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Weather based forecasting models for prediction of leafhopper population *Idioscopus nitidulus* Walker; (Hemiptera: Cicadellidae) in mango orchard

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Abstract
Predicting the population of *Idioscopus nitidulus* well in advance can lead to the successful IPM program where a timely intervention and proper management of pest can be scheduled. The present study aimed at determining the effect of abiotic variables on population buildup of leafhoppers in an organic mango orchard to develop weather forecast models for hoppers. Correlation matrix between *I. nitidulus* and weather parameters was worked out, followed by regression to obtain a comprehensive weather forecast model for the pest. Significant (p= 0.05) correlations were observed in trends of hopper population and between maximum temperature (positive) and relative humidity-I (negative). The simple linear regression explained the highest variability R^2= 0.77 and R^2= 0.42 with maximum temperature and relative humidity-I respectively. Multiple regression analysis with both maximum temperature and relative humidity-I as independent variables could explain the variability up to 70%. Thus, simple linear regression model derived for maximum temperature had the strongest relationship for the population build-up of hoppers. The best single predictor, maximum temperature is proposed as a reasonable precision indicator suitable for forecasting the changes in population of hoppers that can be used in management decisions.

Keywords: Mango, leafhopper, *Idioscopus nitidulus*, prediction, weather

1. Introduction
Mango (*Mangifera indica* L.), known as the 'king of fruits' is an important seasonal fruit crop grown in the tropical and sub-tropical countries of the world [1]. India is the largest producer of mango in the world with an annual production of 16.26 million tons [2]. Mango occupies 36.7 per cent of the area under fruits and contributes 21.3 per cent of the total fruit production in the country [3]. Insect pests and diseases are the major constraints in mango production as they not only reduce the total production but also hamper the fruit quality. Among various pests, leafhoppers are considered as the most serious and widespread, that attack inflorescence and young shoots [4, 5]. The wedge shaped nymphs and adults puncture and suck the sap of tender parts, reduce vigour of plants and damage the inflorescence causing fruit drop [6]. Heavy puncturing and continuous draining of sap causes curling and drying of infested tissue. Hoppers damage the crop by excreting honeydew, which promotes the development of sooty mould, a fungi *Capnodium mangiferae* [7] on the surfaces of leaves, and fruits which reduce the photosynthetic rate thus results in reduced yield. *Idioscopus nitidulus* colonize during both vegetative and reproductive phases of the crop. Hoppers remain active throughout the year in cracks and crevices of the mango trunk [8] but they are recorded on twigs, young leaves and inflorescence [9]. The efficiency of any management strategies mainly depends on the leafhopper population, so prediction of hopper population levels well in advance would help greatly to plan/implement the management strategies as it will aid precise determination of the timings of treatments in order to maximize their effectiveness and minimize the number of sprays required [5]. Hence, it is very crucial to predict the field population of pests and thus, accurate forecasting of pest incidence forms part of an effective management strategy.

Many workers have reported on seasonal incidence and influence of weather parameters on the development of the hoppers [10-14], but information pertaining to its development and predicting the abundance of leafhoppers based on the weather parameters in different phases (vegetative and flowering) is lacking. Hence detailed studies were carried out to determine the effects of some abiotic factors on population build up of hoppers and to develop prediction models for leafhoppers 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. The hopper numbers were estimated by visual counts using a hand lens. For each sampling five random panicles/fresh shoots were selected from the four directions of the canopy *viz.* north, south, east and west. Thus from each tree 20 number of sampling units were selected. Twenty eight trees were sampled, twice in a week from 3rd week of July 2013 to 4th week of March 2015 constituting of 560 sampling units/day. These trees were maintained organically without the use of any pesticides. Observations were taken on the nymphs and adults of the hopper. These were tabulated and then total number/tree from 20 panicles was documented. Observations on population buildup of both nymphs and adult were recorded at morning hours (9.30-10.30 am) since winged pests are sluggish and easily counted. Since *I. nitidulus* colonize both in vegetative and flowering phase the populations of hopper were recorded in both the phases for two consecutive years i.e., vegetative phase (July-Dec 2013 and 2014) and flowering/ reproductive phase (Jan- Mar 2014 and 2015).

