ANSF APPLIED AND NATURAL SCIENCE FOUNDATION

Journal of Applied and Natural Science
15(2), 844 - 851 (2023)
ISSN : 0974-9411 (Print), 2231-5209 (Online)
journals.ansfoundation.org

Research Article

Studies on the relationship of weather on Fall armyworm damage in maize (*Zea mays L.*) under different growing environments

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Article Info
https://doi.org/10.31018/jans.v15i2.4635
Received: April 14, 2023
Revised: June 5, 2023
Accepted: June 11, 2023

How to Cite
Haroli, M. *et al.* (2023). Studies on the relationship of weather on Fall armyworm damage in maize (*Zea mays L.*) under different growing environments. *Journal of Applied and Natural Science*, 15(2), 844 - 851. https://doi.org/10.31018/jans.v15i2.4635

Abstract
Fall armyworm is a recently occurring invasive pest in India, the most important defoliator causing drastic damage to maize production. Hence, the present study aimed to understand the temporal infestation level of Fall armyworms on maize (*Zea mays* L.) with weather patterns. Field experiments were conducted during Summer (February-May) and Rainy seasons, 2022 (August -December) at Agro Climate Research Centre, Tamil Nadu Agricultural University, Coimbatore. Three different growing environments (GE_1, GE_2 and GE_3) were created by providing staggered sowing. Regression models were developed for per cent leaf damage against three-days lagged (LT_3) and seven-day lagged (LT_7) weather variables. Results showed that irrespective of growing environments, weather variables showed negative correlation (Tmax: r = -0.57, -0.81*, -0.31; SSH: -0.30, -0.48, -0.39; Tmean: -0.49, -0.23, -0.30; and SR: -0.48, -0.94*, -0.40) during summer season whereas same variables (*i.e* Tmax =0.62*, 0.41, 0.33; SSH = 0.09, 0.68*, 0.24; Tmean = 0.29, 0.32, 0.44; and SR=0.13, 0 .67*, 0.26) showed a positive correlation with PLD. Rainfall exhibits positive relation (0.06, 0.54, 0.53) and negative correlation (-0.64*, -0.10, -0.02) during summer and rainy season, respectively. Among the regression models, LT_7 model had higher R^2 (0.65 and 0.76) than LT_3 (0.57 and 0.68) during summer and rainy seasons, respectively. These models had good regression values of 0.56 and 0.70 during Rainy and Summer, respectively. It was concluded that Tmax (32.9 °C), Tmin (23.7 °C), Tmean (28.3 °C), RH-I (85.6%), RH-II (56.4%), SSH (4.1), SR (274.6 cal cm^{-2} m^{-2}), afternoon cloud cover (4.8 okta) and weekly total rainfall (10.2 mm) were very conducive for the greater leaf damage.

Keywords: Correlation, Fall armyworm, Maize, Per cent leaf damage, Regression

INTRODUCTION

Maize (*Zea mays* L.), is one of the important cereal crops which stands first concerning production (1,141 million tonnes) in the World, grown in an area of 196.35 m.ha with a productivity of 5813 kg/ha. It is cultivated mainly in USA, China, Brazil, Argentina, Ukraine and India. In India, it is grown over an area of around 9.86 million hectares with a production of 31.51 million tonnes and a productivity of 3195 kg/h which is far below world average productivity (Anonymous, 2021). Predominant maize-growing states in India are Karnataka, Madhya Pradesh, Maharashtra, Tamil Nadu and West Bengal. Among these, Tamil Nadu occupies an area of 0.44 million hectares with production of 4.04 million tonnes and a productivity of 6702 kg/ha above national and global average yield (Anonymous, 2021). Ariyalur, Perambalur, Dindigul, Pudukkottai, Namakkal and Coimbatore are the major Maize-growing districts of Tamil Nadu. It is an important crop not only in terms of acreage but also in context to its versatility for adoption under a wide range of soil, biodiversity and agro-climatic conditions.

