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Analyzing the influence of planting dates and weather variables on fall armyworm incidence in maize

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Abstract
Fall armyworm, shortly abbreviated as FAW, is a serious insect pest that causes significant yield losses in maize. The purpose of this study was to find out how different planting dates influence the incidence of FAW during *kharif* 2021 and *rabi* 2021-22. A total of six plantings have been taken up, and the maize hybrid DHM 117 was sown at fortnightly intervals. At varied planting dates, the percent plant infestation, larval population, and fecundity of fall armyworm were correlated with weather variables. The FAW infestation and larval population were negatively impacted by rainfall, relative humidity *i.e,* RH-I & RH-II, and minimum temperature, while maximum temperature exhibited a positive association. However, egg-laying was negatively influenced by every weather parameter studied. Thus, understanding the role of weather variables in FAW incidence is essential in developing forewarning models and sustainable management strategies.

Keywords: FAW, temperature, rainfall, relative humidity and correlation

Introduction
Maize (*Zea mays*) is a widely cultivated cereal that has been a staple food for various civilizations. It is a versatile crop that can grow in diverse climates and soil conditions, making it a crucial food source in many parts of the world. In addition to its role as a food source, maize has many other uses. It serves as animal feed for livestock, and its by products are used in the production of biofuels and various industrial products. India stands 4th in area and 7th in maize production, contributing about 4.6% of the world's total area and 2.4% of total output (FAOSTAT, 2020) [1].
Fall armyworm, scientifically known as *Spodoptera frugiperda* (J.E. Smith), poses a significant threat for maize worldwide. Originating from the tropical and subtropical areas of the Americas, it rapidly expanded to various parts of the globe, causing extensive damage to maize. In India, Karnataka was where it was first reported in 2018 (Ganiger *et al*., 2018) [2]. Later, it dispersed quickly across the nation, infesting the maize crop in every region where it was grown (Rakshit *et al*., 2019) [3]. FAW multiplies rapidly in a short time because of the favourable climatic conditions in Telangana, which is listed as one of the areas with a high risk of FAW incidence.
Environmental variables govern the density of a pest's population also the extent of damage it does (Becker, 1974) [4]. Formerly, several authors studied the role of weather parameters in regulating pest density in various crops (Saminathan *et al*., 2001; Priyanka *et al*., 2018) [5-6]. FAW requires a minimum threshold temperature of 13.8 °C below which development ceases (Early *et al*., 2018; Li *et al*., 2020) [7-8]. In order to prevent economic yield losses and reduction of pesticide usage, knowledge on the effect of weather variables on the occurrence and population fluctuations of FAW is crucial.

Experimental setup
Research Area
This research was undertaken in Winter Nursery Centre (IIMR), Hyderabad, during *kharif* 2021 and *rabi* 2021–22.

Raising of crop

Maize hybrid DHM 117 was sown at fortnightly intervals from August 2021 to December 2021 on the following dates: On the 2nd and 17th of August, 2021; the 23rd of October, 2021; the 10th and 24th of November, 2021; and the 4th of December, 2021. A plot size of 7.5 m × 3 m was maintained, with a spacing of 75 cm × 20 cm. Except for plant protection measures, the hybrid was cultivated following the recommended agronomic practices.

Materials and Methods

The meteorological station located at the ARI (PJTSAU), Rajendranagar, provided the weather parameters (Appendix).

Table 1: Appendix Weather data during the crop growth period (2/08/21 to 11/03/22).

