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The Pharma Innovation

ISSN (E): 2277-7695
ISSN (P): 2349-8242
NAAS Rating: 5.23
TPI 2023; SP-12(8): 95-101

www.thepharmajournal.com
Received: 08-05-2023
Accepted: 19-06-2023

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Seasonal incidence and weather based forewarning models for foliage feeders of groundnut

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Abstract
Field trials were conducted to study the effect of climatic factors on the occurrence of leaf miner, *Aproaerema modicella* (Deventer) and tobacco caterpillar, *Spodoptera litura* (Fabricius) in groundnut for two years *i.e.,* 2016 and 2017 during *kharif* season at the Agricultural Experimental Station, Darsi, Prakasam district from Andhra Pradesh. Data on the seasonal incidence of foliage feeders and their natural enemies were statistically analyzed for individual years and also cumulatively with meteorological factors using correlation and linear regression methods. The correlation studies showed a significant positive relationship between the population of *A. modicella* and *S. litura* larvae with the minimum temperature. The coefficient of determination (R2) was calculated for all climatic factors together that influenced the *A. modicella* larval population by 79.1% during 2016, 78.3% during 2017, and 84.4% on a cumulative basis for both years. While, the population of *S. litura* larvae was influenced by all climatic factors together by 75.5% during 2016, 64.2% during 2017 and 75.3% cumulatively when the linear regression equations were employed.

Keywords: *Aproaerema modicella,* correlation, groundnut, predators, regression, seasonal incidence, *Spodoptera litura*, weather parameters

Introduction

Groundnut is a major oilseed crop in India ranking globally first in area and second in production (102 lakh tons) after China (179 lakh tons) followed by Nigeria (42.31 lakh tons), United States (27.93 lakh tons) and Sudan (27.73 lakh tons) during 2021 (agricoop.nic.in, 2020-21) [6]. In India, *kharif* groundnut occupied an area of 45.14 lakh hectares during 2022, which is declined from 48.64 lakh hectares during 2021 and the production was estimated at 101.1 lakh tons during 2022 compared to 102.4 lakh tons during 2021 (agricoop.nic.in, 2021-22) [8]. Gujarat, Rajasthan, Andhra Pradesh, Madhya Pradesh and Karnataka are the major productive states which together contribute about 77 percent of the peanut production in the country.

During *kharif* 2022, the area cultivated with groundnuts in Andhra Pradesh (5.37 lakh hectares) is only 12 percent of the groundnut area of all India (des.ap.gov.in, 2022) [7]. The average yield in the state of Andhra Pradesh is lower than the national average. Among the various reasons for this cause, the most important are the infestation of insect pests and the adoption of poor plant protection measures in groundnut. Among the several insect pests infesting groundnut, the foliage feeders, namely the leaf miner, *Aproaerema modicella* (Deventer) and the tobacco caterpillar, *Spodoptera litura* (Fabricius) are key insect pests in *kharif* and *rabi* seasons in India (Praveen *et al*., 2011, Pazhanisamy and Hariprasad, 2014 and Chandrayudu *et al*., 2015) [19, 18, 4]. Naresh *et al*. (2017a and b) [14, 16] reported 70% above pod yield loss on account of leaf miner and up to 15-30% owing to tobacco caterpillar from Andhra Pradesh. *A. modicella* infections are most severe when they damage the flourishing points of young plants, which reduces growth and decreases pod yield by 35 to 44% (Pazhanisamy and Hariprasad, 2014) [18].

Climatic factors play a decisive role in the population fluctuation and spread of groundnut pests and also yield loss (Naresh *et al*. 2018) [15]. Predicting the maximum occurrence of pests and diseases in advance helps to control crop pests in a timely manner. Therefore, the present evaluation was conducted to know the impact of climate on the seasonal incidence of foliage feeders and to develop pest forewarning models for *kharif* groundnut. This would ease the proper execution of insecticide application timing and other control tactics for the management of *A. modicella* and *S. litura* in the groundnut ecosystem.

Material and Methods

Field tests were conducted at the Agricultural Experimental Station, Darsi, Prakasam district, Andhra Pradesh during the *Kharif* seasons of 2016 and 2017 to evaluate the seasonal occurrence of foliage feeders' *viz*., leaf miner and tobacco caterpillar infesting the groundnut. The trial was plotted with groundnut variety, Kadiri-6 (K-6) in a plot size of 25 x 25 sq.m. area with planting distance of 30 cm × 10 cm during the fourth week of July by following the usual crop growing practices developed by ANGRAU without any plant protection measures.