There are four major maize pests such are spotted stem borer [*Chilo partellus* (Swinhoe)], pink stem borer (*Sesamia inferens* Walker), shoot fly (*Atherigona* spp.) and the recent invasive pest fall armyworm [*Spodoptera frugiperda* (J. E. Smith)]. Fall armyworm (FAW) *Spodoptera frugiperda* (J. E. Smith) (Lepidoptera: Noctuidae), is an invasive alien pest that attacks mainly maize crop. This polyphagous pest damages around 80 species, such as rice, maize, sorghum, beans, cotton and many more. They mainly feed on leaf whorls, tassels, ears and cobs of maize, resulting in yield loss. According to the recent studies, fall armyworm can cause yield losses ranging from 8.3 to 20.6 million tonnes of maize per year in the absence of management practices. It is native to America and first reported in West Africa in late 2016 as invasive pest (Goergen *et al.,* 2016) and later in Sub-Saharan Africa. It was first reported on maize in India from Shivamogga district (Karnataka) during May-June 2018 (Kalleshwaraswamy *et al.,* 2018). The occurrence of this pest in the Indian sub-continent has thrown a challenge to maize production due to its rigorous feeding behaviour on foliage and cob, leading to decreased yield levels and increased cost of cultivation for maize growers in the country.

Fall armyworm (*Spodoptera frugiperda*) is one of the most important defoliators, which can cause vigorous leaf damage leaving only midrib (Anjorin *et al.,* 2022). The abiotic factors such as temperature, rainfall, solar radiation, sunshine hours, humidity, cloud cover *etc.,* influence crop production, directly affecting plant physiology, transpiration causing freezing injury, heat stress, water and nutrient uptake *etc*. and indirectly by means creating a favourable environment for pest and disease occurrence (Rodziewicz *et al.,* 2014; Pandey *et al.,* 2017; Khalid *et al.,* 2019). The fall armyworm exhibits continuous generational activity throughout the year in tropical and subtropical climates (Prasanna *et al.,* 2018), So the FAW larvae experience various weather patterns in the subtropical climate of India. Hence, the study was conducted to study the relationship between weather patterns and FAW damage in maize production.

MATERIALS AND METHODS

The field experiments were conducted during the Summer 2022 (February to May 2022) and Rainy season 2022 (August 2022 to December 2022) at Agro Climate Research Centre, Tamil Nadu Agricultural University, Coimbatore. The experiments were conducted so that the cropping period must coincide with all the weather patterns such as rainy period, dry and hot weather, hot and humid, and cooler weather, so that various weather patterns' impact on the FAW infestation can be examined.

By providing staggered sowing windows, three different growing environments (GE) were created for the maize crop in both seasons. During the summer season sowing for the first growing environment (GE_1) was carried out on 17th Feb 2022 (7th SMW), for the second growing environment (GE_2), sowing was taken out on 4th March 2022 (9th SMW) and for the third growing environment (GE_3), it was carried out on 19th March 2022 (12th SMW). Similarly, during the rainy season, sowings were done on 24th Aug 2022(34th SMW), 12th Sept 2022 (37th SMW) and 26th Sept 2022 respectively. This helped to create different environmental conditions to facilitate the prevalence or diminution of Fall Armyworm damage.

The abundance of FAW adult and larval infestation significantly varied with crop phenology, with infestation being high at the vegetative and reproductive stages of the crop, and low at the maturity stage (Niassy *et al.,* 2021). Quantifying pest load in the case of maize fall armyworm is very difficult, time-consuming and not accurate to assess the exact damage caused to the plant. The only first and second instar larvae will be predominant during the initial 20 to 25 days of the sown crop (VE to V3 stage), later instar larvae start to move towards whorl and hide there and cause damage to every emerging leave from the whorl up to V14 stage of the crop. During the V5 to R3 (Milking) crop period, all the stages of the fall armyworm, i.e., egg, larvae and adult, can be seen in correspondence with the weather. The early first and second instar larvae are usually higher in number, less damaging and easily perishable in nature during unpleasant weather. Later, 4th to 6th instar larvae cause heavy damage even in lesser numbers. The study used per cent leaf damage in this connection, which seems more reliable in finding weather and fall armyworm relation.

Agrometeorological observatory data like rainfall (RF), maximum temperature (Tmax), minimum temperature (Tmin), morning relative humidity (RH I), after relative humidity (RH II), solar radiation (SR), afternoon cloud cover (CC II) *etc.,* recorded daily at 7.30 am IST and 2.30 pm IST were collected from the Agro Climate Research Centre, Tamil Nadu Agricultural University, Coimbatore.