Standard week	Date & Month	Temperature (°C)		R.H (%)		Rainfall (mm)
		Max.	Min.	I	II	
32	06 Aug – 12 Aug	32.50	24.00	94.00	66.00	0.30
33	13 Aug - 19 Aug	29.50	22.80	95.00	79.00	7.70
34	20 Aug - 26 Aug	30.50	25.50	95.00	66.00	1.50
35	27 Aug - 02 Sep	28.40	22.30	96.00	81.00	7.80
36	03 Sep - 09 Sep	27.60	22.30	96.00	83.00	11.80
37	10 Sep - 16 Sep	29.40	22.70	91.00	71.00	0.90
38	17 Sep - 23 Sep	30.00	22.60	93.00	76.00	5.90
39	24 Sep - 30 Sep	28.40	22.00	93.00	76.00	17.20
40	01 Oct - 07 Oct	31.60	22.60	94.00	62.00	0.60
41	08 Oct - 14 Oct	31.40	21.00	92.00	58.00	12.60
42	15 Oct - 21 Oct	30.70	21.20	88.00	59.00	1.10
43	22 Oct - 28 Oct	30.70	17.40	90.00	42.00	0.00
44	29 Oct - 04 Nov	29.20	20.90	85.00	63.00	0.00
45	05 Nov- 11 Nov	29.00	16.60	85.00	43.00	0.00
46	12 Nov- 18 Nov	28.70	21.60	86.00	73.00	0.30
47	19 Nov- 25 Nov	28.10	20.60	96.00	67.00	2.30
48	26 Nov- 02 Dec	28.10	17.10	83.00	52.00	0.00
49	03 Dec-09 Dec	29.40	16.40	89.00	46.00	0.00
50	10 Dec-16 Dec	27.70	16.90	91.00	55.00	0.00
51	17 Dec - 23 Dec	27.40	9.60	87.00	32.00	0.00
52	24 Dec - 31 Dec	29.20	14.10	91.00	48.00	0.00
1	1 Jan - 7 Jan	27.90	14.10	91.00	53.00	0.00
2	8 Jan - 14 Jan	28.60	18.50	91.00	56.00	0.70
3	15 Jan - 21 Jan	28.20	15.40	91.00	51.00	0.00
4	22 Jan - 28 Jan	29.20	14.30	81.00	42.00	0.00
5	29 Jan - 4 Feb	30.90	12.10	76.00	25.00	0.00
6	5 Feb - 11 Feb	30.10	14.70	87.00	37.00	0.00
7	12 Feb - 18 Feb	30.10	15.80	86.00	40.00	0.00
8	19 Feb - 25 Feb	32.40	14.90	83.00	38.00	0.00
9	26 Feb - 4 March	33.50	15.00	84.00	43.00	0.00
10	5 March – 11 March	33.30	17.40	82.00	51.00	0.00
Total		921.70	572.40	2762.00	1734.00	70.70
Mean		29.73	18.46	89.10	55.94	2.28

Recording of Data (as per the standard weeks)

In each planting, the entire field of DHM 117 maize hybrid was divided into three replications, with each replication comprising three crop rows. Every week in each plot, observations were recorded for calculating the percentage of plants that were infested, the number of egg masses per plant, and the number of larvae per plant. Later, the results were correlated to weather variables.

$$\text{Percent plant infestation} = \frac{\text{Infested plants}}{\text{Plants in Total}} \times 100$$

Statistical analysis

The influence of dates of planting on FAW incidence was assessed by using the statistical software OPSTAT. The larval count/plant and egg masses/plant have been converted into square root and angular transformed values, respectively. Further, the incidence of FAW was correlated to weather parameters and a regression equation was formed by using the same statistical software.

Results and Discussion

Infestation of fall armyworm on maize hybrid DHM 117

First-sown crop had significantly lower average FAW infestation (36.78%). The infestation of FAW on the second and sixth planting dates was 68.28% and 70.61%, respectively. However, the highest infestation was recorded on the fourth planting date *i.e*,10th November 2021 (87.72%) and was followed by the third (86.61%), and fifth planting dates (84.30%) which were sown on 23rd October and 24th November of 2021, respectively (Table 2).

Table 2: Effect of different planting dates on the incidence of fall armyworm

Dates of planting	Mean values of FAW incidence on maize hybrid DHM 117		
	C(A)- Percent Infestation	C(B)- Larvae/plant	C(C)- Egg mass/plant
D1 (02/08/21)	36.78	0.12 (1.05)	0.04 (1.13)
D2 (17/08/21)	68.28	0.28 (1.13)	0.06 (1.43)
D3 (23/10/21)	86.61	0.21 (1.10)	0.06 (1.40)
D4 (10/11/21)	87.72	0.15 (1.07)	0.05 (1.26)
D5 (24/11/21)	84.30	0.14 (1.06)	0.04 (1.18)
D6 (04/12/21)	70.61	0.11 (1.05)	0.04 (1.23)

1. C- Column
2. NS- Non-significant
3. Figures in the parenthesis of columns C(B) and C(C) are square root transformed values and angular transformed values, respectively

Larval incidence on maize hybrid DHM 117

The mean number of FAW larvae per plant on the maize sown in the 1st fortnights of August and December was found to be significantly lower *i.e*., 0.12 & 0.11, respectively (Table 2). The larvae per plant were moderately higher in maize sown at the 1st and 2nd fortnights of November (0.15 & 0.14, respectively). The highest larvae per plant was observed in the maize sown during 2nd fortnight of August (0.28) and was followed by the maize sown on 2nd fortnight of October (0.21).

