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Prediction models for *Bactrocera dorsalis* (Hendel) (Diptera: Tephritidae) based on weather parameters in an organic mango orchard

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Abstract
The present study was aimed to determine the effect of abiotic factors on population of *B. dorsalis* in an organic mango orchard and to develop weather forecast models at ICAR- Indian Institute of Horticultural Research, Bangalore, Karnataka in an organic mango orchard during Jan 2014- Dec 2015. Correlation studies showed that there was a significant positive correlation between maximum and minimum temperature, wind speed and rainfall. The linear regression explained the highest variability R^2=0.74 with wind speed and multiple regression analysis with all the significant weather variables could explain the variability to an extent of 83% during the fruiting phase of mango. Thus, the simple linear regression model derived from windspeed can be considered as a best single predictor for forecasting the changes in population of *B. dorsalis* that can be used in the management decisions.

Keywords: *Bactrocera dorsalis*, mango, weather parameters, prediction models

1. Introduction
The oriental fruit fly, *Bactrocera dorsalis* (Hendel), is a major pest on mango grown in tropical and subtropical regions which cause loss up to 80% [1]. The crop loss due to *B. dorsalis* varies with the season and region. Considering the huge loss incurred by fruit flies various studies have been carried out across the globe to minimize the pest population, which includes use of pheromone traps, proteinaceous food baits, insecticidal cover sprays, classical biological control and integrated methods [2]. Current integrated pest management program in mango includes field sanitation, male annihilation technique (MAT) with need based insecticidal cover spray during fruit maturity. The number of cover sprays depends on the population of the fruit flies [1]. Prediction of fruit fly in mango orchard and administrating the intervention for management of fruit flies form an important tool in IPM of fruit fly.

Biotic and abiotic factors play a vital role in the occurrence and perpetuation of pests. Among abiotic factors weather parameters are considered to be major component which influences the pest population. The efficiency of fruit fly management strategy mainly depends on its population. Prediction of fruit fly in advance helps the farmers to schedule the management strategies effectively and to enforce from appropriately to get the maximum yield with minimum yield loss [2]. Thus prediction models form an integral part of effective management strategy.

Various studies have been carried out across the globe to monitor the fruit fly population and to study the effect of weather parameters. But information pertaining to predicting the abundance of fruit fly based on the weather parameters in different vegetative and flowering phases is lacking and attempts have not made to develop prediction models for *B. dorsalis* in organic mango orchard. Hence detailed studies were carried out to determine the effects of abiotic factors on population build up of fruit flies and to develop prediction models for fruit fly based on weather parameters for proper implementation of management practices.

2. Materials and Methods
A detailed study was conducted at ICAR-Indian Institute of Horticultural Research (12^0 58' N; $77^0$35' E) Hesaraghatta, Bangalore, Karnataka in an organic mango orchard of *cv* Totapuri aged 15 years in an area of one acre comprising of 28 trees. The population of fruit flies were estimated by using methyl-eugenol para pheromone traps as trap catches are good indicators of *B. dorsalis* [2]. Eight traps were placed at a spacing of 80m apart.

The traps were made of plastic container of 750ml capacity consisting of six veneered ply wood block impregnated with methyl-eugenol. Water level of one inch was maintained within the container to trap the entered flies. Traps were prepared by opening circular holes of 2cm diameter on two sides, 5cm from the top of the container. The impregnated plywood blocks were tied firmly by passing the thread through the holes. Recharging of blocks was done every month. The traps were held firmly to the mango branch with thread at a height of 4 feet from the ground level. Monitoring the fly catch was done once a week from Jan 2014 to Dec 2015. The trapped flies were brought to the laboratory and identified based on the keys [3] to sort out *B. dorsalis* from other *Bactrocera* spp. Weather parameters *viz.*, maximum and minimum temperature (°C), relative humidity (morning) I and II (evening) (%), total rainfall (mm) and wind speed (km/h) of selected site were collected everyday from meteorological observatory of ICAR-IIHR. This was subsequently utilized to correlate with the status of pest population in both vegetative and fruiting phase for the years of the study.

Statistical Analysis: Data were analysed for correlation and regression to obtain prediction models with r and R^2 as test criteria respectively [4]. From the models developed, predicted fruit fly population (dependent variable) for a given independent weather variable, the observed and predicted fruit fly population were subjected to student ‘t’ test at p= 0.05 to test if there was any significant difference between the observed and predicted number of fruit fly population.