Fall Armyworm damage assessment

Assessment of leaf damage (defoliation by FAW) caused by Fall armyworm were calculated from randomly selected 25 plants in a zig-zag manner at weekly interval during the cropping period. The data were recorded from 10 to 60 days after sowing (DAS) using the Davis 0 to 9 whorl and furl method (Table 1) and Williams whole plant assessment method (Toepfer *et al.,* 2021). Davis scale provided weekly dynamic damage assessment of fresh whorl of the leaves, which is more suitable and realistic in studying weather and the insect relationship.

Per cent leaf damage (%)

The per cent damage of plant leaves was calculated as a percentage ratio of the total sum of the scores measured to the multiplied value of the total number of plants observed and the maximum score assigned for the method (Eq. 1). It is expressed in percentage. In the Davis and Williams method (1992), the maximum assigned score for leaf damage is 9.

Statistical analysis

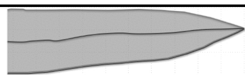
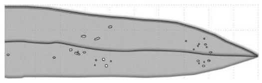
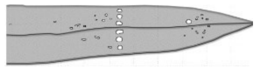
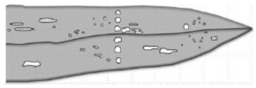
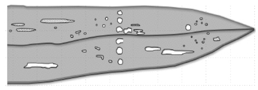
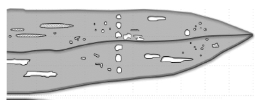
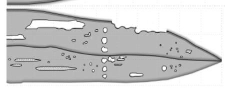
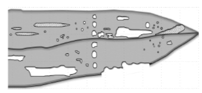
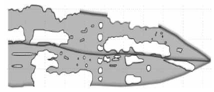
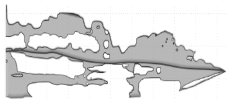
Correlation and multiple regression studies were carried out using SPSS software for leaf damage against the weather variables. Here lead time concept, was used to understand the association or interrelation between per cent leaf damage and varying intervals of weather variables. The three days lead time (LT_3) means the data on agrometeorological variables collected at prior to three days interval were regressed against the per cent leaf damage values collected on the corresponding days and similarly seven days lead time (LT_7) means the previous seven days weather data collected were regressed against the per cent leaf damage values collected. Lead time concept was first introduced by Venkatesh *et al.,* to predict grape diseases. It was adopted by Balikai and Venkatesh (2019) to predict sorghum pests; and Mahesh and Venkatesh (2019) to study the pod borer damage in soybean.

RESULTS AND DISCUSSION

Correlation with weather variables

The correlation analysis performed between weekly per

Table 1. Original and simplified Davis 0 to 9 whorl and furl damage scale for the Fall armyworm (leaf whorl and furl assessed)

Score	Seven-day ratings (Davis *et al.*)	
0	No visible damage	
1	Pinholes and circular lesions present on whorl leaves	
2	Pinholes, small circular lesions present on whorl leaves	
3	Pinholes, small circular lesions and a few small elongated (rectangular-shaped) lesions of up to 1.3 cm (1/2") in length present on whorl and furl leaves	
4	Small elongated lesions present on whorl leaves and a few mid-sized elongated lesions of 1.3 to 2.5 cm (1/2-1") in length on whorl and/or furl leaves	
5	Small elongated lesions and several mid-sized elongated lesions present on whorl and furl leaves	
6	Small and mid-sized elongated lesions plus a few large elongated lesions of greater than 2.5 cm (1") in length present on whorl and/or furl leaves	
7	Many small and mid-sized elongated lesions present on whorl leaves plus several large elongated lesions present on the furl leaves	
8	Many small and mid-sized elongated lesions present on whorl leaves plus many large elongated lesions present on the furl leaves	
9	Many elongated lesions of all sizes on most whorl and furl leaves plus a few uniform to irregular shaped holes (basement membrane consumed) eaten from the base of whorl and/or furl leaves	