Fecundity of fall armyworm on maize hybrid DHM 117

The mean egg mass of FAW per plant was found to be the lowest in the maize sown in the 1st fortnight of August, the 2nd fortnight of November, and the 1st fortnight of December (0.04) (Table 2). Significantly, the highest egg mass per plant was recorded on the 2nd fortnight of August (0.063) and was followed by the 2nd fortnight of October (0.06) and the 1st fortnight of November (0.05).

Correlation between weather parameters & FAW infestation on maize hybrid DHM 117 (Table 3)

At various planting dates, the incidence of FAW has been correlated with weather variables, and it was evident that on the first planting, *i.e*, the 1st fortnight of August, the only factor that had a positive influence on FAW infestation was the maximum temperature (0.183), whereas the rainfall was having a negative effect on the population of FAW (-0.474). However, a significant negative impact was noticed in cases of minimum temperature, RH-I and RH-II (-0.728**, -0.831**, and -0.777**). A similar pattern was seen in the second planting of DHM 117 (2nd fortnight of August), with a positive correlation coefficient value (r) for maximum temperature (0.370) and negative for minimum temperature (-0.728**), RH-I (-0.807**), RH-II (-0.643*), and rainfall (-0.476), respectively. And a non-significant correlation was reported for all factors on the third (2nd fortnight of October) and fifth (2nd fortnight of November) plantings of the DHM 117 hybrid, having correlation values of -0.310, -0.525, 0.236, -0.341, and -0.074 in the third sown and 0.347, -0.169, -0.348, -0.222, and -0.002 in the fifth sown, respectively, for the maximum temperature, minimum temperature, rainfall, and relative humidity. In contrast to other plantings, the third planting done on the 2nd fortnight of October, FAW infestation showed an adverse relation with maximum temperature (-0.310), but a positive association for RH-I (0.236). For the first fortnight of the November sown crop (4th planting), the values of correlation for maximum and minimum temperature, RH-I, RH-II and rainfall had been calculated as 0.381, -0.576*, -0.505, -0.621* and -0.921**, with minimum temperature, RH-II, and rainfall having significant association with FAW infestation on the DHM 117 hybrid. In the first fortnight of the December sown crop (6th planting), the r values for maximum temperature, minimum temperature, RH-I, RH-II, and rainfall were found to be -0.370, -0.525, 0.236, -0.341, and -0.074, respectively. However, a significant correlation was observed only in the case of maximum temperature, which showed a positive correlation (0.671*). The findings of the multiple regression test showed that weather variables contributed to 90, 94, 40, 88, 24, and 52% of the overall variance in FAW infestation in DHM 117 maize hybrid in each of the 6 plantings, respectively.

Lavan Kumar (2020) [9] reported that the incidence of FAW started 12 days after planting and persisted throughout the crop growth. He noticed a significant and negative correlation between FAW incidence and rainfall in both early and late-sown maize crop, Conversely, for mid-sown crops, there was a substantial negative correlation between FAW incidence and the RH-I & RH-II, which further supports the present findings. Whereas in the mid-sown crop, RH-I and RH-II showed a significant negative correlation, which supports current findings. The findings aligned with the results of Manohar (2020) [10], indicating that there was a considerable positive correlation (r= 0.581*) between maximum temperature and the infestation of FAW. Conversely, both RH-I (r= -0.507) and RH-II (r= -0.410) demonstrated insignificant negative correlations. Rajisha et al. (2020) [11] observed results consistent with the present study, showing a non-significant positive relationship (r = 0.127) between FAW population and maximum temperature. Moreover, they identified a significant negative correlation with RH-II (r = -0.714) and rainfall (r = -0.763). Anil (2021) [12] also found similar results, demonstrating that RH-II and rainfall showed a non-significant negative association (r = -0.410 and r = -0.530, respectively) with FAW infestation. On the other hand, FAW infestation exhibited a significant but positive correlation with maximum temperature (r = 0.780). In their study, Reddy et al. (2020) [13] noted that there was no significant positive relationship between maximum temperature and FAW damage. However, they found that relative humidity and rainfall exhibited non-significant negative correlations with FAW infestation during the *kharif* season of 2019. During *rabi*, 2019–20, relative humidity and FAW infestation were found to be strongly negatively correlated, which supports the present study.

