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Nonlinear modelling of rice leaf folder infestation on Boro rice in Pundibari (A part of Cooch Behar district)

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Abstract
To an agricultural scientist crop pest is a major problem as it creates enormous damage to crops. Hence, a study was undertaken to study the dynamics *i.e.,* pattern of growth of the insect population over time during the life-term of the crop related to the occurrence of pest-growth on rice at Terai region, Uttar Banga Krishi Viswavidyalaya, Pundibari, Cooch Behar, West Bengal in the year 2015. Appropriate models have been investigated to model the pest-dynamics (per hill) on the rice crop, the pest and the crop being Rice-Leaf Folder and Boro Rice respectively. Out of the many models explored, the Cubic model provides the best fit and the said model has been employed to find out the date at which the maximum infestation has occurred. The data emanated from the present experiment (after analysis) reveal that the date (at which the maximum rate of growth with respect to infestation is observed) lies around 51 DAT in 2015.

Keywords: Nonlinear model, rice leaf folder, boro rice, pest-dynamics, pest-growth-rate

Introduction

In natural sciences one mainly studies the mechanistic formulation of different models and special emphasis is ascribed to the two streams of natural sciences, namely, agricultural and ecological sciences. It is obvious that mechanistic formulation explains the mechanism of the system under study in a better way, thus modelling plays a very important role in comprehending the underlying relationships among crucial variables operating in any system, nay, in natural sciences [1]. The objective of modelling the dynamics of any population (of insects/pests) is to understand how the respective population change arises owing to the interplay of environmental forces, density dependent regulation and inherent stochastic element embedded in the system [1]. This paper is devoted to an account (by means of modelling) of the growth of the pest, Rice Leaf Folder, over time on Boro rice crop in the Terai agro-climatic zone of North Bengal (rice being- the major and widely grown crop in West Bengal). Rice (season specific) is grown both as Boro crop and as *Aman* crop respectively [2].

Rice yield is declining slightly at global level [3] due to diminishing land and water resources, increased pests and diseases, global climatic change, environmental pollution and erosion of agricultural biodiversity partially caused by agrochemicals. The rice production in traditional rice-wheat zone (Kallar tract) is also towards decline [4]. Among the various factors contributing to low rice production, pests are among the most important ones. The rice crop provides food to more than half of the world’s population and hosts to over 800 species of insect herbivores from nursery to harvest but only a few of them are of potential threat and have gained the major importance as far as losses in yields caused by them, are concerned [5 & 6]. The control of these pests and insects has often relied on the extensive use of insecticides, which disrupt the beneficial insects and other insect fauna besides causing environmental pollution [7]. The rice varieties which are grown in Terai region are, Annanda, GB-1, MTU-1010, Parijat, Satabdi, Mashuri, MTU-7029, Malsira, Jaldhapa, Ranjana, Niranjana, etc.

Materials and Methods

A field experiment was conducted at the Farm of Uttar Banga Krishi Viswavidyalaya, Pundibari and seed sowing was initiated on 05.02.2015 at the nursery bed. Transplantation of the variety, *GB*-1into the main field was done on 03.03.2015.

The recording of the data was initiated on 17.03.2015 and it was continued up to 31.05.2015 for the year 2015. Harvesting of the crop was done on 10.06.2015.

For the above experiment, the field (Field size: 30 X 15 sq. m.) was divided into 4 numbers of strata and from each stratum the selection of the co-ordinates of one square meter area was randomly chosen (using random number table). Thus 10 co-ordinates per stratum were chosen for collection of the pest (Rice-leaf folder) data. During collection of pest data from Boro rice field, all plants in each square unit area were checked for the presence of number of pests (total number of pests were counted and recorded).

Growth model methodology has been widely used in the modelling-work on plant/pest growth. Since growth of living organisms are usually nonlinear, it is reasonable to explore the use of non-linear growth models to represent the growth-process of the pests. In order to tackle the devastating damage in crops by pests, it is required to know the growth trend of the pest population as part of formulating an integrated pest management system. Thus the dynamics of the growth of pest population, which is often non-linear as mentioned earlier, a host of the nonlinear growth models (along with linear growth model) has been explored for the pest (Rice-leaf folder) growth in agricultural field (under UBKV) in Terai region on Boro rice (details given above). The research work undertaken in the paper is based on the parameter estimation procedure with respect to the nonlinear growth model. The procedure consists of (i) determination of the initial values for each parameter and conduction of the statistical tests for studying pest dynamics of Boro rice crop. Eight nonlinear models are investigated and the corresponding equations are presented in Table 1. The best model has been selected on the application of the model performance criteria and it (best model) has been used to determine the pest (Rice-leaf folder) dynamics at any stage of the Boro rice crop subsequently.