3. Results

3.1 Effect of abiotic factors on population of *B. dorsalis* in different phases of mango

The population of *B. dorsalis* were monitored in fruiting phase (Jan-Jun) and vegetative phase (Jul-Dec) of mango during 2014-15. The correlation studies of *B.dorsalis* with weather parameters during the first year of the study period (2014) showed that maximum and minimum temperature, wind speed and rainfall had a significant positive influence on trap catch of *B. dorsalis*. The same trend was observed during the second year (2015) of the study period 2015 and in the pooled data of both the years of fruiting phase. When the data of two consecutive years 2014 and 2015 of both fruiting (Jan-Jun) and vegetative phase (Jul-Dec) were pooled the same trend was observed where, both maximum and minimum temperature, wind speed and rainfall had a positive influence on trap catch, with increase in these weather variables the fruit fly population also increased (Table 1). Since maximum and minimum temperature, wind speed and rainfall had a consistent significant effect on fruit fly trap catch in both the phases only these parameters were taken into account for developing prediction models for fruiting and vegetative phase.

Table 1: Correlation matrix between *B. dorsalis* and weather parameters in different phases of mango

Weather parameters	Fruiting phase (Jan-June)			Vegetative and Fruiting phase
	2014	2015	Pooled	Pooled
Maximum Temp °C	0.79*	0.76*	0.76*	0.67*
Minimum Temp °C	0.84*	0.78*	0.80*	0.71*
RH I % (7.30 am)	-0.18	0.24	0.06	-0.16
RH II % (1.30 pm)	-0.35	0.01	-0.12	-0.29*
Wind speed (km/h)	0.86*	0.64*	0.69*	0.72*
Rainfall (mm)	0.71*	0.51*	0.59*	0.48*

*Significant p@0.05

3.2 Prediction models for *B. dorsalis* in fruiting and vegetative phase based on maximum temperature

Prediction models at fruiting phase for *B. dorsalis* were developed based on maximum temperature. The highest coefficient of determination was obtained in fruiting phase of 2014 with R^2= 0.63. The variability in occurrence of fruit fly could explain to an extent of 45% in pooled data of 2014 and 2015 which includes both vegetative and flowering phase. Based on these models, predicted number of fruit flies was calculated by substituting the value of maximum temperature as x in the equation. Student ‘t’ test showed that there was no significant difference between observed and predicted number of fruit flies (Table 2). Hence these models hold good to predict the fruit fly population based on maximum temperature.

The graphical representation of effect of maximum temperature on fruit fly population during flowering phase is given in Fig.1. Plotting the residuals of observed and predicted fruit fly population with maximum temperature as independent variable is given in Fig. 2. When the data of fruiting phase of two consecutive years of study (2014 and 15) were pooled, a positive trend was observed with occurrence of fruit flies and maximum temperature. With increase in the maximum temperature the number of fruit flies increased and this was explained to the extent of 58%. Dynamics of *B. dorsalis*, was explained best by the linear model y = 3.001x - 74.23. The observed and predicted number of fruit flies in fruiting phase of 2014 and 2015 based on maximum temperature is indicated in Fig.2. Plotting observed and predicted average number of trap catch in y-axis, observed dates in x-axis and maximum temperature in z-axis indicated that there was no significant difference between observed and computed number of fruit flies. Hence this model can be considered as reliable in predicting the fruit fly population.

Table 2: Linear regression models to estimate *B. dorsalis* in fruiting and vegetative phase population based on maximum temperature

Period	Year	Models	R^2	Observed no. of fruit flies	Predicted no. of fruit flies	‘t’ test
Fruiting phase	2014	y = 3.960x - 101.5	0.63	13.54	13.59	NS
	2015	y = 2.782x - 69.38	0.52	15.88	14.65	NS
	2014 and 2015	y = 3.001x - 74.23	0.58	14.64	14.63	NS
Fruiting and vegetative phase	Pooled 2014 and 2015	y = 2.963x - 74.8	0.45	12.37	12.38	NS

