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Effect of weather parameter on seasonal incidence of sorghum shoot fly, *Atherigona soccata* Rondani (Diptera: Muscidae)

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Abstract
Sorghum is an important cereal crop in India. Sorghum shoot fly, *Atherigona soccata* Rondani has been known to be the most serious pest causing grain yield losses. A field experiment was conducted during the cropping season of 2015- 16 at MARS, Raichur to characterize relationship of various meteorological parameters with shoot fly, incidence in terms of egg load and dead heart. The oviposition by shoot fly reached peak (3.10 eggs/ plant) during 35th MSW and also it was almost equal (2.9 eggs/ plant) during 33rd MSW. Similar trend was observed with respect to dead hearts, where it gradually increased and reached peaks (96.12 and 94.32%) during 33rd and 35th MSW. In all the correlated weeks, maximum and minimum temperature had non-significant negative association with dead heart. The rainfall and rainy days had significant positive association on egg load on one week and three week lead time, respectively. The rainfall had significant positive association on dead heart during second and third week lead time.

Keywords: Sorghum shoot fly, *Atherigona soccata*, seasonal incidence, weather parameters, correlations, lead time

1. Introduction
Sorghum (*Sorghum bicolor* (L.) Moench) is an important food and fodder crop in India and world's fifth most important cereal crop after maize, rice, wheat and barley [1]. More than 150 species of insects have been reported attacking sorghum crop during different stages of its growth [2]. Among them shoot fly, *Atherigona soccata* Rondani (Diptera: Muscidae) is one of the most important insect pests of sorghum in India. The pest attacks the crop only in the early stage of the crop growth and lasts up to four weeks[3]. The incidence of shoot fly is known to vary from region to region and season to season. Its incidence is moderate to high (30-50%) at Dharwad, Parbhani, Akola, Indore, Surat and Udaipur areas [4]. Similarly, Balikai [5] reported peak incidence during August (32nd MSW) in Bijapur. Its activity is influenced by extreme temperature (above 35 ^{0}C and below 18 ^{0}C) and also by continuous rains. However, high relative humidity (> 60%) increased its population [6]. The knowledge regarding time of appearance of a pest on the crop and period of its maximum activity helps in deciding sowing date and timing of control operations against the pest. The peak activity of shoot fly, *A. soccata* was determined by sowing the sorghum crop at fortnightly intervals [7]. Keeping this in view, the present experiments were planned to record peak activity periods of shoot fly and to know the relationship between weather parameters and occurrence of shoot fly for particular season. Regression models on shoot fly incidence with weather parameters on different lead weeks were developed for early prediction of damage. This may be fruitfully utilized for forewarning farmers.

2. Material and methods
The present studies were undertaken on the seasonal occurrence of sorghum shoot fly from June-2015 to February-2016. This experiment was carried out at Main Agricultural Research Station, University of Agricultural Sciences, Raichur. Population dynamics of *A. soccata* in the form of level of incidence on the staggered sown sorghum population was studied. Sowing of susceptible sorghum hybrid CSH-14 was taken at fortnightly intervals commencing from second week of July, 2015 to second fortnight of February, 2016 (Plate 3). The sowing was carried out in two plots measuring 5m X 5m present at a distance of 200 m with spacing of 15x

15 cm (non-replicated). Observation on egg count was taken on 14 days old crop during each sowing. Per cent dead heart was taken on 21st and 28th day after sowing in each plot by adopting the formula.

$$\% \text{ dead hearts due to shoot fly} = \frac{\text{Number of plants with dead hearts per plot}}{\text{Total no. plants per plot}} \times 100$$

Weather parameters that prevailed during 1st, 2nd, 3rd and 4th week prior (last weeks) were correlated with biological observations (Number of egg per plant and per cent dead hearts). Multiple regression equation models were developed for the relationship. The statistical software SPSS was used for correlation and regression analysis.