The experimental data on the incidence of *A. modicella* and *S. litura* were collected at weekly intervals from 15 Days After Sowing (DAS) until the harvest of the crop on the percentage damage to the leaflets by counting total number and damaged leaflets from 10 randomly selected plants of each quadrate of 1 X 1 sq.m of the experimental plot and expressed as percent leaflet damage. Absolute larval population was also recorded from same selected 10 plants in each quadrate of the experimental plot. There were three quadrates in the experimental plot and for each species of insect pest, observations recorded on a total of 30 plants were considered. The observations were also made for seasonal occurrence of generalist predators in groundnut ecosystem *viz*., *Coccinella* Sp., *Chilomenus sexmaculata* Fabricius and spiders, simultaneously. The mean insect population was pooled and expressed at Standard Meteorological Week (SMW) wise. Meteorological data collected daily throughout the crop growing season from the automatic weather station placed at the research station were averaged.

Statistical analysis of the data obtained during the growth period of the crop on the average number of larvae per plant, the percentage of foliage damage by each foliage feeder and the average climatic parameters were administered to a correlation analysis. The correlation between the incidence of *A. modicella* and *S. litura* larvae and the predatory population of coccinellids and spiders during two *kharif* seasons of 2016 and 2017 was analyzed individually and cumulatively. The combined effect of meteorological factors on the incidence of *A. modicella* and *S. litura* larvae in groundnut variety K-6 was determined separately for *kharif*, 2016 and 2017, as well as cumulatively using the MLR equation of type 1, namely Yi = a + b1x1 + b2x2 + - - - + bnxn where larval incidence was represented as the response variable (Y) and weather factors as predictor variables to fit the equation.

Results and Discussion

Seasonal incidence of *A. modicella* during *kharif* seasons of 2016 and 2017

The incidence of *A. modicella* larvae was low at the beginning of the 2016 *kharif* season was observed from 31st (1st week of August) to 44th (2nd week of November) SMW with a peak incidence of 5.9 larvae plant-^{1} recorded during 38th SMW (4th week of September) at 67 DAS coinciding with pod development stage of crop (Table 1). Whereas in *kharif* 2017, the incidence was initiated on 31st SMW with 0.2 larvae plant-^{1}, reached to a peak by 37th SMW during 3rd week of September at 60 DAE with a mean number of 4.1 larvae plant-^{1} and thereafter declined gradually to a minimum by 43rd SMW (1st week of November). The *kharif* 2016 and 2017 pooled abundance of *A. modicella* varied from 0.1 to 4.5 larvae plant-^{1} with highest incidence on 37th SMW (Table 1).

The peak foliar damage was occurred on 38th SMW in both the seasons of *kharif* 2016 (47.6%) and 2017 (40.5%) and also it was corresponded with highest larval incidence of *A. modicella* during both the years. A similar trend also existed in pooled analysis wherein the crop suffered less due to *A. modicella* in the early stage, thereafter foliar damage gradually increased and maximum damage of 44.0% was noticed during 38th SMW followed by 37th SMW (34.3%) during September in *khatrif* season These results are keep up by the outcome of Basha Hussain *et al.* (2012) [2] who indicated that highest incidence of the leaf miner was recorded during the month of September (15.40 larvae plant-^{1}) in groundnut. Furthermore, similar results were also reported by Pazhanisamy and Hariprasad, 2014 [18] where the incidence of *A. modicella* in groundnut come to a maximum level of 4.8 larvae per plant during the 38th SMW. The peak incidence of *A. modicella* during 3rd and 4th weeks of September during *kharif* 2016 and 2017, respectively as revealed in the current study, is also in harmony with the reports by Joshi and Patel (2010) [11] who reported the maximum incidence of 6.9 larvae of *A. modicella* plant-^{1} in soybean during 3rd week of September.

Seasonal incidence of *S. litura* during *kharif* seasons of 2016 and 2017: Incidence of *S. litura* larvae in groundnut was not observed in the initial two weeks of crop growth during *kharif* 2016. Initial occurrence was noted during the 33rd SMW (3rd week of August) at 30 DAS with 0.2 larvae plant-^{1} (Table 1). Thereafter, the larval population gradually increased and peaked during the 37th SMW falls on 3rd week of September at 60 DAS with a mean number of 7.7 larvae plant-^{1} corresponding with pod development stage of the crop. During *kharif* 2017, *S. litura* larvae infested groundnut from the first week of August (31st SMW) and continued until the first week of November (43rd SMW). The highest larval incidence was noticed during 35th SMW (1st week of September) at 45 DAS with 6.3 larvae plant-^{1} corresponding with pod formation stage of the crop. The pooled data on the incidence of *S. litura* revealed the highest mean population of 5.6 larvae plant-^{1} during both the standard weeks of 37th and 38th.