The weather parameters *viz.*, maximum and minimum temperature (°C), relative humidity I and II (%), total rainfall (mm) and wind speed (km/h) of selected site were collected everyday from meteorological section of ICAR-IIHR from July 2013 to March 2015.This was subsequently utilized to correlate with the status of pest population in both vegetative and flowering phase for the two study years. Data were analyzed using correlation and regression to obtain prediction models [15]. From the models developed predicted hopper population (dependent variable) for a given independent weather variable was calculated, the observed and predicted hopper population were subjected to‘t’ test at p= 0.05 to test if there was any significant difference between them.

3. Results and Discussion

3.1 Population dynamics of mango leafhoppers and their relationship between weather parameters in vegetative and flowering phase

3.1.1 Vegetative phase

Leafhoppers were monitored during vegetative phase (leaf formation stage) and reproductive growth phase (flower formation stage) of mango during 2013-2015. During first year of the study period (Jul-Dec, 2013) there was a significant positive correlation between hopper population and maximum and minimum temperatures and a significant negative correlation between hopper population and relative humidity I and II (morning and evening). There was a non-significant correlation with rainfall and wind speed (Table 1).

During the second year of the study period (2014) hopper population had significant positive correlation with maximum temperature and non-significant correlation with minimum temperature. Relative humidity had significant negative correlation on hoppers. The pooled analysis of both the years further confirmed this. There was a significant positive correlation with rainfall and wind speed had no significant correlation with hopper population. Hence maximum temperature and relative humidity-I were consistently significantly related to the hopper population than any other weather parameters during vegetative phase (Table-1).

3.1.2 Flowering phase

Similar analyses were performed on the data collected during 2013 for hopper populations in flowering phase of the study period. It was found that the maximum temperature and hopper population were correlated significantly positive. However, the hopper population had significant negative correlation with relative humidity-I. The results were consistent and the same trend was noticed in the second year, 2014 (Table-1). Further the pooled analysis of vegetative phase and flowering phase of two years and combining both vegetative and flowering phase of both the years confirmed that maximum temperature and relative humidity-I were the most significant weather parameters to relate the hopper population. Thus it may be opined that among six weather parameters maximum temperature and relative humidity-I were significantly correlated with hopper population.

Table 1: Correlation matrix of mango leafhopper and weather parameters in different phases

Weather parameters	Vegetative phase			Flowering phase			Vegetative and flowering phase
	Jul-Dec 2013	Jul-Dec 2014	Pooled	Jan- Mar 2014	Jan-Mar 2015	Pooled	Pooled
Maximum Temp °C	0.84*	0.84*	0.81*	0.81*	0.94*	0.84*	0.83*
Minimum Temp °C	0.80*	0.23	0.39*	0.85*	0.32	0.52*	0.10
RH I (7.30 am)%	-0.46*	-0.33*	-0.37*	-0.65*	-0.60*	-0.50*	-0.51*
RH II (1.30 pm)%	-0.42*	-0.16	-0.21	-0.20	0.11	-0.02	-0.27*
Wind speed (km/h)	0.15	0.17	0.10	0.34	0.46	0.39	0.03
Rainfall (mm)	0.18	0.51*	0.48*	0.00	0.12	0.11	0.12

*Significant at p= 0.05

3.2 Prediction models for leafhoppers in vegetative and flowering phase based on maximum temperature

Prediction models were worked based on the correlation established between hopper population and weather parameters. Since maximum temperature and relative humidity-I of all the different phases had its impact on population build-up in the organic mango orchard only these two parameters were taken for developing the prediction models.

Population of hoppers and maximum temperature were subjected to linear regression to obtain the models for different phases. From the data collected, it was noticed that the computed predicted hopper population was closer to the observed hopper population in the field with coefficient of determination (R^2) 0.82 and 0.76 in vegetative phase in 2013 and 2014 respectively (Table.2). This showed that the variability in the hopper population could be explained by temperature by 82% and 76% in 2013 and 2014 respectively.