NS= Non-significant

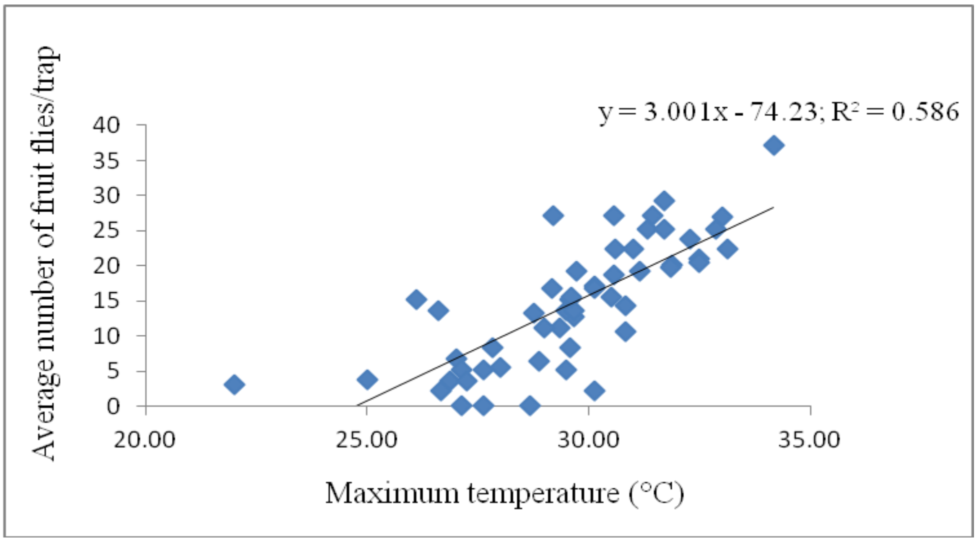

Fig 1: Effect of maximum temperature on populaion of *B.dorsalis* in fruiting phase of mango (pooled) 2014-15

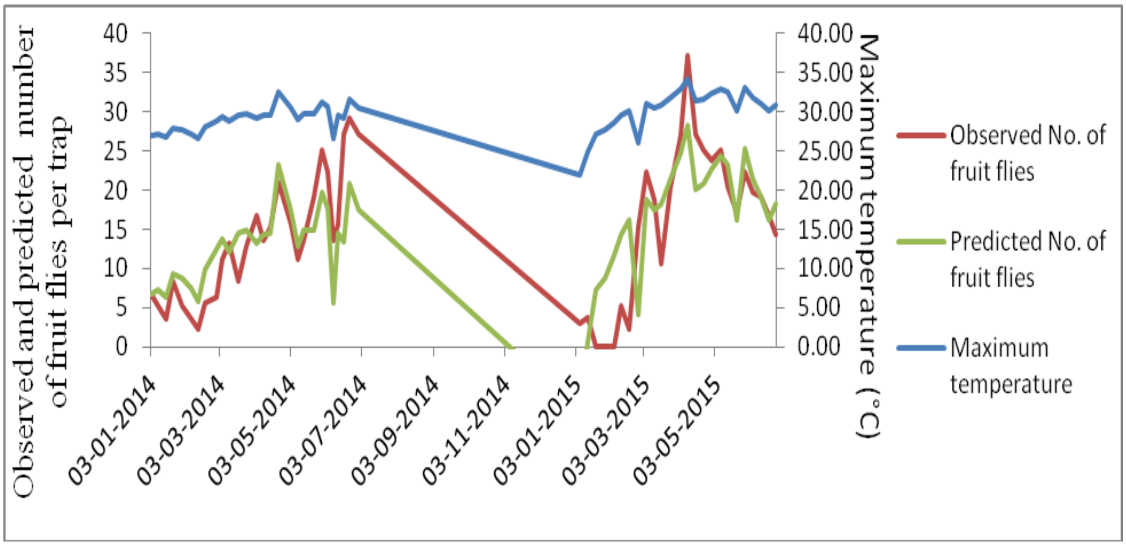

Fig 2: Observed and predicted number of fruit flies per trap in fruiting phase (2014-15) based on maximum temperature

3.3 Prediction models for *B. dorsalis* in fruiting and vegetative phase based on minimum temperature

Prediction models at fruiting and vegetative phase for *B. dorsalis* were developed based on minimum temperature. The highest coefficient of determination was obtained in fruiting phase of 2014 with R^2= 0.71. The variability of occurrence fruit fly could explain to an extent of 63% in pooled data of 2014 and 2015 which included both vegetative and flowering phase (Table 3). Based on these models, predicted number of fruit flies was calculated by substituting the value of minimum temperature as x in the equation. Student 't' test showed that there was no significant difference between observed and predicted number of fruit flies. Hence these models are found to be reliable in predicting the fruit fly population in mango orchard. The graphical representation of effect of minimum temperature on fruit fly population in fruiting and vegetative phase is given in Fig. 3.