During *kharif* 2016 a continuously increasing trend in foliar damage by *S. litura* was observed starting from 30 DAS (4.5%) till pod maturity of the crop (11.0%) where in peak damage of 38.7 percent was recorded at 60 DAS during 37th SMW. Foliar damage by *S. litura* during *kharif* 2017 was started from 15 DAS itself during 31st SMW (3.5%) and this damage increased accordingly on subsequent observation dates and peaked at 30.8% during 36th SMW. On an average basis of both the years of *kharif* 2016 and 2017, the crop suffered the most due to foliar damage (33.0%) by *S. litura* during the 37th SMW followed by the 38th SMW (30.7%). Current studies on the seasonal occurrence of *S. litura* in groundnut indicated that the larval population was highest in September during the 2016 and 2017 *kharif* seasons. Mishra *et al.* (2021) [12] also found that the incidence of *S. litura* in JL -774 variety of groundnut was noticed from 32nd to 42nd SMW with a maximum incidence at 37th SMW during the second week of September. These results are in agreement with Rathod (2006) [21], Arvind Kumar (2014) [1], Harish *et al.* (2014) [10], Roopa and Ashok Kumar (2014) [23], Nath *et al.* (2017) [17] and Wankhade *et.al.* (2020) [26]. The research results are also keep up by the remarks of Hanamant *et al*. (2013) [9] and Naresh *et al*. (2017b) [16] who reported that the highest incidence of *S. litura* corresponded with the reproductive and pod formation stage of the crop.

Seasonal incidence of Predatory population during *kharif* seasons of 2016 and 2017

The coccinellid population varied between 0.1 and 3.2 per plant with a peak incidence during 37th SMW (3rd week of September) during *Kharif* 2016. Furthermore, the population was highest during the 1st week of September to 3rd week of October (35th to 41st SMW) compared to the rest of the weeks. Coccinellid densities recorded during *kharif* 2017 were relatively high, ranging between 0.2 and 3.3 plant-1 with a peak incidence during 36th SMW (2nd week of September). It was more during 35th to 40th SMWs contrast to the population recorded during other weeks. The pooled abundance of *Coccinellids* population varied from 0.1 to 3.0 beetles' plant-1 with a top incidence at the 36th SMW (Fig. 1). This can be attributed to the availability of more prey during the month of September.

Although a large number of spider species were found throughout the season at the study site, *Araneus* sp. is the most common. The numbers of each species were very low and therefore recorded as a single group. Average densities ranged from 0.1 to 3.6 spiders' plant-1 during *kharif* 2016 and the highest average number of spiders per plant was found during 37th SMW (3rd week of September). Spider abundance increased over time during *kharif* 2017 and ranged from 0.2 to 4.0 plant-1 with maximum activity recorded during 37th SMW. The pooled population during *kharif* 2016 and 2017 fluctuated from 0.1 to 3.8 spiders' plant-1 with a peak incidence in 37th SMW (Fig. 1).

Correlation coefficients between larval populations of *A. modicella* and weather parameters

The results of the correlation study revealed that there was a significant positive relationship existed with the average larva per plant and the minimum temperature (r= 0.733) during *kharif* 2016. While, the minimum temperature (r= 0.637), maximum temperature (r= 0.638) and rainfall (r= 0.613) manifested significant positive correlation with larval population of *A. modicella* during *kharif* 2017. On mean basis of both the years also minimum temperature (r = 0.687) exhibited a significant positive correlation with the larval population of *A. modicella* (Table 2), leaving no significant relationship with the other meteorological parameters. Chaudhuri and Senapati, 2004 [5] also reported that the leaf miner incidence was significantly and positively correlated with minimum temperature as reported in this study during *kharif*. The current findings are also in accordance with Radhika (2013) [20] and Pazhanisamy and Hariprasad (2014) [18] demonstrating the significant positive association of minimum temperature with larval population of groundnut leaf miner. The *A. modicella* larval population exhibited a positive and significant correlation with foliage damage during *kharif* 2016 (r = 0.957) as well as cumulatively (r = 0.837). However, a non-significant positive correlation was seen during *kharif* 2017 between the larval population and foliage damage by *A. modicella*.

