) and Central America (FAO, 2018).

The mean weekly catches varied within 1.2- 6.6 in Udalguri, 0-5.6 in Sonitpur, and 0-3.2 in Biswanath Chariali. Such inter-location variations may be attributed to the variation in ecological factors associated with the maize ecosystem, e.g., crop acreage, non-crop vegetation around the crop, abundance of predatory birds, light sources in and

around the cropped area, and the history of FAW invasion in the locality. Such variations have also been recorded in India (Bhanu *et al.*, 2020) and other countries (Andrade *et al.*, 2000; Malo *et al.*, 2001; Meagher *et al.*, 2013; Bratovich *et al.*, 2019). The dispersal of FAW mostly occurs through winged adults, although at smaller scales, dispersal to surrounding plants can occur via larvae (Garcia *et al.*, 2018). The present study highlights the importance of temperature, particularly minimum temperature, as a major driver of pest population build-up, while rainfall plays a comparatively minor role. The proposed models may help in predicting the pests and disseminating the model-based information to the farmers.

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