The pooled data of fruiting phase of both the years 2014 and 2015 also showed the same positive trend. With increase in minimum temperature the fruit fly population also increased (Fig. 5). The variability of occurrence of fruit fly population could explain the variability up to 65%. The linear y = 2.566x - 36.39, explained the occurrence of this relationship. The observed and computed number of fruit flies in fruiting phase of 2014 and 2015 based on minimum temperature is indicated in Fig.4. Plotting observed and predicted average number of trap catch in y-axis, observed dates in x-axis and minimum temperature in z-axis indicated that there was no significant difference between observed and computed number of fruit flies. Hence this model holds good in predicting the fruit fly population.

Table 3: Linear regression models for *B. dorsalis* in fruiting and vegetative phase based on minimum temperature

Period	Year	Models	R^2	Observed no. of fruit flies	Predicted no. of fruit flies	't' test
Fruiting phase	2014	y = 2.451x - 34.74	0.71	13.54	13.53	NS
	2015	y = 2.635x - 37.08	0.61	15.48	15.89	NS
	2014 and 2015	y = 2.566x - 36.39	0.65	14.64	14.64	NS
Fruiting and vegetative phase	Pooled 2014 and 2015	y = 2.741x - 41.49	0.63	12.37	13.53	NS

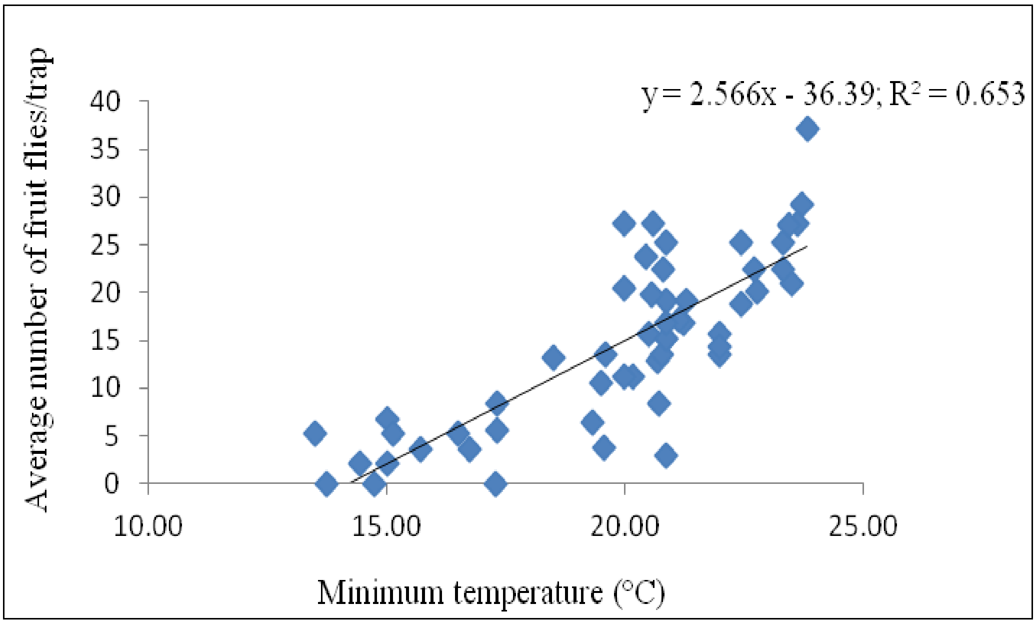

Fig 3: Effect of minimum temperature on populaion of *B.dorsalis* in fruiting phase of mango (pooled) 2014-15