3. Results and Discussion

Observations recorded on egg load and per cent dead hearts on fortnightly sown crop are presented in Table 1. The number of eggs laid on the crop sown during 24th standard week was 0.25 and it gradually increased and reached peak (3.10 eggs/ plant) during 35th standard week. Similar trend was observed with respect to dead hearts. The per cent dead heart on the crop sown during 24th standard week was 2.05 and it gradually increased and reached peaks (96.12 and 94.32%) during MSW and was almost equal to 43rd MSW sown crop (89.80%).

The above finding are in agreement with the reports of Karibasavaraja and Balikai [8] who reported the oviposition by shoot fly reached a peak on 33rd standard week (3.2 eggs/plant) and declined gradually on 44th standard week and similar trend was observed with respect to dead hearts which recorded 43 per cent on 27th standard week and it reached a peak with 93.4 per cent on crop sown during 33rd standard week and gradually declined to 35 per cent during 44th standard week. Similarly, Balikai [5] reported that shoot fly population began to increase in July, reached its highest peak in August and declined thereafter with a slight peak in October which again declined confirming the present findings. Raigar *et al.* [9] reported that shoot fly dead hearts increased rapidly during first week of August 47.63 per cent and thereafter the infestation continues to increase and became constant after third week of August.

In present study, the rainfall (0.533) exerts a significant positive relationship with egg load during 1 week lead time and the rainy days (0.507) exerts a significant positive relationship with egg load during three week lead time weather data (Table 2). Total weather parameters of different correlated weeks influenced the egg load to the extent of 38.9 per cent (four week prior), 53.5 per cent (three week prior), 52.5 per cent (two week prior) and 53.3 per cent (one week prior).

Similarly, in the correlated lead weeks with per cent dead heart, the rainfall (0.533) exerts a significant positive relationship with dead heart during two and three week lead time. In all the correlated weeks, maximum temperature and minimum temperature had non-significant negative association with dead heart. Except those none of weather parameters showed any significant correlation with dead heart formation (Table 3). Multiple regression equations on egg load and dead hearts for different weeks correlated are presented in table 4. Total weather parameters of different correlated weeks influenced the per cent dead hearts (on 28th day) to the extent of 33.6 per cent (four weeks prior), 47.6 per cent (three week prior), 47.3 per cent (two weeks prior) and 42.0 per cent (one weeks prior) in observation.

The present findings are in agreement with the reports of Singh and Verma [6], Balikai and Venkatesh [10], Venkatesh and Balikai [11] and Karibasavaraja and Balikai [8] who reported negative association with maximum temperature. However, the findings of Rai and Wakgari [12] and Aghav *et al.* [13] contradicted the present findings by reporting positive relationship with egg load which may be due to variation in temperature between two regions (Ethiopia and Raichur), the temperature ranged from minimum of 3.10^0 C to maximum of 24.11^0 C in Ethiopia. Whereas, in Raichur location it is varied between 10.8 to 42.3^0 C. During the study, rainfall had non-significant positive relationship with shoot fly oviposition (except one week lead time) and a significant positive association with dead heart (2nd and 3rd week lead time) which confirms the earlier findings of Karibasavaraja and Balikai [8] who reported positive association between egg load and dead hearts with rainfall. However, Nair *et al.* [14] reported rainfall intensity to have detrimental effect on egg laying and adult population because that may washing eggs with high intensity. Delobel and Lubega [15], Gahukar [16] and Pavana kumar *et al.* [17] also reported similar results. This may be due to differences in the climatic conditions, irregular distribution of rainfall or rainfall pattern prevailed there.

Table 1: Seasonal incidence of shoot fly, *Atherigona soccata* Rondani on sorghum during *kharif* - 2015, *rabi* 2015 and Summer-2015-16.