Correlation coefficients between larval populations of *S. litura* and weather parameters

The correlation between mean larval population and climatic parameters revealed that the minimum temperature (r= 0.514) and evening relative humidity (r= 0.551) manifested a significant positive association with the mean number of *S. litura* larvae per plant during *kharif* 2016 (Table 2). While the minimum temperature (r= 0.698) and the maximum temperature (r= 0.572) exhibited a significant positive correlation with mean larval population of *S. litura* during *kharif* 2017. On cumulative basis of *kharif* 2016 and 2017, the minimum temperature (r= 0.540) only exerted a significant positive impact with the average larval population of *S. litura*, while the remaining meteorological parameters did not show a significant correlation. Current study also manifested a significant positive correlation between the larval population and foliage damage by *S. litura* (r= 0.858). Correlation studies showed that the abundance of tobacco caterpillar was mainly affected by minimum temperature, indicating that the drop in temperature increases the population of tobacco caterpillar which is in near agreement with the report of Mishra *et al.* (2021) [12]. Wankhede *et al.* (2020) [26] reported that the population of *S. litura* exerted a significant and positive correlation with evening relative humidity as observed in the present study during *kharif* 2016. Reddy *et al.* (2016) [22] also found that *S. litura* larval population exhibited a significant positive correlation with minimum temperature (r = 0.481), while a non- significant positive correlation with relative humidity (r = 0.359). In the current studies, the maximum temperature during *kharif* 2017 and on cumulative basis of *kharif* 2016 and 2017 exhibited a non-significant positive correlation with *S. litura*. These reports can be partly weighed up with that of Sundar *et al*. (2018) [24] and Mohapatra *et al*. (2018) [13] wherein the maximum temperature exhibited a non-significant positive correlation with larval population of tobacco caterpillar.

Correlation coefficients between larval populations of *A. modicella, S. litura* and their predators

The population of the two predators, coccinellids and spiders was positively and significantly correlated with population of *A. modicella* larvae during the two study years of *kharif* 2016 (r = 0.801 and 0.919); *kharif* 2017 (r = 0.792 and 0.853) as well as cumulatively (r = 0.905 and 0.904). Correlation data (Table 2) also showed that coccinellids and spiders had positive correlation significantly with *S. litura* larvae during *kharif* 2016 (r = 0.779 and 0.851); *kharif* 2017 (r = 0.740 and 0.812) as well as cumulatively (r = 0.920 and 0.915).

Multiple linear regression models between larval populations of *A. modicella* and weather parameters

During *kharif* 2016, the minimum temperature and morning relative humidity exhibited a positive and significant impact and contributed the most (65.9%) in combination with each another to cause the change in larval population of *A. modicella* compared to the effect of all the factors worked out together (79.1%). It was found that the minimum temperature and rainfall were the significant factors contributing 57.4 percent to the larval population fluctuation during *kharif* 2017 compared to the contribution of all climatic factors together (78.3%). On a cumulative basis, minimum temperature and evening relative humidity played a key role (70.5%) in modifying the larval population of *A. modicella* as against the overall possible contribution of 84.4 percent induced by all the factors together. The Multiple Linear Regression (MLR) equation on mean of two years after step down withdrawl was $Y = -22.134+1.204X_1-0.438\ X_2-0.082\ X_3+0.221X_4+0.008X_5$ indicating an increase of one unit of minimum temperature, evening relative humidity and rainfall, the population of *A. modicella* increases by 1.204, 0.221and 0.008 units, respectively. Whereas, with each increase in one unit of maximum temperature and morning relative humidity, population of *A. modicella* lowered by 0.438 and 0.082 units, respectively (Table 3). Current research is in harmony with Birajdar *et al*. (2015) [3] who outlined that multiple regression coefficient (R^2) between climatic parameters and larval population of leaf miner in groundnut was greatly significant (R^2= 0.985) appearing that climatic parameters impact the incidence of leaf miner in groundnut. Naresh *et al.* (2017a) [14] developed regression equations that showed all the meteorological parameters together influenced the damage by leaf miner up to 79% (R^2=0.79) and 75% (R^2=0.75) in Dharani and K-6 varieties of groundnut, respectively. The MLR equation fitted by Radhika (2012) [20] with meteorological parameters for pheromone trap catches of *A. modicella* contributing to 81 percent of the prediction.