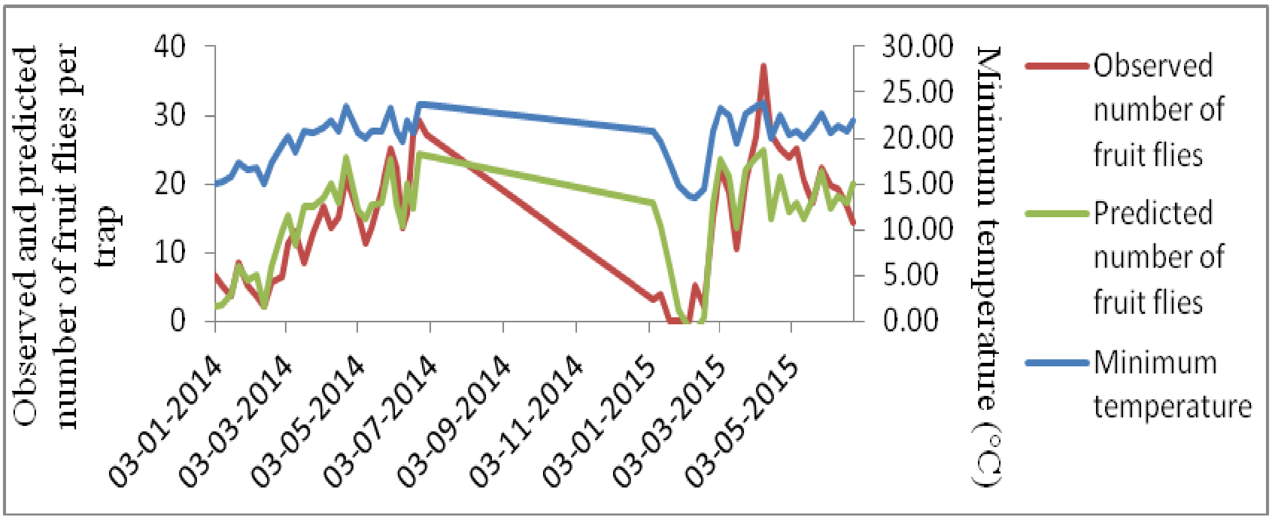

Fig 4: Observed and predicted number of fruit flies per trap in fruiting phase (2014-15) based on minimum temperature

3.4 Prediction models for *B. dorsalis* in fruiting and vegetative based on wind speed

Prediction models at fruiting and vegetative phase for *B. dorsalis* were developed based on wind speed. The highest coefficient of determination was obtained in fruiting phase of 2014 with R^2=0.74. The variability of occurrence fruit fly could explain to an extent of 52% in pooled data of 2014 and 2015 which includes both vegetative and flowering phase of mango (Table 4). Based on these models, predicted number of fruit flies was calculated by substituting the value of wind speed as x in the equation. Student 't' test showed that there was no significant difference between observed and predicted number of fruit flies. Hence these models hold good to predict the fruit fly population based on wind speed. The pooled data of fruiting phase of both the years 2014 and 2015 also showed the positive trend in the occurrence of *B. dorsalis* with wind speed (Fig.5). With increase in the windspeed, the number of fruit flies also increased. Variability in the occurrence of *B. dorsalis* due to wind speed was further regressed and accounted to the extent of 48%. The linear model y = 2.513x - 0.883 explained this occurrence the best.

The observed and computed number of fruit flies in fruiting phase of 2014 and based on wind speed is indicated in Fig. 6. Plotting observed and predicted average number of trap catch in y-axis, observed dates in x-axis and windspeed in z-axis indicated that there was no significant difference between observed and computed number of fruit flies. Hence this model holds good in predicting the fruit fly population.

Table 4: Prediction models for fruit fly in fruiting and vegetative phase based on wind speed

Period	Year	Models	R^2	Observed	Predicted	't' test
Fruiting phase	2014	y=2.66x-3.94	0.74	13.54	13.13	NS
	2015	y=2.67x+0.54	0.41	15.88	15.87	NS
	2014 and 2015	y=2.51x-0.88	0.48	14.64	14.63	NS
Fruiting and vegetative phase	Pooled 2014 and 2015	y=2.44x-1.30	0.52	12.37	12.36	NS