Season	(Std. Week) Sowing week	Mean eggs per plant (14 DAE)	Per cent dead heart (21 DAE)	Per cent dead heart (28 DAE)
Kharif	24 (Jun 11-17)	0.25*	1.55	2.05
	26 (Jun 25-01)	0.90	21.55	26.30
	28 (Jul 09-15)	0.45	25.50	30.02
	30 (Jul 23-29)	2.25	38.40	49.84
	33 (Aug 13-19)	2.90	88.60	96.12
	35 (Aug 27-02)	3.10	91.05	94.32
Rabi	37 (Sep 10-16)	1.05	30.15	42.35
	39(Sep 24-30)	1.90	37.50	51.21
	41 (Oct 08-14)	0.80	16.40	24.02
	43 (Oct 22-28)	2.35	81.70	89.80
	46 (Nov 12-18)	0.90	31.25	38.80
	48 (Nov 26-02	1.95	73.90	83.32
Summer	50 (Dec 10-16)	1.00	20.80	32.30
	52 (Dec 24-31)	1.45	34.80	49.67
	2 (Jan 8-14)	1.25	30.70	39.04
	4 (Jan 22-28)	2.05	51.55	63.50
	6 (Feb 05-11)	0.35	13.20	18.03

DAE = Days after emergence; * = Mean number of eggs / 20 plants

Table 2: Correlation matrix between egg load and weather parameters at different lead times

	Temperature (ºC)		Rainfall (mm)	Relative Humidity (%)		Rainy days	Egg load per plant at 14 DAE
	Maximum	Minimum		Morning	Afternoon		
	Max T	Min T	RF	RH l	RH ll	RD	Y
	Weather parameters at 4 weeks lead times (4 weeks prior)						
Max T	1.000	0.740**	-0.114	-0.211	-0.111	0.372	-0.164
Min T		1.000	0.397	0.233	-0.525*	0.586*	0.016
RF			1.000	0.622**	0.843**	0.654**	0.154
RH l				1.000	0.845**	0.297	0.203
RH ll					1.000	0.532*	0.245
RD						1.000	0.389
Y							1
	Weather parameters at 3 weeks lead times (3 weeks prior)						
Max T	1.000	0.798**	-0.105	-0.232	-0.181	0.542*	-0.100
Min T		1.000	0.290	0.101	0.370	0.589*	0.026
RF			1.000	0.585*	0.806**	0.200	0.117
RH l				1.000	0.806**	-0.019	0.206
RH ll					1.000	0.228	0.280
RD						1.000	0.507*
Y							1.000
	Weather parameters at 2 weeks lead times (2 weeks prior)						
Max T	1.000	0.765**	-0.143	-0.115	-0.160	0.284	0.009
Min T		1.000	0.250	0.313	0.436	0.494*	0.017
RF			1.000	0.522*	0.743**	0.361	-0.126
RH l				1.000	0.869**	0.260	0.070
RH ll					1.000	0.444	0.112
RD						1.000	0.372
Y							1.000
	Weather parameters at 1 weeks lead times (1 weeks prior)						
Max T	1.000	0.698**	0.050	-0.053	-0.128	0.200	-0.130
Min T		1.000	0.309	0.322	0.519*	0.426	-0.020
RF			1.000	0.438	0.588*	0.093	0.533*
RH l				1.000	0.751**	0.250	0.357
RH ll					1.000	0.478	0.432
RD						1.000	0.299
Y							1.000

N = 17, 'r' value 0.575 at 0.01 level 'r' value 0.456 at 0.05 level.
DAE = Days after emergence, ** Significant at 0.01 level. * Significant at 0.05 level