Similarly hopper population during flowering phase was also compared and found that the observed and predicted values were closely related with R^2 value of 0.86 and 0.88 respectively in 2013 and 2014. In pooled analysis the linear model for weather variable independently explained the variability for population buildup of hoppers up to 71% and 80% in vegetative phase and flowering phase respectively for two study years (Fig.1). When the data of both vegetative and flowering phase of both the study years were pooled the variability was explained up to 77% (Table.2). The t-test was done to test the significance between observed and predicted number of hoppers and was found non-significant, which indicated that there was no significant difference between observed and predicted number of hoppers (Table-2).

The graphical representation of effect of maximum temperature on hopper population during vegetative and flowering phase is given in Fig.1. Plotting the residuals of observed and predicted hopper population with maximum temperature as independent variables is given in Fig.2.

Table 2: Prediction models for leafhoppers in vegetative and flowering phase based on maximum temperature

Period	Vegetative phase						Flowering phase	
	Jul-Dec 2013		Jul-Dec 2014		Pooled		Jan-Mar 2014	
Model based on Max. temp	y= 10.03x-267.2, R^2= 0.82		y= 9.35x-241.8, R^2= 0.76		y = 9.50x-248.5, R^2= 0.71		y = 16.70x-432.9, R^2= 0.86	
	Observed	**Predicted**	**Observed**	**Predicted**	**Observed**	**Predicted**	**Observed**	**Predicted**
No. of hoppers/tree	16.24	15.75	20.03	19.39	18.62	17.93	38.13	38.56
t (p=0.05)	NS		NS		NS		NS	

Period	Flowering phase				Pooled (Vegetative and Flowering phase 2013-15)	
	Jan- Mar 2015		Pooled			
Model based on Max. temp	y =10.35x-266.4 R^2= 0.88		y = 9.46x-235.6, R^2= 0.80		y = 10.18x-264.5, R^2= 0.77	
	Observed	**Predicted**	**Observed**	**Predicted**	**Observed**	**Predicted**
No. of hoppers/tree	42.08	41.84	40.23	39.32	25.40	24.08
t (p=0.05)	NS		NS		NS	

*NS=Non-significant

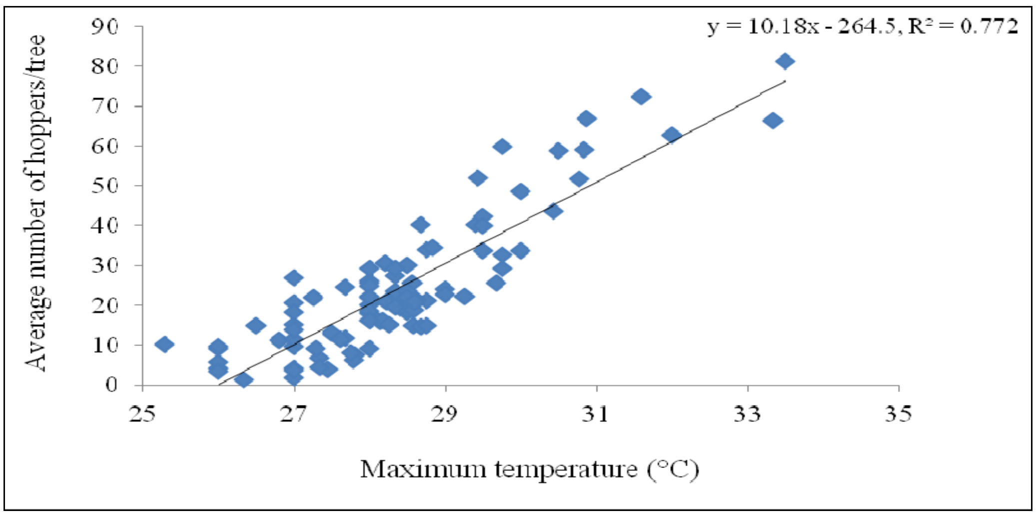

Fig 1: Effect of maximum temperature on population of *I. intidulus* in vegetative and flowering phase of mango (pooled) 2013-2015