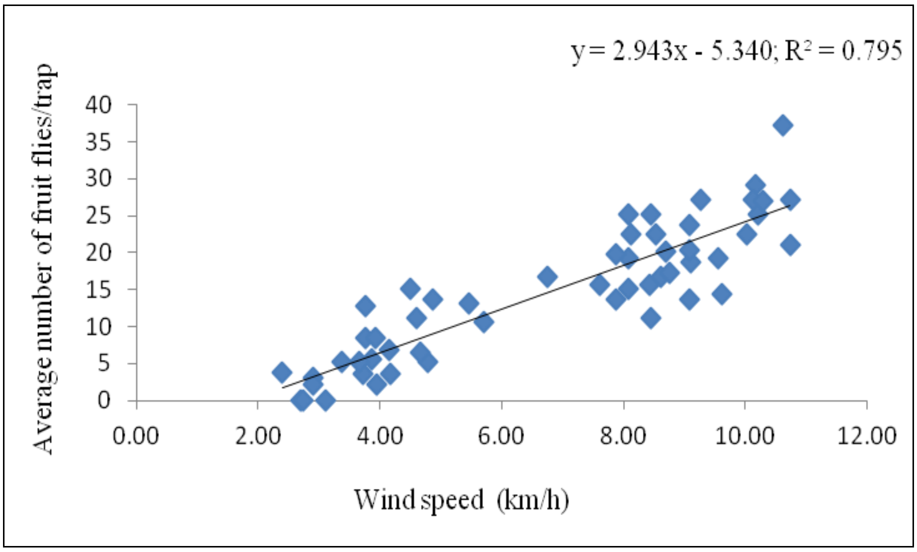

Fig 5: Effect of wind speed on populaion of *B.dorsalis* in fruiting phase of mango (pooled) 2014-15

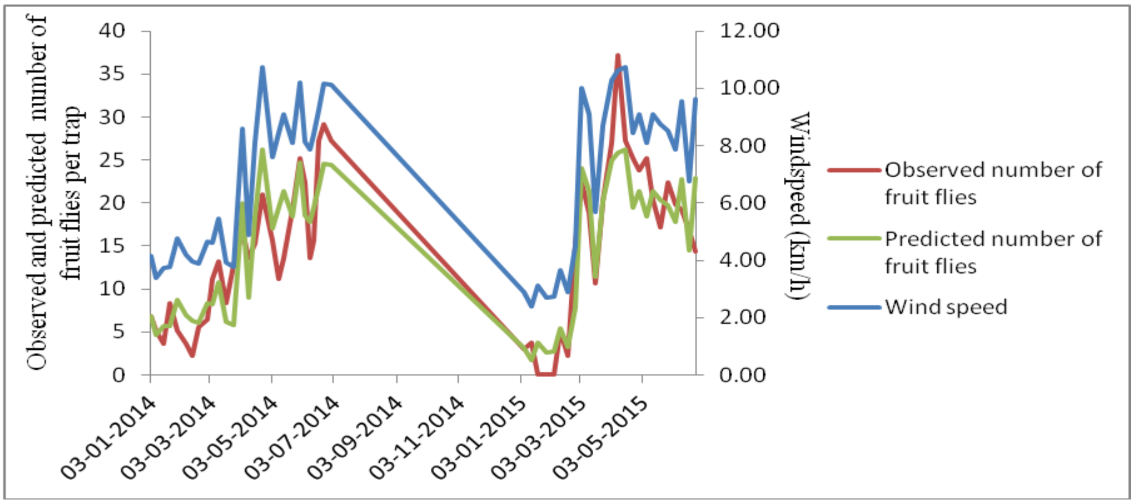

Fig 6: Observed and predicted number of fruit flies per trap in fruiting phase (2014-15) based on wind speed

3.5 Prediction models for *B. dorsalis* in fruiting and vegetative phase based on rainfall

Prediction models were developed for *B. dorsalis* based on rainfall. The highest coefficient of determination was obtained in fruiting phase of 2014 with R^2=0.51. The variability of occurrence fruit fly could explain to an extent of 31% in pooled data of 2014 and 2015 which includes both vegetative and flowering phase (Table 5). Based on these models, predicted number of fruit flies was calculated by substituting the value of rainfall as x in the equation. Student't' test showed that there was no significant difference between observed and predicted number of fruit flies. Hence these models hold good to predict the fruit fly population based on rainfall.

The pooled data of fruiting phase of two years of study 2014 and 2015 also showed a positive trend in fruit fly trap catch with rainfall. With increase in the rainfall the number of fruit flies also increased and this was explained to the extent of 41%. Dynamics of *B. dorsalis*, was explained the best by the linear model y = 0.183x + 10.92 (Fig.7).

The observed and predicted number of fruit flies in fruiting phase of 2014 and 2015 based on rainfall is indicated in Fig.8. Observed and predicted average number of trap catch was plotted on y-axis, observed dates on x-axis and rainfall on z-axis indicated that there was no significant difference between observed and computed number of fruit flies. The computed predicted fruit fly population was closer to the observed fruit fly population in the field. The number of *B. dorsalis* increased with increase in rainfall.