cent leaf damage (PLD) caused by Fall Armyworm and the previous week's weather variables is given in Table 2. To facilitate the incidence and better understanding of weather variables, maize was grown in three growing environments (GE1, GE2 and GE3) created by fifteen days interval sowing during summer and rainy seasons. Irrespective of growing environments, weather variables showed negative correlation (Tmax: r = -0.57, -0.81*, -0.31; SSH: -0.30, -0.48, -0.39; daily mean temperature -0.49, -0.23, -0.30; and solar radiation -0.48, -0.94*, -0.40) during summer season whereas variables (i.e Tmax =0.62*, 0.41, 0.33, SSH = 0.09, 0.68*, 0.24 Tmean = 0.29, 0.32, 0.44 and SR=0.13, 0 .67*, 0.26) showed positive correlation with PLD. The minimum temperature (Tmin) was having positive correlation (0.78*, 0.36, 0.21) in all summer growing environments but in rainy season, it had a negative correlation in GE_1 (-0.67*) and GE_3 (-0.34) except GE_2 (0.16) which had a positive correlation. The morning (Relative Humidity - RHI) and afternoon (Relative Humidity - RHII) relative humidity were found to be positively correlated with the per cent leaf damage in both summer and rainy seasons across all growing environments except in rainy season GE_1 (RHI = -0.13, RHII = 0.66*).

The rainfall (RF) exhibited a positive correlation (0.06, 0.54, 0.53) during the summer season and a negative correlation (-0.64*, -0.10, -0.02) in the rainy season under all growing environments (GE). Afternoon cloud cover (CCII) showed a positive correlation among both the seasons and growing environments except in GE_3 (-0.17). Wind speed was found to be negatively correlated in both summer and rainy except for the GE_3 summer season.

Temporal variation of per cent leaf damage with maximum temperature, sunshine hours and rainfall

The correlation studies between per cent leaf damage and some weather variables may not show a significant correlation even though short-term variation in such weather variables greatly impacts the leaf damage. The temporal variation of weekly per cent leaf damage throughout the cropping period were analysed graphically for varying previous week weather parameters like weekly average maximum temperature, summer sunshine hours, and rainfall for rainy season growing environments.

The sharp rise in the per cent leaf damage (PLD) value during the summer season from 30.6 % to 67.4 % in

Table 2. Correlation between per cent leaf damage and previous week weather variables in maize grown under different growing environments (GE_1, GE_2, GE_3) and seasons

	SUMMER SEASON			RAINY SEASON		
	GE_1	**GE_2**	**GE_3**	**GE_1**	**GE_2**	**GE_3**
Tmax	-0.57	-0.81*	-0.31	0.62*	0.41	0.33
Tmin	0.76*	0.36	0.21	-0.67	0.16	-0.34
RH I	0.78*	0.35	0.04	-0.13	0.66	0.26
RH II	0.55	0.84**	0.48	-0.66	0.58	0.64*
WS	-0.76*	-0.10	0.06	-0.11	-0.85*	-0.75*
SSH	-0.30	-0.48	-0.39	0.09	0.68*	0.24
Tmean	-0.49	-0.23	-0.30	0.29	0.32	0.44
SR	-0.48	-0.94**	-0.40	0.13	0.67*	0.26
CCII	0.20	0.62	0.33	0.12	0.58	-0.17
RF	0.06	0.54	0.53	-0.64*	-0.10	-0.02

CCs significant at 5% level*, CCs significant at 1% level**

Table 3. The Maximum increase in weekly per cent leaf damage in maize grown under different growing environments and seasons

		PLD (%)	**Tmax (°C)**	**Tmin (°C)**	**RH I (%)**	**RH II (%)**	**SSH (hours)**	**Tmean (°C)**	**SR cal/cm²/m²**	**CCII (okta)**	**RF (mm)**
Summer Season	GE_1	15.20	34.9	23.4	86.9	44.7	6.3	29.1	350.9	4.2	9.2
	GE_2	36.83	32.9	23.7	85.6	56.4	4.1	28.3	274.6	4.8	10.2
	GE_3	48.24	32.9	23.7	85.6	56.4	4.1	28.3	274.6	4.8	10.2
Rainy Season	GE_1	13.89	31.8	22.5	84.0	51.3	6.1	27.2	272.1	5.0	2.5
	GE_2	14.82	30.9	22.4	85.0	52.6	4.0	26.7	265.1	5.1	15.5
	GE_3	11.33	30.5	22.5	86.6	62.7	5.5	26.5	262.9	4.8	32.5