Multiple linear regression models between larval populations of *S. litura* and weather parameters

During *kharif* 2016, minimum temperature showed a positive and significant influence when the effect of all the climatic factors on the *S. litura* larval population was calculated. This equation seems to be good enough with an overall contribution of climatic factors estimated at 75.5 percent significant variation in larval population. During *kharif* 2017, minimum temperature alone had a positive and significant impact on the larval population of *S. litura* and was found to be the significant contributing factor of 48.8% of larval population fluctuation. The cumulative effect of the climatic factors of two years indicates that the minimum temperature and evening relative humidity showed a significant positive impact and contributed the maximum (65.1%) in combination with each other on the larval population of *S. litura*. The coefficient of determination was 0.753, when the effect of all the meteorological factors calculated together with an overall contribution of 75.3 percent significantly. The MLR equation on cumulative basis of both the years after step down reduction was Y = -28.826 +1.311X_1-0.374 X_2-0.121 X_3+0.321X_4-0.045 X_5. This explains that when there was a unit increase in minimum temperature and evening relative humidity, the larval population of *S. litura* increased by 1.311 and 0.321 units and with a unit increase in maximum temperature, morning relative humidity and rainfall the population decreased by 0.374 and 0.121 and 0.045 units, respectively (Table 4).

According to Vijayalakshmi *et al.* (2021) [25] the coefficient of determination (R^2) between meteorological factors and the *S. litura* population during the *rabi* season was observed to be 65% with non-linear models using three-year pooled data. While, Naresh *et al.* (2017b) [16] found that maximum temperature, minimum temperature, morning relative humidity, evening relative humidity, sunshine hours and wind speed combinedly influenced the *S. litura* damage to the tune of 86% (R^2= 0.86) and 84% (R^2= 0.84) in Dharani and K-6 cultivars of groundnut. Wankhede *et al.* (2020) [26] developed prediction models for *S. litura* populations in different sowing windows by calculating climate-based regression equations (R^2) that revealed 72 to 83 percent validation for variety JL-501, 66 to 85 percent validation for variety RHRG-6083, 71 to 87 percent validation for variety TAG-24 and 69 to 84 percent validation for JL-776 variety of groundnut which are in tune with the current prediction results of 75.3 percent for the K-6 groundnut variety. The MLR equation fitted by Radhika (2012) [20] with meteorological parameters for pheromone trap catches of *S. litura* contributing for 66 percent of prediction. The regression equation between tobacco caterpillar and minimum temperature (R^2 = 0.2481) and for average temperature (R^2 = 0.326) developed by Mishra *et al.* (2021) [12] revealed a contribution of 24.8 and 32.6 percent variance, respectively in causing change in the larval population of *S. litura*. The current results are also aided by Harish *et al.* (2014) [10] who outlined that R^2 for *S. litura* on groundnut was 76, 35 and 53 percent during *kharif*, *rabi* and summer seasons, respectively.

Relationship between larval populations of *A. modicella, S. litura* and the predatory populations

The impact of predators' *viz*., *Coccinellids* and spiders on the larvae of *A. modicella* by computing data into MLR equations (Table 5) for *kharif* 2016 was Y = -0.208 -0.375 X_1+1.626X_2 which indicating each unit increase in *A. modicella* larval population increased spider's predation by 1.626 units with the influence to the tune of 83.1 percent (R^2 = 0.831). The MLR equation in *kharif* 2017 was Y = -0.315 +0.098 X_1+0.831X_2 indicating a unit increase in population of *A. modicella* larvae, *coccinellids* and spiders' predation increased by 0.098 and 0.831 units, respectively with the significant influence to an amount of 73.5 percent (R^2 = 0.735). For the pooled data of *kharif* 2016 and 2017, a unit increase in leaf miner larval population, increased the *coccinellids* and spiders' predation by 0.654 and 0.590 units and the influence was 84.1 percent (R^2 = 0.841).

The predatory impact of spiders on the larvae of *S. litura* for *kharif* 2016 could be explained by MLR equation Y = -0.068 - 0.169 X_1+1.827X_2 which indicates that each unit increase in the larval population increased spider's predation by 1.827 units with the influence to the level of 72.3 percent (R^2 = 0.723). Variability in the larval population of *S. litura* due to predation during *kharif* 2017 indicated that a unit increase in the larval population increased *coccinellids* and spiders' predation by 0.121 and 1.029 units, respectively with the significant influence to the magnitude of 65.4 percent (R^2 = 0.654). The MLR equation for the pooled data was Y = 0.151+0.970X_1+0.573 X_2 which indicates an increase in the population of *S. litura* larvae, increased the predation of coccinellids by 0.970 and spiders by 0.573 units and the influence was 86.1 percent (R^2 = 0.861).