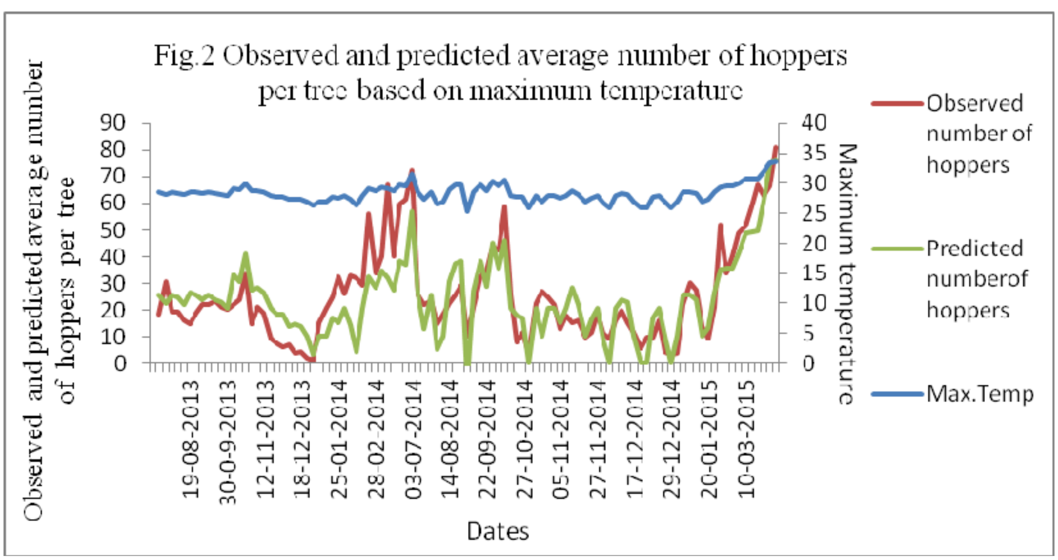

Fig 2: Observed and predicted average number of hoppers per tree based on maximum temperature

3.3 Prediction models for leafhoppers in vegetative and flowering phase based on relative humidity –I

The regression analysis using relative humidity-I as independent variable and hopper population as dependent variable showed that variability of hopper population was not beyond 31% in vegetative phase of the two study years with R^2 0.30 and 0.31for the years 2013 and 2014 respectively. However, in flowering phase, the variability could explain up to 70% and 67% in 2014 and 2015 and when pooled only 54% of variability was explained. The pooled data of both vegetative and flowering phase was regressed and the variation in the population of hopper due to relative humidity-I could be explained up to 42% (Table.3). The graphical representation of effect of relative humidity–I on hopper population in vegetative and flowering phase is given in Fig.3. Observed and predicted number of hoppers with relative humidity as independent variable is given in Fig.4.

Table 3: Prediction models for leafhoppers in vegetative and flowering phase based on relative humidity –I

Period	Vegetative phase						Flowering phase	
	Jul-Dec 2013		Jul- Dec 2014		Pooled		Jan-Mar 2014	
Model based on RH- I	y=-1.27x+114.9, R^2=0.30		y = -1.95x+156.9, R^2=0.31		y = -1.32x+116.3, R^2=0.33		y = -3.72x+320.6, R^2=0.70	
	Observed	**Predicted**	**Observed**	**Predicted**	**Observed**	**Predicted**	**Observed**	**Predicted**
No. of hoppers/tree	16.24	16.81	20.03	20.53	18.62	20.50	38.13	40.40
t (p=0.05)	NS		NS		NS		NS	

Period	Flowering phase				Pooled (vegetative and flowering 2013-15)	
	Jan- Mar 2015		Pooled			
Model based on RH- I	y = -1.80x+151.1, R^2=0.67		y = -1.39x+135.7, R^2=0.54		y = -1.350x + 120.3, R^2=0.42	
	Observed	**Predicted**	**Observed**	**Predicted**	**Observed**	**Predicted**
No. of hoppers/tree	42.08	41.19	40.23	41.07	25.40	24.37
t (p=0.05)	NS		NS		NS	