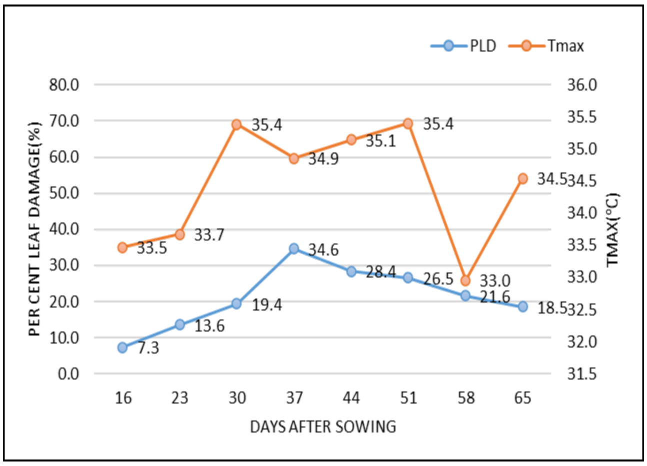


Fig. 1. *Temporal variation of per cent leaf damage vs Maximum Temperature during summer season in GE₁*

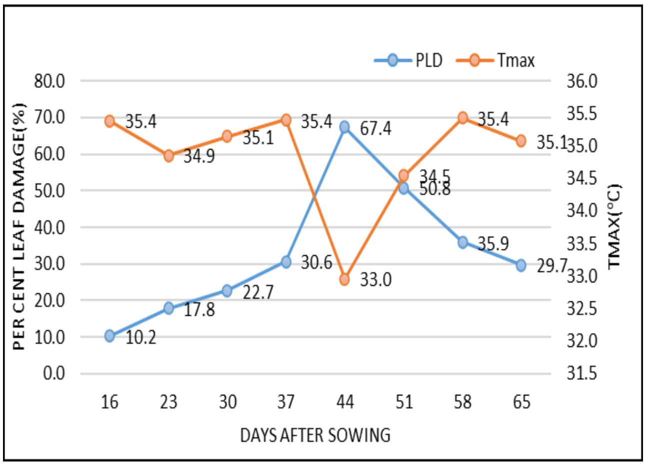


Fig. 2. *Temporal variation of per cent leaf damage vs Maximum Temperature during summer season in* GE_2

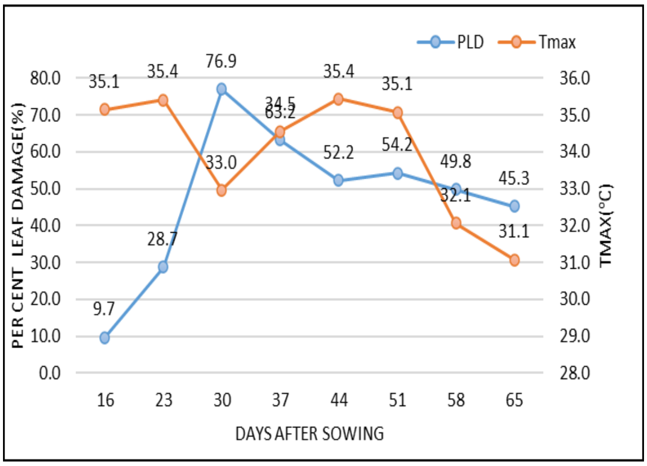


Fig. 3 *.Temporal variation of per cent leaf damage vs maximum temperature during the summer season in* GE_3

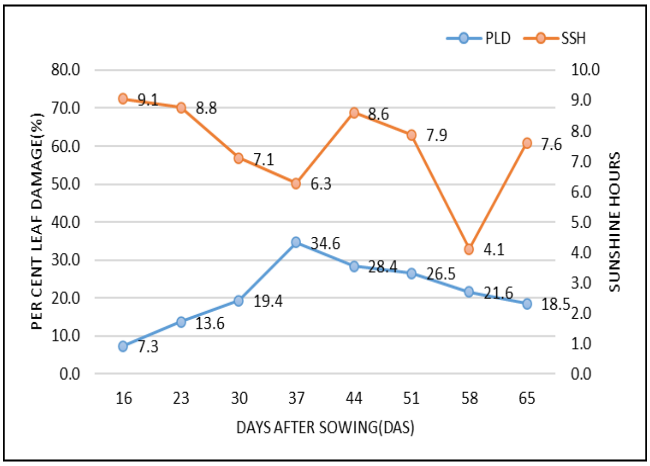


Fig. 4. *Temporal variation of per cent leaf damage vs Sunshine hours during summer season in* GE_1