Table 1: Seasonal incidence of *A. modicella* and *S. litura* in groundnut during *kharif*, 2016 and 2017

Stand. Met. week	Days after sowing (DAS)	*A. modicella* larvae per plant			% Foliage damage by *A. modicella*			*S. litura* larvae per plant			% Foliage damage by *S. litura*		
		Kharif 2016	*Kharif* 2017	Pooled	*Kharif* 2016	*Kharif* 2017	Pooled	*Kharif* 2016	*Kharif* 2017	Pooled	*Kharif* 2016	*Kharif* 2017	Pooled
31 (Aug.-1wk)	15	0.2	0.2	0.2	7.1	2.6	4.8	0.0	0.8	0.4	0.0	3.5	1.8
32 (Aug.-2wk)	22	0.5	1.8	1.2	7.4	11.4	9.4	0.0	1.9	0.9	0.0	5.8	2.9
33 (Aug.-3wk)	30	0.7	3.0	1.8	13.6	18.8	16.2	0.2	2.1	1.1	4.5	5.5	5.0
34 (Aug.-4wk)	37	1.4	2.8	2.1	20.9	17.6	19.3	0.5	4.9	2.7	11.5	11.0	11.3
35 (Sept.-1wk)	45	2.1	3.2	2.6	22.7	23.8	23.2	1.4	6.3	3.9	23.5	14.5	19.0
36 (Sept. -2wk)	52	4.1	3.5	3.8	33.8	24.0	28.9	3.5	5.3	4.4	28.8	30.8	29.8
37 (Sept. -3wk)	60	4.8	4.1	4.5	33.0	35.6	34.3	7.7	3.5	5.6	38.7	27.3	33.0
38 (Sept. -4wk)	67	5.9	2.5	4.2	47.6	40.5	44.0	7.4	3.8	5.6	36.2	25.3	30.7
39 (Oct.-1wk)	75	3.0	1.6	2.3	26.8	38.3	32.5	4.6	2.8	3.7	31.8	20.0	25.9
40 (Oct.-2wk)	82	1.5	0.9	1.2	23.7	27.4	25.5	3.3	2.1	2.7	28.8	21.5	25.1
41 (Oct.-3wk)	90	0.6	0.7	0.6	17.5	22.8	20.1	2.8	2.8	2.8	26.2	16.3	21.2
42 (Oct.-4wk)	97	0.5	0.5	0.5	11.3	30.9	21.1	2.1	1.4	1.8	28.8	14.3	21.5
43 (Nov.-1wk)	105	0.5	0.2	0.3	9.2	12.7	10.9	1.8	0.7	1.2	17.3	16.5	16.9
44 (Nov.-2wk)	112	0.2	0.0	0.1	5.2	7.4	6.3	0.7	0.2	0.4	11.0	13.5	12.3

Dates of sowing during *Kharif*, 2016:16.07.2016 (29th SMW) and *Kharif*, 2017: 15.07.2017 (29th SMW)