*NS=Non-significant

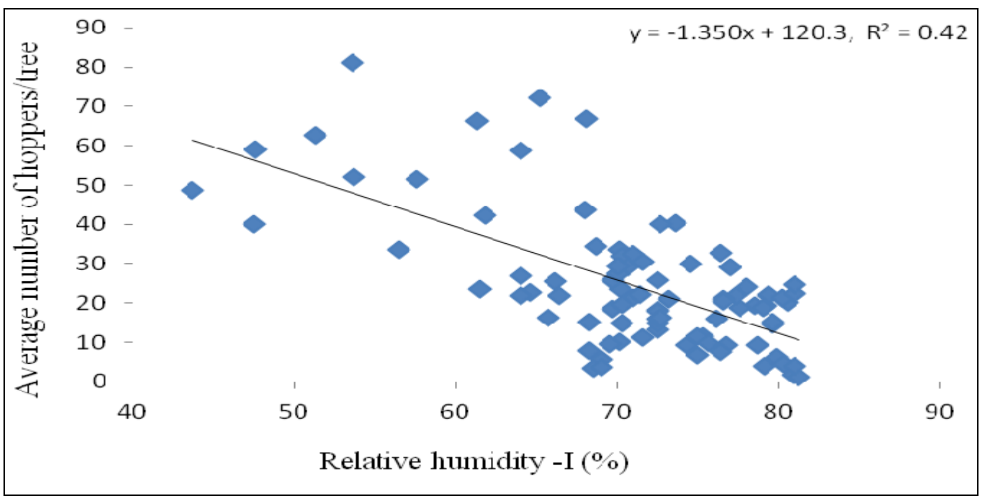

Fig 3: Effect of relative humidity on population of *I. intidulus* in vegetative and flowering phase of mango (pooled) 2013-2015

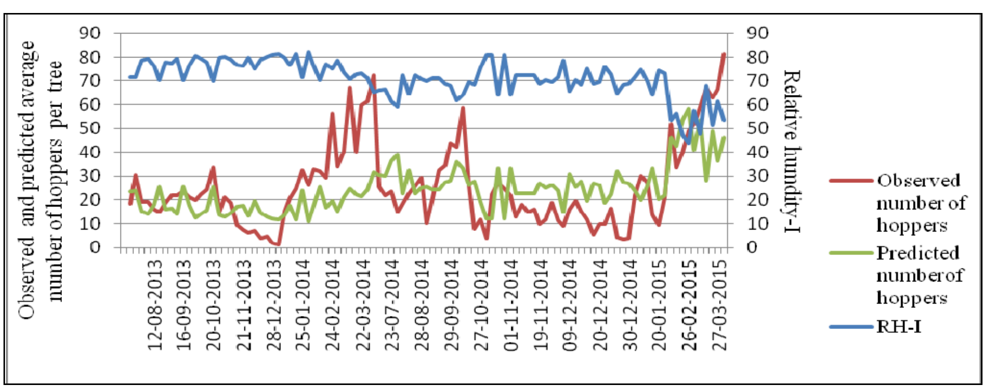

Fig 4: Observed and predicted average number of hoppers per tree based on relative humidity-I

Multiple regression analysis using both maximum temperature and relative humidity as independent variables, the variability in different phases was more than 70% during vegetative phase of both the years (Table.4). However when the pooled data of different seasons were analysed using maximum temperature alone as independent variable the variability was 77% compared with pooled data with both maximum temperature and relative humidity-I was 70%.

Hence, simple linear regression analysis of maximum temperature alone can predict the hopper population accurately to obtain precise and accurate models for prediction with minimum number of variables. Therefore, only maximum temperature alone can be used for the prediction of hopper population.

