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Population growth study of cowpea aphid, *Aphis craccivora* using statistical modeling

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Abstract
The present investigation deals with the critical study of population growth of cowpea aphid by using Prajneshu's nonlinear regression model. The parameters of the model were estimated using Levenberg-Marquardt's method. Coefficient of determination (R^2), root mean squared error (RMSE) and mean absolute error (MAE) were used to examine the goodness of fit of the model. Diagnostics of residuals were carried out using run test and Shapiro-Wilk test. Prajneshu's model described well the behavior of aphid population growth in cowpea crop.

Keywords: Aphid, nonlinear model, cowpea

Introduction

Cowpea, *Vigna unguiculata* (Linnaeus) Walpers belong to family Fabaceae/ Papilionaceae and sub family Fobaidae/ Papillionoidae. It is one of the most essential pulse crops of tropics. In India, the total area under pulses is 25.26 million hectares with the total production of 16.47 million tonnes and productivity of 652 kg per hectare. Whereas in Gujarat, the total area under pulses is 0.60 million hectares having total production of 0.53 million tonnes with the productivity of 890 kg per hectare. In Gujarat, the area under cowpea is 0.52 million hectares and the production of 0.35 million tonnes with a productivity of 665 kg per hectare (Anon., 2015) [1]. Out of different constraints responsible for the low yield of pulse crops, the damage by the insect pest is considered to be a key constraint. Studies revealed that 21 insect pest of different groups are involved in damaging the cowpea crop (Prajapati *et al.*, 2009) [7]. Among them, aphid (*Aphis craccivora*) is the key pest of cowpea causing economic and significant losses directly by sucking the cell sap from leaves, twigs, pods. Whereas, ramblingly through the transmission of viral diseases. It causes significant yield loss of about 20-40 per cent in Asia (El-Ghareeb *et al*., 2002) [3]. Obopile (2006) [6] reported that allowing aphids to feed on cowpea plants further than three weeks resulted in more than 50 per cent yield losses. Keeping in view of these points, population growth study of cowpea aphid (*Aphis craccivora*) was carried out.

In order to study complex phenomenon like population growth of an organism nonlinear models are used. Different types of nonlinear models available depending on the variation in the data set. In the present study, a special aphid population growth model is fitted to describe the growth of cowpea aphid population.

Materials and Methods

In order to study the population growth of aphid attacking cowpea, an investigation was carried out during *summer*, 2017. The study was carried out from 4^{th} week of February 2017 to 1^{st} week of May 2017 i.e. from 9^{th} to 19^{th} Standard Meteorological Week (SMW). Cowpea variety Pusa phalguni was sown at Main Vegetable Research Station, AAU, Anand. The crop was grown in plot size 15.30 x 10.80 meter with a spacing of 60 x 30 cm. All recommended agronomical practices were followed to raise the cowpea crop. The whole plot was kept free from the application of any insecticides. The cowpea plot was divided into six equal quadrates to record the incidence of aphid population. From each quadrate, five plants were randomly selected and tagged for recording the observations. The observations were recorded at weekly interval starting from one week after germination till the crop maturity. Aphid population was recorded by counting the number of aphids from 3 twigs of 3 cm per plant.

For present investigation, a special nonlinear model developed by Prajneshu (1998) [8] was used to study the dynamics of aphid population growth. The model was deterministic in nature and successfully described the dynamics of the aphid population growth. Prajneshu's model was fitted on the data set utilizing R v 3.6.1. The model proposed by Prajneshu was mentioned below:

$$Y_{(t)} = ae^{-bt}\left(1+de^{-bt}\right)^{-2} + \epsilon_t \quad (1)$$

Where,
$Y_{(t)}$ is aphid population density at time t,
ϵ_t is the error associated with time t,
a, b and d are the descriptive parameters which can be related to interpretative parameters by the following equations:

$$\gamma = \frac{a}{2db^2}, \quad (2)$$

$$Y_0 = \frac{a}{(1-d)^2} \quad \text{and} \quad (3)$$

$$\lambda = \left(b^2 - 2\frac{Y_0}{\gamma}\right)^{1/2} \quad (4)$$

Where,
λ is the intrinsic birth rate,
γ the death rate divided by the cumulative population density and
Y_0 the initial population density at time 0.
In literature, there are three different promising methods to fit nonlinear regression model *viz.* linearization, Steepest descent method and Livenberg-Marquardt's method (Draper and Smith, 1998) [2]. Among the three methods, Levenberg-Marquardt's method is most widely used as it outcomes the shortcomings of other methods (Marquardt, 1963) [5]. The present study utilizes Levenberg-Marquardt's method to fit the model.
R^2, RMSE (Root Mean Squared Error) and MAE (Mean Absolute Error) were utilized to check the goodness of fit of the model. Kvalseth (1985) [4] pointed out eight different forms of R^2. The expression of R^2 emphasized by him for nonlinear models is mentioned below along with RMSE and MSE.

$$R^2 = 1 - \frac{\sum_{i=1}^{n}(Y_i - \widehat{Y}_t)^2}{\sum_{i=1}^{n}(Y_i - \bar{Y})^2}, \quad (5)$$

$$RMSE = \left[\frac{\sum_{t=1}^{n}\left(Y_t - \widehat{Y}_t\right)^2}{n}\right]^{1/2} \quad and \quad (6)$$

$$MAE = \frac{\sum_{t=1}^{n}\left|Y_t - \widehat{Y}_t\right|}{n} \quad (7)$$

Where,
Y_t is the observed aphid population at time t;
$\widehat{Y}_t$ is the predicted aphid population at time t;
n is the number of observations

The two main assumptions of nonlinear model i.e., normality and independence of the residuals were checked by examining the residuals. The independence of residuals was checked by using run test (Siegel and Castellan, 1988) [10]. The normality of the residuals was examined by using Shapiro-Wilk test (Shapiro and Wilk, 1965) [9].