GE_2 during 37 to 44 DAS and from 28.7 % to 76.9 in GE_3 during 23 to 30 DAS can be noticed in Fig. 2 and Fig. 3 respectively. These sharp rises in PLD are explained due to the decrease in the previous week's average maximum temperature to 33.0 °C from 35.4 °C (Fig. 2 and Fig. 3) and the sudden downfall in the previous week's average sunshine hours to 4.1 hours from 7.9 hours (Fig. 5 and Fig. 6). In contrast, in summer season GE_1 (Fig. 1) there was no increase in the leaf damage rather decreased at 58 DAS, despite a decrease in weekly average temperature and sunshine hours (Fig. 4) at 51 to 58 DAS, it may be due the decrease in the palatability of matured leaves by the fall armyworms. He *et al.* (2021) reported that the early phenological stages of maize proved the most suitable natural diet for FAW growth, development and reproduction. Also, it was mentioned that the palatability of matured leaves decreased by the FAW.

Fig. 7, Fig. 8 and Fig. 9 showed temporal variation of the weekly per cent leaf damage with varying previous week rainfall during rainy season GE_1, GE_2 and GE_3 respectively. During the rainy season in GE_1(Fig. 7), there was no much rainfall from 13 DAS to 48 DAS leading to higher 40.6 per cent leaf damage at 41 DAS than the GE_2(Fig. 8), which was having maximum of 28.3 % leaf damage at 41 DAS because of the 42.5 mm previous week rainfall could be seen from the graph. Similarly, in rainy season GE_3, the 80 mm rainfall from 20 DAS to 34 DAS led to a limit in leaf damage to 25.72 % at 41 DAS.

Favourable weather parameters causing greater leaf damage during the summer and rainy season

The highest weekly per cent leaf damage occurred during the cropping period in all the growing environments of both summer and rainy seasons with respect their previous average weekly weather parameters are tabulated in Table. 3. The maximum weekly leaf damage of 48.24 % at 30 DAS and 36.83 % at 44 DAS occurred in the summer season GE_3 and GE_2, respectively. The associated weekly weather parameters causing the highest leaf damage were *viz.,* Tmax (32.9□), Tmin (23.7□), RH I (85.6%), RH II (56.4%), SSH (4.1), Tmean (28.3□), SR (274.6 cal/cm^2/m^2), afternoon cloud

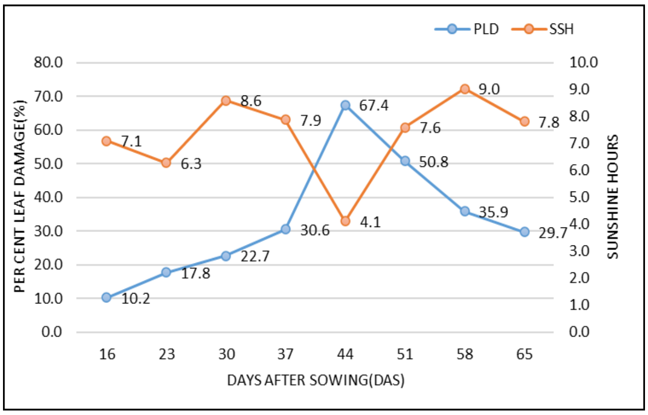


Fig. 5. *Temporal variation of per cent leaf damage vs sunshine hours during the summer season in* GE_2

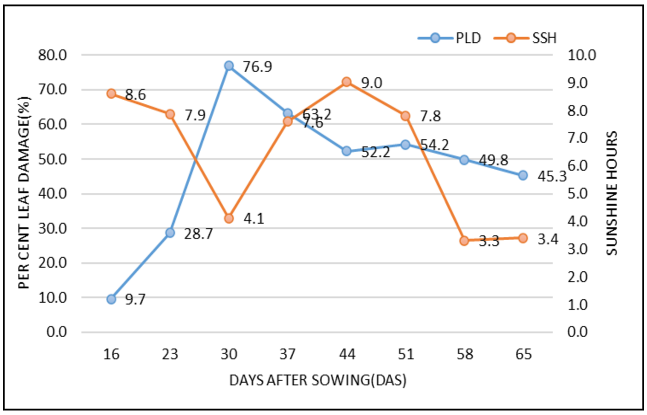


Fig. 6. *Temporal variation of per cent leaf damage vs Sunshine hours during the summer season in* GE_3