Table 3: Correlation and regression analysis between fall armyworm infestation on maize cultivar DHM 117 and weather parameters at different dates of planting

Different dates of planting	r values					Regression equation	Coefficient of determination (R^2)
	Max. Temp(X_1)	Min. Temp(X_2)	R.H I (X_3)	R.H II (X_4)	Rainfall (X_5)		
1st planting (02/08/21)	0.183	-0.728**	-0.831**	-0.777**	-0.474	$Y= 569.66- 5.60X_1-1.85X_2- 2.57X_3- 1.20X_4- 0.71X_5$	0.90
2nd planting (17/08/21)	0.370	-0.664*	-0.807**	-0.643*	-0.476	$Y= 57.14+23.43 X_1 -13.05X_2 - 6.18X_3+ 2.45X_4- 0.38X_5$	0.94
3rd planting (23/10/21)	-0.310	-0.525	0.236	-0.341	-0.074	$Y= 14.62+ 2.14X_1-7.19X_2+ 0.80X_3+ 1.13X_4+ 2.47X_5$	0.40
4th planting (10/11/21)	0.381	-0.576*	-0.505	-0.621*	-0.921**	$Y= -62.56+ 3.93X_1+ 0.48X_2+ 0.48X_3- 0.13X_4- 28.66X_5$	0.88
5th planting (24/11/21)	0.347	-0.169	-0.348	-0.222	-0.002	$Y= 116.89+ 4.52X_1-5.07X_2- 1.71X_3+ 1.29X_4+ 22.47X_5$	0.24
6th planting (4/12/21)	0.671*	-0.050	-0.549	-0.413	-0.210	$Y= -122.48+ 6.05X_1+ 0.95X_2+ 0.43X_3-0.89X_4- 2.29X_5$	0.52

* Indicates correlation is significant at 5% (p=0.05)

** Indicates correlation is significant at 1% (p=0.01); r = correlation coefficient

Correlation between weather parameters & population dynamics of FAW larvae on maize hybrid DHM 117 (Table 4)

It was evident from the data that the larval incidence of FAW was influenced by the weather parameters observed at different planting dates. The data clearly showed that during the first date of planting (in the 1st fortnight of August), the larval population of FAW was positively influenced by the maximum temperature with a correlation coefficient of 0.409, whereas the minimum temperature and RH-I were having a negative effect on the larval population of FAW (-0.341 and -0.485, respectively). In the case of RH-II and rainfall, a significant negative correlation was observed, with coefficients of -0.695** and -0.653* respectively. The parameters examined during the second, third, fourth, fifth, and sixth planting dates did not demonstrate any significant correlation. The correlation coefficients values are as follows: Second planting date (2nd fortnight of August): 0.533 (maximum temperature), -0.291 (minimum temperature), -0.135 (RH-I), -0.410 (RH-II), and -0.124 (rainfall). Third planting date (2nd fortnight of October): 0.068 (maximum temperature), -0.034 (minimum temperature), 0.037 (RH-I), -0.103 (RH-II), and -0.299 (rainfall). Fourth planting date (1st fortnight of November): 0.301 (maximum temperature), -0.129 (minimum temperature), -0.342 (RH-I), -0.185 (RH-II), and -0.387 (rainfall). Fifth planting date (2nd fortnight of November): 0.031 (maximum temperature), -0.159 (minimum temperature), -0.485 (RH-I), -0.383 (RH-II), and -0.196 (rainfall). Sixth planting date (1st fortnight of December): 0.024 (maximum temperature), -0.284 (minimum temperature), -0.454 (RH-I), -0.437 (RH-II), and -0.288 (rainfall). During the 1st, 2nd, 3rd, 4th, 5th, and 6th plantings, weather parameters played a significant role in contributing 62%, 44%, 28%, 34%, 43%, and 37% of the overall variability in FAW incidence on maize cultivar DHM 117.