Results and Discussion

Large set of initial values were tried out during modelling to ensure global convergence. The parameters, as well as standard error of the fitted model, are presented in Table 1.

Table 1: Parameter estimates of the fitted model

A	b	d
0.062 (0.046)	-1.038 (0.108)	0.0005 (0.0004)

The values in the parenthesis are standard error.

The R^2 value (Table 2 A) for the model was observed to be 0.937, indicated that 93.7 percent of the observed variation in the number of aphids was explained by the model. The RMSE and MAE values were found to be 2.501 and 1.905, respectively. Similar results of high R^2 were obtained by Prajneshu (1998) [8] while studying aphid population for five years from 1976 to 1980 on two mustard varieties YSS-8 and Pusa Kalyani. Singh *et al.* (2017) [11] fitted the model on mustard aphid data and reported the RMSE and MAE to be 6.51 and 5.20, respectively. The result of the run test (Table 2 B) was a non-significant indicating fulfilment of the assumption of independence of the residuals. The Shapiro-Wilk test result (Table 2 B) revealed that the residuals were normally distributed.

Table 2: Model diagnostics

A) Goodness of fit statistics	
R^2	0.937
RMSE	2.501
MAE	1.905
B) Residual analysis	
Run test Z value	0.630 (0.529)
Shapiro-Wilk test statistic	0.901(0.1899)

The values in the parenthesis are p values

The graph of the predicted aphid population obtained from the model along with the observed aphid population is represented in figure 1. The highest observed, as well as the highest predicted aphid population, were found for the same week *i.e.* 15th SMW (Table 3). Similar findings were reported by Singh *et al.* (2017) [11] for the mustard aphid by using the same model. The management practices must be carried out in 13th or 14th SMW i.e., one or two weeks before the 15th SMW week where the aphid population is maximum. This will not allow the aphid population to reach a peak and prevent cowpea from the major damage.

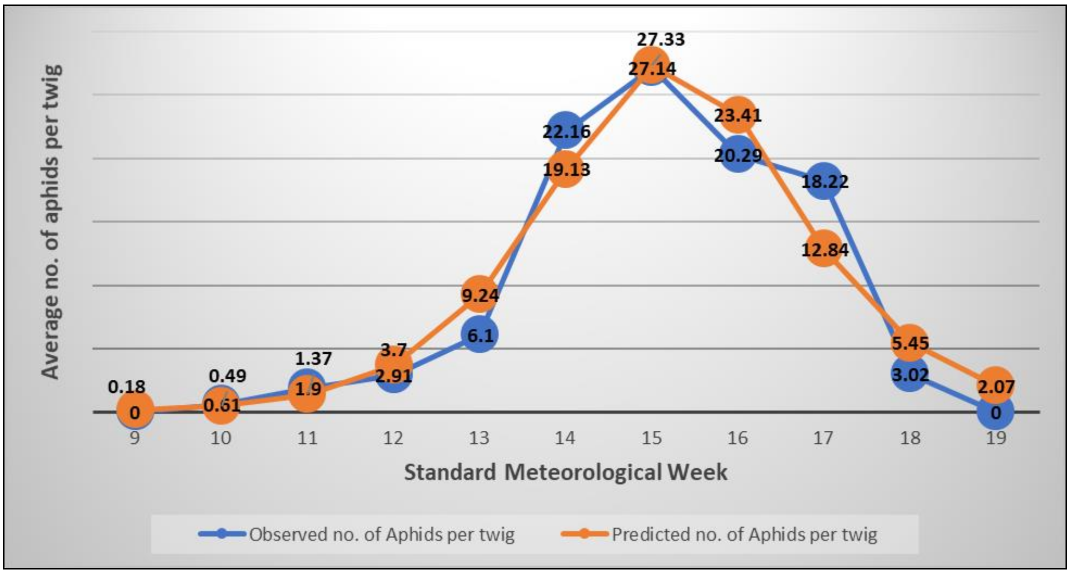

Fig 1: Observed and predicted aphids per twig

Table 3: Observed and predicted number of aphids per twigs

Standard Meteorological Week	Observed number of aphids per twig	Predicted number of aphids per twig
Week 9	0	0.18
Week 10	0.61	0.49
Week 11	1.9	1.37
Week 12	2.91	3.7
Week 13	6.1	9.24
Week 14	22.16	19.13
Week 15	27.14	27.33
Week 16	20.29	23.41
Week 17	18.22	12.84
Week 18	3.02	5.45
Week 19	0	2.07

Conclusion

The assumptions of randomness and normality of residuals were not violated. Further the goodness of fit statistics for the model were also satisfactory. Thus, it can be concluded that the model utilized in the study described well the behavior of aphid population growth in cowpea crop for Anand, Gujarat. This model can be utilized for the study of cowpea growth dynamics in area where climate resembles to the Anand, Gujarat.

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