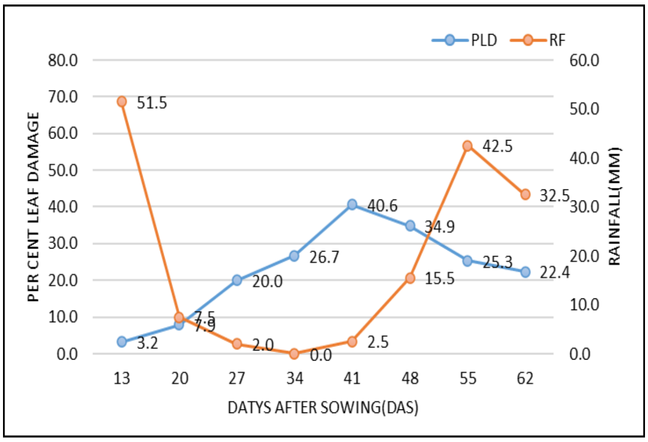


Fig. 7. *Temporal variation of per cent leaf damage vs rainfall during the rainy season in* GE_1

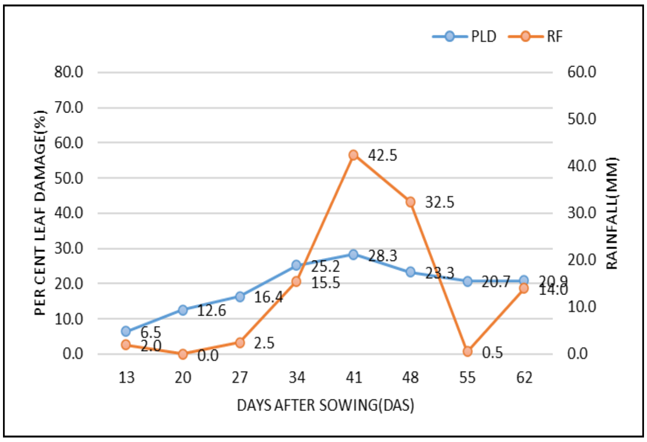


Fig. 8. *Temporal variation of per cent leaf damage vs rainfall during the rainy season in* GE_2

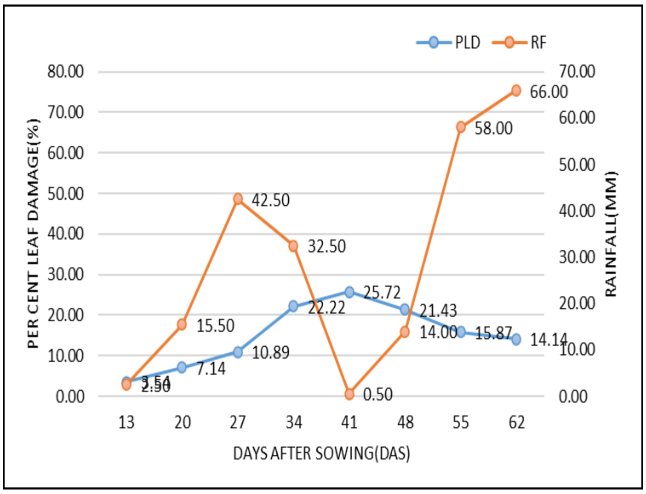


Fig. 9. *Temporal variation of per cent leaf damage vs rainfall during the rainy season in* GE_3

cover 4.8 okta and weekly RF (10.2mm) during the summer season.

He *et al.* (2019) reported that the growth and development of FAW were higher when the mean temperature was 19–30 °C and reached its peak at 29 °C. Its presence decreased when the mean temperature was >30 °C. Prasad *et al.* (2022) reported that temperatures between 27 and 30°C are favourable for *S. frugiperda* development, survival and reproduction and have higher mortality levels above 35°C and below 15 °C.