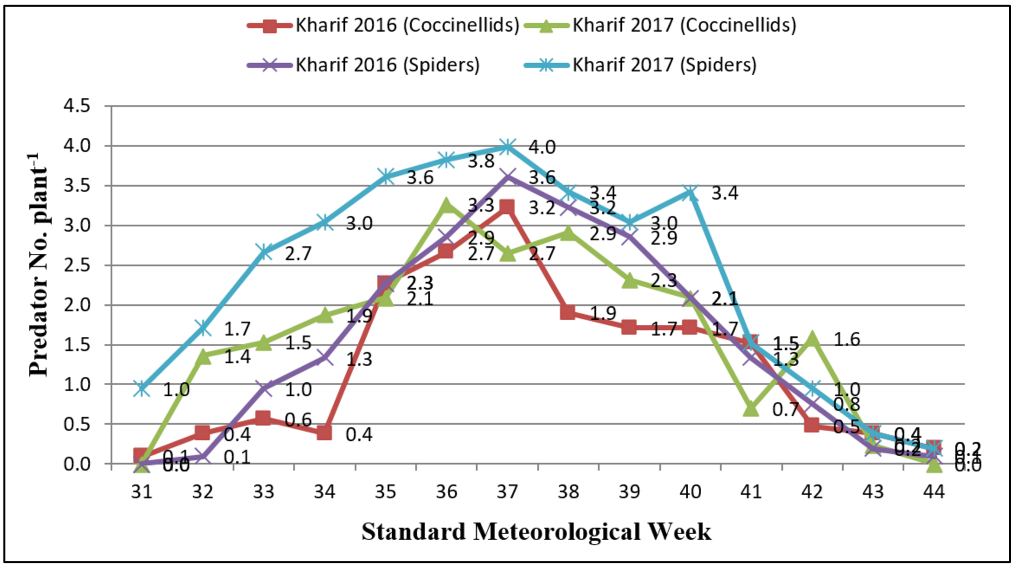

Fig 1: Seasonal incidence of Coccinellid beetles and Spiders predating on groundnut foliage feeders during *kharif* 2016 and 2017

Table 2: Correlation between foliage feeders and weather parameters and predator populations in Groundnut during *kharif*, 2016 and 2017

Year	Correlation coefficient (r) values							
	Rainfall (mm)	Min. Temp. (°C)	Max. Temp. (°C)	Morning RH (%)	Evening RH (%)	Foliage damage (%)	Coccinellids	Spiders
Larvae of *A. modicella*								
Kharif 2016	-0.118	0.733*	-0.074	0.122	0.315	0.957*	0.801*	0.919*
Kharif 2017	0.613*	0.638*	0.637*	0.148	-0.048	0.442	0.792*	0.853*
Pooled	0.300	0.687*	0.246	0.032	0.108	0.837*	0.905*	0.904*
Larvae of *S. litura*								
Kharif 2016	-0.397	0.514*	-0.106	0.337	0.551*	0.881*	0.779*	0.851*
Kharif 2017	0.413	0.698*	0.572*	0.004	-0.237	0.420	0.740*	0.812*
Pooled	0.079	0.540*	0.201	0.042	0.230	0.858*	0.920*	0.915*

* Significant at $p<0.05$

Table 3: Multiple linear regression models between larval population of *A. modicella* and weather parameters

Year	Regression Equation	SE	R^2	$100R^2$
Kharif 2016	$Y = -18.560 + 0.809^* X_1$	1.318	0.541	54.1
	$Y = -10.590 + 0.902^* X_1 - 0.326 X_2$	1.238	0.633**	63.3
	$Y = -25.889 + 1.021^* X_1 - 0.177 X_2 + 0.090^* X_3$	1.048	0.751**	75.1
	$Y = -24.122 + 0.940^* X_1 - 0.129 X_2 - 0.009 X_3 + 0.104 X_4$	1.040	0.788**	78.8
	$Y = -25.712 + 0.934^* X_1 - 0.086 X_2 - 0.027 X_3 + 0.139 X_4 + 0.015 X_5$	1.075	0.791**	79.1
Kharif 2017	$Y = -10.286 + 0.476^* X_1$	1.125	0.404	40.4
	$Y = -12.761 + 0.253 X_1 + 0.267 X_2$	1.129	0.441	44.1
	$Y = -15.256 + 1.170 X_1 + 0.331 X_2 + 0.031 X_3$	1.159	0.464	46.4
	$Y = -29.854 + 0.262 X_1 + 0.435 X_2 + 0.028 X_3 + 0.144 X_4$	1.035	0.613**	61.3

	Y = -19.309 +0.259 X_1+0.314 X_2+0.006 X_3+0.072 X_4+0.120* X_5	0.826	0.783**	78.3
Cumulative	Y = -14.301 +0.638* X_1	1.141	0.468	46.8
	Y = -6.993 +1.004* X_1-0.525 X_2	1.023	0.609**	60.9
	Y = -7.771 +0.994*X_1 -0.512 X_2 +0.002X_3	1.070	0.603**	60.3
	Y = -21.145 +1.213* X_1 -0.442 X_2 -0.080X_3 +0.227*X_4	0.702	0.840**	84.0
	Y = -22.134 +1.204* X_1-0.438 X_2-0.082 X_3+0.221*X_4+0.008 X_5	0.749	0.844**	84.4

X_1- Min. Temp.(°C), X_2- Max. Temp.(°C), X_3- Morning RH (%), X_4- Evening RH (%), X_5- Rainfall (mm)
* = Significant at 5% level, ** Significant at p<0.05
R^2 -Coefficient of Determination, SE- Standard Error

Table 4: Multiple linear regression models between larval populations of *S. litura* and weather parameters