Table 4: Observed and predicted population of hopper (*Idioscopus nitidulus*) in different phases of organic mango orchard based on maximum temperature and relative humidity-I (multiple regression)

Period	Vegetative phase						Flowering phase	
	Jul-Dec 2013		Jul- Dec 2014		Pooled		Jan-Mar 2014	
Model based on max. temp and RH-I	$y= -208.86+9.08x_1-0.40x_2$ $R^2=0.73$		$y=-188.25+8.40x_1-0.37x_2$ $R^2=0.73$		$y= -168.97+8.19x_1-0.58x_2$ $R^2= 0.72$		$y= -110.59+10.29x_1-1.88x_2$ $R^2= 0.84$	
	Observed	**Predicted**	**Observed**	**Predicted**	**Observed**	**Predicted**	**Observed**	**Predicted**
No. of hoppers/tree	16.23	16.44	20.06	20.36	18.61	18.45	39.76	39.83
t (p=0.05)	NS		NS		NS		NS	

Period	Flowering phase				Pooled (vegetative and flowering 2013-15)	
	Jan- Mar 2015		Pooled			
Model based on max. temp and RH-I	$y=-224.52+9.53x_1-0.28x_2$ $R^2= 0.84$		$y= -236.45+9.34x_1+0.07x_2$ $R^2=0.71$		$y= -211.19+9.25x_1-0.36x_2$ $R^2= 0.70$	
	Observed	**Predicted**	**Observed**	**Predicted**	**Observed**	**Predicted**
No. of hoppers/tree	42.07	42.2	40.22	39.66	25.39	25.44
t (p=0.05)	NS		NS		NS	

*NS=Non-significant

The maximum temperature alone gave the highest coefficient of determination of 77% compared to relative humidity 42% in pooled data.

4. Discussion

From the above results it was noticed that in an organic mango orchard the population of *I. nitidulus* had a significant positive correlation with maximum temperature and significant negative correlation with relative humidity which are in accordance with the findings of many workers viz., Dalvi [11]. and Dwivedi [13]. Relative humidity had negative effect on hopper population, which was in conformity with the findings of Tandon [16]. Hiremath [12]. and Pezhman [17]. Their studies have not gone beyond to suggest prediction models for use in IPM. There is scanty information on weather forecast model for mango orchard managed under organic plant protection schedule.

Based on the result of two years study, prediction models were developed for both temperature and humidity to predict the occurrence of leafhoppers in vegetative and flowering phases in an organic mango orchard. Simple linear regression of maximum temperature as independent variable gave the highest co-efficient of determination ($R^2= 0.77$) and relative humidity could explain the variability up to 42% in pooled data. Multiple regression analysis using both maximum temperature and relative humidity-I as independent variables explained the variability up to 70%. However, the maximum temperature as an independent variable can be used to predict the hopper population accurately as there was no significant difference in the observed and predicted number of hoppers.

The linear model for maximum temperature can be considered as an optimized model to predict hopper population in mango orchard. Further, the validation of the optimized model based on the observed number of hoppers compared with predicted values clearly indicated that the model could predict the hopper population efficiently and reliably.

Higher temperature seemed to promote hopper build up, while rising relative humidity indicated declining trend in the population of hoppers. Hoppers, therefore seemed to adapt well to drier weather, which is the situation during the flowering and fruiting phases of mango during summer. However, between the two variables temperature and relative humidity the former is critical. Even if relative humidity is high, if temperature goes up, hoppers can show increasing trend, which is the case in coastal belts [11]. When forecasting becomes central it is therefore, more appropriate to choose the most reliable factor which was maximum temperature in this study. Relative humidity the next important factor will be valid in the plains and non-coastal areas.

The hopper *Idioscopus nitidulus* is a major limiting factor in flower survival and fruit set. It has two phases of breeding during flowering and vegetative phases. If it can be predicted at vegetative phase, then managing them will prevent establishment in the orchard during the flowering phase which follows. Monitoring temperature and relative humidity will help in keeping vigil on the hopper. This is crucial in both organic and conventional mango orchards. In organic available means for managing *I. nitidulus* is only through sprays of azadirachtin [18] which work only at low to moderate population levels. So it is crucial to use the botanicals at initial incidence levels. This study is therefore useful in generating timely organic intervention for management of *I. nitidulus* in organic mango, and in conventional orchard as well, as weather parameters equally affect the *I. nitidulus* population in either situation. This forms the base line for integrated pest management strategies for the timely intervention and management of leafhoppers.

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