Similar results were observed in a study by Madhubhasini (2021) [14], where the findings were consistent with the present study. Madhubhasini found a significant negative correlation (r = -0.549) between the FAW larval population and minimum temperature, as well as with total rainfall (r = -0.548). Warkad et al. (2021) [15] observed similar outcomes, finding that the larval population of FAW exhibited a strong positive correlation with maximum temperature (r= 0.694). Conversely, they discovered significant negative correlations between the larval population and RH-I (r= -0.799) as well as RH-II (r= -0.664). In agreement with Madhu Kumari (2020) [16], it was observed in the current study that there existed a significant positive correlation (r= 0.516*) between the FAW population and maximum temperature in the 2019 *kharif* season, However, relative humidity exhibited a significant negative correlation of -0.519*. Nandita Paul's study (2020) [17] revealed that the FAW larval population showed a negative correlation with RH-II (r = -0.233) and total rainfall (r = -0.320). In contrast, there was a significant and positive correlation between the larval population and maximum temperature (r = 0.586). The findings of Darshan's study (2020) [18] also supported that the presence of FAW larvae during the *kharif* and *rabi* seasons of 2019-20 was positively influenced by maximum temperature, while rainfall and relative humidity exhibited a negative correlation. Kumar et al. (2020) [19] documented a significant positive correlation (r= 0.720) between FAW larval population and maximum temperature, while also observing significant negative correlations with relative humidity (r= -0.673) and rainfall (r= -0.829). These findings align with the current study.

Table 4: Correlation and regression analysis between fall armyworm larval population per plant on maize cultivar DHM 117 and weather parameters at different dates of planting

Different dates of planting	r values					Regression equation	Coefficient of determination (R^2)
	Max. Temp(X_1)	Min. Temp(X_2)	R.H I (X_3)	R.H II (X_4)	Rainfall (X_5)		
1st planting (02/08/21)	0.409	-0.341	-0.485	-0.695**	-0.653*	$Y= 0.689- 0.013X_1+ 0.003X_2+ 0.001X_3- 0.004X_4- 0.005X_5$	0.62
2nd planting (17/08/21)	0.533	-0.291	-0.135	-0.410	-0.124	$Y= -2.657+ 0.128X_1-0.059X_2- 0.002X_3+ 0.009X_4+ 0.001X_5$	0.44
3rd planting (23/10/21)	0.068	-0.034	0.037	-0.103	-0.299	$Y= -1.116- 0.039X_1+ 0.060X_2+ 0.025X_3- 0.015X_4- 0.207X_5$	0.28
4th planting	0.301	-0.129	-0.342	-0.185	-0.387	$Y= -0.833+ 0.054X_1-0.021X_2-$	0.34

(10/11/21)						$0.009X_3$+ $0.011X_4$- $0.059X_5$	
5th planting (24/11/21)	0.031	-0.159	-0.485	-0.383	-0.196	Y= 2.440- $0.036X_1$+ $0.027X_2$- $0.017X_3$ -$0.004X_4$- $0.133X_5$	0.43
6th planting (4/12/21)	0.024	-0.284	-0.454	-0.437	-0.288	Y= 1.857- 0.026 X_1+ $0.016X_2$- $0.012X_3$ -$0.003X_4$- $0.134X_5$	0.37

* Indicates correlation is significant at 5% (p=0.05)
** Indicates correlation is significant at 1% (p=0.01)

Correlation between weather parameters on the fecundity of FAW on maize hybrid DHM 117 (Table 5)