Table 5: Prediction models for fruit fly in fruiting and vegetative phase based on rainfall

Period	Year	Models	R^2	Observed	Predicted	't' test
Fruiting phase	2014	y = 0.166x + 10.87	0.51	13.54	13.43	NS
	2015	y = 0.178x + 12.58	0.26	15.88	15.72	NS
	2014 and 2015	y = 0.183x + 10.92	0.41	14.64	14.01	NS
Fruiting and vegetative phase	Pooled 2014 and 2015	y = 0.126x + 8.606	0.31	12.37	11.46	NS

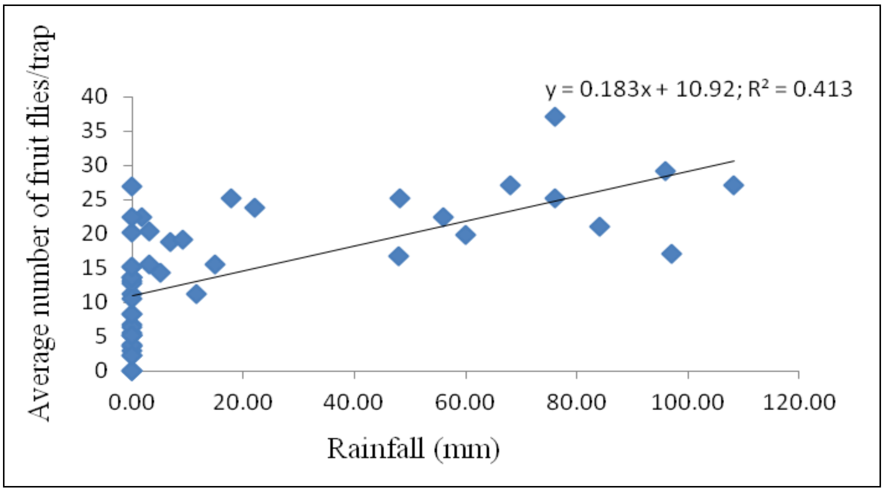

Fig 7: Effect of rainfall on populaion of *B.dorsalis* in fruiting phase of mango (pooled) 2014-15

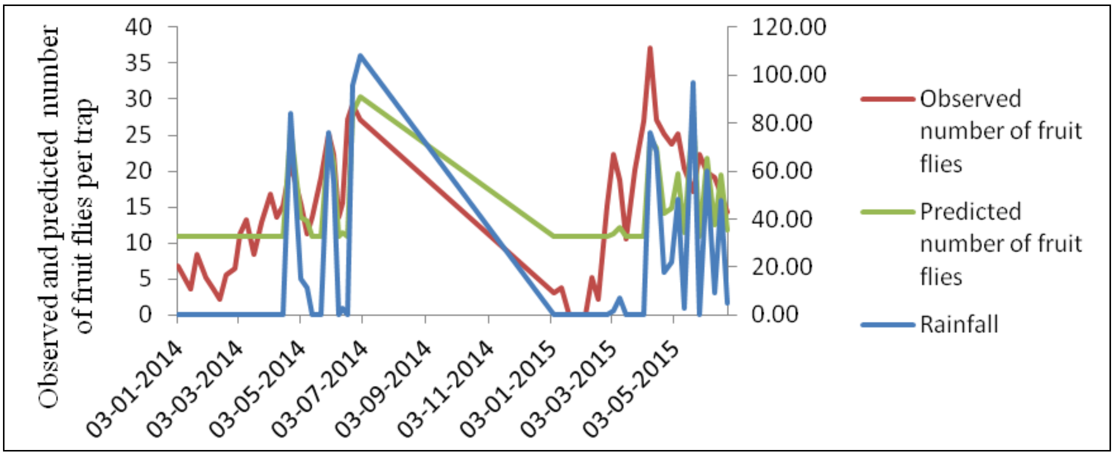

Fig 8: Observed and predicted number of fruit flies per trap in fruiting phase (2014-15) based on rainfall

3.6 Multiple regression models to estimate the *B. dorsalis* population based on weather parameters

The multiple regression model considering abiotic factors such as maximum temperature (x_1), minimum temperature (x_2), wind speed (x_3) and rainfall (x_4) that are significantly correlated with fruit fly population in fruiting phase of both the years resulted in 83% of variability. However the highest coefficient of determination (R^2) was found in the second year (2015) of fruiting phase which explained the variability up to 91% compared to first year (2014) of fruiting phase which could explain the variability up to 83%. Multiple regression analysis of both flowering and vegetative phase of 2014 and 2015 along with weather parameters could explain the variability up to 75% (Table 6).