The activity of insects (development, feeding behaviour, oviposition, emergence from pupae *etc.*) is highly weather sensitive and dynamic. Changes in any one weather variable may alter the insect activity, so above-mentioned favourable weather variables only as a combined effect may cause greater leaf damage. During rainy season growing environments weather parameters like cloud cover, solar radiation and sunshine hours were similar to the above-mentioned summer season favourable parameters. Still, they could not cause higher leaf damage because of the lesser maximum temperature and mean temperature parameters.

Regression models

The regression models were developed for the per cent leaf damage collected in weekly intervals during the summer and rainy seasons separately against the three -days lagged (LT_3) and seven-days lagged (LT_7) average weekly variables (Table 4). Among the models developed during the rainy season LT_7 model have a higher R^2 (0.65) than the LT_3 (0.57) and the combined

Table 4. Regression equations for per cent leaf damage developed by three day lagged (LT_3), seven days lagged (LT_7) and combined in summer and rainy season

Regression equation	R^2	SE	F
Rainy season LT_3 model	0.56	6.72	0.86
Y=33.77+6.052Tmax+ 6.929Tmin+0.082RHI-1.027RHII+1.338SSH+0.06SR+ 5.18CCII +0.116RF			
Rainy seasonLT_7 model	0.65	7.23	0.59
Y= -382.6+12.139Tmax-13.439Tmin+3.641RHI+1.736RHII+5.335WS-8.599SSH+1.236Tmean +0.038SR -22.36CCII-0.38RF			
Rainy season combined LT_3 and LT_7 model	0.57	7.41	0.54
Y=-269.31+19.65Tmin[LT_7]+0.963RHI[LT_7]-0.837RHII[LT_7]+0.842SSH[LT_7]-8.169CCII [LT_7]-1.196 Tmax[LT_3]-5.769min [LT_3]-1.233WS[LT_3]+1.502CCII[LT_3]-14.055AVD[LT_3]-0.298RF[LT_3]			
Summer season LT_3 model	0.68	16.90	2.03
Y= 338.6-10.64Tmax+6.202Tmin-0.303RHII+4.549SSH-0.161SR-13.809CCII+2.979RF			
Summer season LT_7 model	0.76	17.06	1.83
Y=70.22-1.734Tmax-0.733RHI+1.348RHII-1.307SSH-2.962Tmean-0.62SR-9.205CCII+ 0.397RF			
Summer season combined LT_3 and LT_7 model	0.70	17.38	1.50
Y=38.57+13.31Tmin[LT_3]+3.48RHI[LT_3]-0.531RHII[LT_3]+1.25WS[LT_3]-2.68CCII[LT_3]-35.43AVD[LT_7]+1.023RF[LT_7] 1.99RHI[LT_7]-11.91Tmean[LT_7]-0.044SR[LT_7]-13.209CCII[LT_7]			

R^2- Regression coefficient; SE- Model standard Error; F- Overall model significance

model of LT_3 and LT_7 (0.56). Similarly, in the summer season models, also LT_7 model had a greater R^2 (0.76) than the LT_3 (0.68) and combined model of LT_3 and LT_7 (0.70). This indicated that variability in the per cent leaf damage caused by fall armyworm was more explained by the seven days lagged weather variables than the three days lagged variables.

Conclusion

The present study concluded that Fall Armyworm is a destructive pest which caused vigorous leaf damage in maize crop during favourable weather conditions. The results obtained from field trials concluded that maximum temperature of 32.9 °C, minimum temperature of 23.7 °C, morning relative humidity of 85.6 %, relative afternoon humidity of 56.4 %, sunshine hours of 4.1, mean temperature of 28.3 °C, solar radiation 274.6 cal/ cm^2/m^2, afternoon cloud cover 4.8 okta and weekly total rainfall of 10.2 mm were found very conducive (that means hot and humid with partly cloudy afternoon) for the vigorous leaf damage. Prior identifying/forewarning this kind of weekly weather patterns may help advise the farming community to take necessary precautions. The regression models indicated that seven days lagged weather variables were found more promising in predicting leaf damage than three days lagged variables. The maximum temperature, sunshine hours and solar radiation had negatively related in summer and positively related in the rainy season. This indicated that insect seek a favourable temperature range to cause greater damage. Similarly, higher rainfall during the rainy season limited damage, whereas smaller rainfall act as an additive for fall armyworm damage in summer.

Conflict of interest

The authors declare that they have no conflict of interest.

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