A correlation was observed between the weather parameters and the fecundity of FAW on DHM 117. The parameters examined during the first (1st fortnight of August), third (2nd fortnight of October), fourth (1st fortnight of November), fifth (2nd fortnight of November), and sixth planting dates (1st fortnight of December) did not demonstrate any significant correlation, with correlation values of -0.031, -0.314, -0.465, -0.420, and -0.425 for maximum temperature, lowest temperature, RH-I, RH-II, and rainfall on the first date of planting. Then the r values for the third date of planting (-0.304, -0.305, -0.256, -0.198 & -0.372) fourth date of planting (-0.193, 0.229, 0.209, 0.281 & -0.293), in the fifth date of planting (-0.350, -0.413, 0.192, -0.215 & -0.322) and in the sixth date of planting (-0.302, -0.329, -0.153, -0.290 & -0.292), respectively. Here almost all the weather parameters on different dates of planting were negatively correlated with the fecundity of FAW. Except on the second planting date (2nd fortnight of August), maximum temperature (0.280) showed a positive influence on FAW fecundity, whereas the remaining 4 weather variables had significant and negative correlations, (minimum temperature -0.691**, RH-I -0.699**, RH-II -0.768** and rainfall -0.662* respectively). The findings of the multiple regression test showed that weather variables contributed to 49, 77, 32, 40, 53, and 38% of the overall variance in FAW egg laying on DHM 117 maize hybrid in each of the 6 plantings, respectively.

Gedia *et al.* (2007) [20] observed results consistent with the current findings, revealing a notable negative correlation between *S. litura* egg masses and rainfall (-0.482 and -0.468, respectively) for the years 2003 and 2004. Perhaps the heavy rainfall wiped away the egg masses. This might be due to the fact that the egg stage was the most vulnerable to heat shock and temperature fluctuations, resulting in reduced egg hatching. He also confirmed that between 2003 and 2004, minimum temperature (r= -0.026 & r= -0.237) and RH-II r= (-0.102 & r= -0.048) were negatively correlated with the fecundity of *S. litura*. Sunitha et al. (2021) [21] documented similar results, revealing a significant negative correlation (r= -0.081) between RH-I and the fecundity of fall armyworm, which is line with the present findings. At the increased RH levels, eggs could drown or become infected more easily by pathogens.

Table 5: Correlation and regression analysis between fall armyworm egg mass per plant on maize cultivar DHM 117 and weather parameters at different dates of planting

Different dates of planting	r values					Regression equation	Coefficient of determination (R^2)
	Max. Temp(X_1)	Min. Temp(X_2)	R.H I (X_3)	R.H II (X_4)	Rainfall (X_5)		
1st planting (02/08/21)	-0.031	-0.314	-0.465	-0.420	-0.425	Y= 0.695- $0.018X_1$+ 0.005 X_2- $0.001X_3$- $0.002X_4$- $0.002X_5$	0.49
2nd planting (17/08/21)	0.280	-0.691**	-0.699**	-0.768**	-0.662*	Y= 0.507+ $0.004X_1$-0.012 X_2- $0.003X_3$- $0.001X_4$-$0.004X_5$	0.77
3rd planting (23/10/21)	-0.304	-0.305	-0.256	-0.198	-0.372	Y= 0.731 -$0.016X_1$ -0.005 X_2 -$0.002X_3$+ 0.001 -0.013	0.32
4th planting (10/11/21)	-0.193	0.229	0.209	0.281	-0.293	Y= 0.003 -$0.001X_1$+ 0.004 X_2 -$0.001X_3$+ $0.002X_4$ -$0.050X_5$	0.40
5th planting (24/11/21)	-0.350	-0.413	0.192	-0.215	-0.322	Y= -0.166- $0.005X_1$+ $0.001X_2$+ $0.005X_3$-$0.003X_4$- $0.034X_5$	0.53
6th planting (4/12/21)	-0.302	-0.329	-0.153	-0.290	-0.292	Y= 0.601- $0.012X_1$+ $0.005X_2$- $0.003X_3$-$0.001X_4$- $0.059X_5$	0.38

* Indicates correlation is significant at 5% (p=0.05)
** Indicates correlation is significant at 1% (p=0.01);

Conclusion

The correlation and regression analysis showed that the FAW infestation on maize, the larval population, and eggs laid depend on the weather prevailing during the crop growth period. The results of present research found that the FAW fecundity was negatively impacted by all five weather variables. With respect to plant infestation and larvae population, maximum temperature had a positive influence, while the remaining four weather factors exhibited a negative impact.

Future scope

The present work provides knowledge for developing forecasting models and early warning systems for timely management of fall armyworm.

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Conflict of Interest: None

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