Table 3: Correlation matrix between per cent dead hearts and weather parameters

	Temperature (ºC)		Rainfall (mm)	Relative Humidity (%)		Rainy days	% DH at 28 DAE
	Maximum	Minimum		Morning	Afternoon		
	Max T	Min T	RF	RH l	RH ll	RD	Y
	Weather parameters at 4 weeks lead times (4 weeks prior)						
Max T	1.000	0.710**	-0.149	-0.251	-0.144	0.118	-0.373
Min T		1.000	0.421	0.235	0.532*	0.573*	-0.110
RF			1.000	0.621**	0.850**	0.880**	0.419
RH l				1.000	0.859**	0.513*	0.365
RH ll					1.000	0.754**	0.363
RD						1.000	0.371
Y							1
	Weather parameters at 3 weeks lead times (3 weeks prior)						
Max T	1.000	0.724**	-0.118	-0.218	-0.144	0.090	-0.384
Min T		1.000	0.358	0.226	0.496*	0.562*	-0.137
RF			1.000	0.560*	0.808**	0.903**	0.545*
RH l				1.000	0.848**	0.532*	0.408
RH ll					1.000	0.810**	0.441
RD						1.000	0.371
Y							1.000
	Weather parameters at 2 weeks lead times (2 weeks prior)						
Max T	1.000	0.678**	-0.198	-0.207	-0.235	0.047	-0.470
Min T		1.000	.345	0.173	0.453	0.514*	-0.158
RF			1.000	0.595*	0.829**	0.817**	0.531*
RH l				1.000	0.816**	0.462	0.396
RH ll					1.000	0.715**	0.462
RD						1.000	0.270
Y							1.000
	Weather parameters at 1 weeks lead times (1 weeks prior)						
Max T	1.000	0.706**	-0.019	-0.106	-0.233	0.114	-0.330
Min T		1.000	0.244	0.238	0.384	0.440	-0.188
RF			1.000	0.463	0.647**	0.850**	0.388
RH l				1.000	0.763**	0.446	0.250
RH ll					1.000	0.645**	0.411
RD						1.000	0.218
Y							1.000

N = 17, 'r' value 0.575 at 0.01 level 'r' value 0.456 at 0.05 level.
DAE = Days after emergence, DH = Dead heart
** Significant 0.01 levels. * Significant at 0.05 levels

Table 4: Multiple linear regression models for estimation of shoot fly egg load

Correlated weeks	Multiple regression equation for shoot fly egg load	R^2 value
4 week lead time	Y= 13.421 -0.703 MaxT + 0.401 MinT -0.025 RHI – 0.092 RHII – 0.1178 RF + 0.949 RD	0.389
3 week lead time	Y= 9.317 – 0.623 MaxT + 0.405 MinT + 0.002 RHI + 0.123 RHII – 0.156 RF + 0.933 RD	0.535
2 week lead time	Y= -9.121 + 0.913 MaxT – 0.885 MinT -0.032 RHI – 0.176 RHII + 0.337 RF + 0.158 RD	0.525
1 week lead time	Y= - 1.134 + 0.242 MaxT – 0.351 MinT + 0.009 RHI - 0.012 RHII + 0.072 RF + 0.142 RD	0.533
Correlated weeks	**Multiple regression equation for shoot fly dead heart**	**R^2 value**
4 week lead time	Y= 121.217+ 1.198 MaxT – 6.685 MinT – 0.178 RHI - 0.512 RHII + 1.766 RF + 13.229 RD	0.336
3 week lead time	Y= -28.967 + 8.859 MaxT – 11.692 MinT + 0.571RHI – 1.407 RHII + 3.703RF -10.091 RD	0.476
2 week lead time	Y= 43.130 + 6.142 MaxT – 9.591 MinT + 0.508 RHI – 1.598 RHII + 3.360 RF -7.100 RD	0.473
1 week lead time	Y= -9.138 + 6.650 MaxT – 9.083 MinT + 0.175 RHI – 1.189 RHII + 3.316 RF – 5.372 RD	0.420

R^2 = Coefficient of determination

4. Conclusion

The crop sown during 24th standard week (June, 10-17) of *kharif*, 41st standard week (October, 8-14) of *rabi* and 50th standard week (December, 10-16) recorded 0.25, 0.80 and 1.00 egg / plant on 14th day respectively. Similarly the dead heart percentage of 2.05, 24.02 and 32.30 was recorded by looking at lower egg load and dead heart percentage sowing of sorghum during 24th standard week of *kharif*, 41st standard week of *rabi* and 50th standard week of *summer* seems to be safer at Raichur location. The three lead week weather parameters influenced more on egg load (53.5%) and dead heart formation (47.6%) due to shoot fly.

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