Based on these models the predicted fruit fly population was calculated by substituting the value of respective weather parameters in x. Observed and predicted number of fruit flies was subjected to t-test to test the significant difference between them. It was found that there was no significant difference between observed and predicted number of fruit flies in both the years of study period.

Table 6: Multiple regression models to estimate the population of B. dorsalis trap catch based on weather parameters

Period	Year	Models	R^2	Observed no. of fruit flies	Predicted no. of fruit flies	't' test
Fruiting phase	2014	$y= -21.022+0.16x_1+1.02x_2+1.36x_3+0.04x_4$	0.83	13.54	13.29	NS
	2015	$y= -83+2.03x_1+2.03x_2-0.70x_3+0.07x_4$	0.91	15.88	15.54	NS
	2014 and 2015	$y= -62.38+1.51x_1+1.49x_2+0.28x_3+0.04x_4$	0.83	14.64	14.56	NS
Fruiting and vegetative phase	Pooled 2014 and 2015	$y= -54.32+1.31x_1+0.95x_2+1.399x_3+0.03x_4$	0.75	12.37	11.33	NS

x_1 maximum temperature, x_2 minimum temperature, x_3 wind speed and x_4 rainfall

4. Discussion

Insect pests are highly sensitive to weather and appear less hardy to withstand the vagaries of climate change. This sensitivity of the host plants to shows its effect on the insect populations, foraging activity and insect diversity [5]. Abiotic factors are universal determinants for insect biodiversity [6] affecting the activity or condition of individuals of a species that may alter their competitiveness or defensive ability [7]. Temperature plays a vital role on insects, as they are poikilotherms and probably it is the single most important environmental factor that could influence insect behaviour, distribution, development, survival and reproduction [8, 9]. Kanan and Rao [10] reported that maximum and minimum temperature was positively correlated whereas rainfall and relative humidity were negatively correlated with fruit fly population. Ye and Liu [11] reported that temperature and rainfall positively correlated to population build up of fruit fly. Rainfall below 50mm per month or above 250mm reduced the fruit fly population significantly whereas rainfall below 100-200mm increased the fuit fly population significantly; the present study is also in resonance with the above findings.

The present study showed that there was a significant positive correlation with maximum and minimum temperature, wind speed and rainfall which is in accordance with findings of Verghese and Devi [12], Verghese and co-workers [13]. Studies conducted by Singh [14] with *B. dorsalis* in India indicated that the pupal period was the longest (18 days) at 15 ^{0}C and the shortest (6 days) at 35 ^{0}C. Abundance of *Anastrepha* populations has been positively correlated with temperature and negatively correlated with relative humidity [15]. However, a study by Aluja [16] demonstrated the lack of a clear relationship between rainfall and *Anastrepha* fly captures in mango orchards in Mexico. However, studies conducted by Tan and Serit [17] showed that rainfall, temperature, relative humidity and wind speed had no significant correlation with estimated *B. dorsalis* male fruit fly population in Penang Island, Malaysia and also found that population of fruit fly was low during dry season and whereas high during wet season. Jayanthi and Verghese [2] reported that small immature fruits of *Psidium guajava* were found as the most efficient predictor for forecasting the population of *B.dorsalis* in guava

5. Conclusion

It may be concluded that fruit fly population was positively and significantly correlated with maximum, minimum temperature, wind speed and rainfall at fruiting and vegetative phase of mango. Prediction models were developed for maximum and minimum temperature, wind speed and rainfall to predict the fruit fly population in vegetative and flowering phase. Simple linear regression of wind speed during the second year of the study period gave the highest co-efficient of determination (R^2=0.74) compared to other weather variables in fruiting phase of mango. However, multiple linear regression analysis using all the significant four weather parameters as independent variables explained the variability up to 83% in the pooled data of fruiting phase. However, wind speed can alone could explain the variability up to 74%. Thus, the wind speed as an independent variable can be used to predict the fruit fly population accurately as there was no significant difference in the observed and predicted number of fruit fly. The linear model for wind speed can be considered as an optimized model to predict fruit fly population in the organic mango which forms a baseline for the effective IPM strategy.

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