Year	Regression Equation	SE	R^2	$100R^2$
Kharif 2016	Y = -16.846 +0.769X_1	2.261	0.267	26.7
	Y = -7.292 +0.889* X_1 -0.391 X_2	2.259	0.335	33.5
	Y = -37.378 +1.125* X_1 -0.094 X_2 +0.170*X_3	1.833	0.602**	60.2
	Y = -31.848 +0.863* X_1 +0.075 X_2 -0.111X_3 +0.316*X_4	1.525	0.750**	75.0
	Y = -30.348 +0.876* X_1+0.031X_2 -0.094X_3 +0.287X_4 -0.016 X_5	1.602	0.755**	75.5
Kharif 2017	Y = -14.614 +0.683*X_1	1.369	0.488	48.8
	Y = -14.963 +0.654 X_1 +0.034 X_2	1.429	0.484	48.4
	Y = -11.787 +0.766X_1 -0.050 X_2 -0.035X_3	1.473	0.499	49.9
	Y = -19.379 +0.811X_1 -0.008 X_2 -0.037X_3 +0.076X_4	1.517	0.526	52.6
	Y = -7.321 +0.791 X_1-0.139 X_2-0.079 X_3-0.013 X_4+0.146 X_5	1.377	0.642**	64.2
Cumulative	Y = -12.474 +0.596*X_1	1.561	0.298	29.8
	Y = -6.065 +0.912* X_1 -0.462 X_2	1.545	0.367	36.7
	Y = -8.101 +0.900X_1 -0.425 X_2 +0.013X_3	1.617	0.375	37.5
	Y = -28.713 +1.228*X_1 -0.328 X_2 -0.114X_3 +0.310*X_4	1.123	0.728**	72.8
	Y = -28.826 +1.311* X_1-0.374 X_2-0.121 X_3+0.321* X_4-0.045 X_5	1.134	0.753**	75.3

X_1- Min. Temp.(°C), X_2- Max. Temp.(°C), X_3- Morning RH (%), X_4- Evening RH (%), X_5- Rainfall (mm)
* = Significant at 5% level, ** Significant at p<0.05
R^2 -Coefficient of Determination, SE- Standard Error

Table 5: Multiple linear regression models between larval populations of *A. modicella, S. litura* and predatory populations

Year	Regression Equation	SE	R^2
Larvae of *A. modicella* and predatory population			
Kharif 2016	Y = -0.208 -0.375 X_1+1.626* X_2	0.829	0.831**
Kharif 2017	Y = -0.315 +0.098 X_1+0.831 X_2	0.771	0.735**
Cumulative	Y = -0.280 +0.654 X_1+0.590 X_2	0.656	0.841**
Larvae of *S. litura* and predatory population			
Kharif 2016	Y = -0.068 -0.169 X_1+1.827* X_2	1.454	0.723**
Kharif 2017	Y = 0.150 +0.121 X_1+1.029* X_2	1.161	0.654**
Cumulative	Y = 0.151 +0.970 X_1+0.573 X_2	0.718	0.861**

X_1- Coccinellids, X_2- Spiders
* = Significant at 5% level, ** Significant at p<0.05
R^2 -Coefficient of Determination, SE- Standard Error

Conclusion
It is evident from the current experimentation that the highest population of foliage feeders in groundnut *viz.*, leaf miner (5.9 and 4.1 larvae plant^{-1} in 38th and 37th SMWs) and tobacco caterpillar (7.7 and 6.3 larvae plant^{-1} in 37th and 35th SMWs) were observed at pod formation and pod development stage during September months of 2016 and 2017, respectively. Predatory species manifested seasonality shifts that seem to be connected to their preferred life stages of leaf miner and tobacco caterpillar abundance in the crop. Correlation studies showed that the incidence of leaf miner and tobacco caterpillar was significantly affected by minimum temperature, indicating that the drop in temperature increases the population of foliage feeders. Multiple regression analysis clearly showed the importance of climatic factors in predicting the leaf miner and tobacco caterpillar incidence in groundnut. The results of the experiment provide an idea about the effect of climatic parameters on the occurrence of the major foliage feeders in groundnut and the developed regression models can be utilized in issuing the pest alerts to the farming community so as to plan timely control measures.

Acknowledgements
The authors acknowledge the support from Principal Scientist & Head, Agricultural Research Station, Darsi; University Head of Department of Entomology and Director of Research, ANGRAU for their valuable suggestions and providing facilities for conducting the experiment.

Conflict of Interest
The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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