Nonlinear models are difficult to construct as the parameter-solutions are determined iteratively [8]. The iterative method used in the nonlinear regression model include the modified Gauss – Newton method (Taylor series), gradient or steepest-descent method, multivariate secant or false position and more popularly the Marquardt method [8].

Table 1: Forms of different models used

Linear	$y = \alpha + \beta^* t$
Cubic	$y = \alpha + \beta^* t + \gamma t^2 + \delta t^3$
Logistic	$y = \alpha / \{1 + \beta e^{-kt}\}$
Gompertz	$y = \alpha \exp(-\beta e^{-kt})$
Malthus model	$y = \alpha \exp kt$
Monomolecular model	$y = \alpha \{1 - \beta e^{-kt}\} + e$
Richards model	$y = \alpha / \{1 + \beta e^{-kt}\}^{1/m}$
Chanter growth model	$N = \dfrac{N_0 - \beta}{N_0 + (\beta - N_0)\exp\{-\mu(1-\exp(-kt))/k\}}$

The usual statistical tests, which are appropriate in the general linear model case, are, in general, not appropriate when the model is nonlinear and one cannot simply use the F statistic to obtain the conclusions at any stated level of significance. The present study considers several procedures to test for the goodness of fit in case of nonlinear model. The procedures, confidence interval of the parameters estimated, asymptotic correlation matrix, residuals analysis and normality probability plots, have been carried out. The Mean Square Error (MSE), Mean Absolute Error (MAE), R^2 and Mean Absolute Percentage Error (MAPE) are used to measure the model performance. Here, MAPE is the average absolute percentage error over the forecast period considered. Following its definition, MAPE $= \frac{1}{N}\sum_{k=1}^{N}\frac{|F_k - A_k|}{A_k}$, where F_k and A_k are the forecast and actual values at the k-th point of time. Mean Absolute Deviation (MAD) or Mean Absolute Error (MAE) has been evaluated by the formula $\frac{1}{N}\sum_{k=1}^{N}|F_k - A_k|$.

Akaike's Information Criteria (AIC)

The general form for calculating AIC is: $AIC = -2.\ln(\text{likelihood}) + 2K$, where, *ln* is the natural logarithm and K is the number of parameters in the model. AIC can also be calculated using residual sums of squares from regression: Thus, $AIC = n.\ln\left(\frac{RSS}{n}\right) + 2K$, where, *n* is the number of data points (observations) and RSS is the residual sums of squares.

Bayesian Information Criterion (BIC)

In terms of the residual sum of squares (RSS) the BIC is $BIC = n.\ln(RSS/n) + K.\ln(n)$ where, K is the number of model parameters in the test. The process of selection among different models prefers the model which has the lowest BIC. The BIC is an increasing function of the error variance σ_e^2 and an increasing function of K. The implication is: the magnitude of the unexplained variation of the dependent variable and also the number of explanatory variables increase the value of BIC. Hence, the lower value of BIC implies either fewer explanatory variables or better fit or both.

ARPE (Average Relative Predictive Error) $= \frac{1}{n}\sum\frac{|\hat{y}_i - y_i|}{y_i}$, where, $\hat{y}_i$ is predicted value and y_i is the original observation.

Estimation of the time-points (in case of RLF) when (i) the rate of growth is maximum and (ii) the infestation is maximum, based on the best fitted model

After determination of the best fit model it may be interesting to obtain the time-instances at which (i) the maximum rate of growth of RLF population occurs and (ii) maximum infestation due to RLF occurs. In the following, the above

time points are denoted by the symbols, t_{opt} and t_{max} respectively. The time-point t_{opt} is important as it indicates the point of time when a protection measure, if undertaken, produces most effective control over the pest population. Also, the point of time, t_{max} addresses the time-point when the maximum built-up of the pest (RLF) population occurs.
The formulae for estimation of t_{opt} and t_{max} based on the cubic equation (best fitted) are given below:

Cubic Equation:
$y = \alpha + \beta t + \gamma t^2 + \delta t^3$; $t_{opt} = -\frac{\gamma}{3\delta}$; and
$t_{max} = -\frac{2\gamma \pm \sqrt{4\gamma^2 - 12\beta\delta}}{6\delta}$.

Results
The various models presented above are fitted on the RLF data (Table 2). For fitting the non-linear growth models the present study consider the average values of the number of pests obtained from different locations in each stratum at first. The number of pests are shown in Table 2 (corresponding to each DAT) and these values are actually an average of the observations (on number of pests) obtained from different strata. Statistical significance of each parameter in case of a particular non-linear model can be obtained by evaluating the 95 % confidence interval with respect to each parameter. The null hypothesis H_0: (all the parameters = 0) is tested by using appropriate F statistic. The scatter plot of the error (residual) is important in deciding whether the residual values (obtained after fitting the best model) are random or not.
Note: The RLF pest populations are allowed to grow in its natural way as no remedial measure like insecticidal spray is adopted. The pest data obtained from the rice field are plotted against time. The plot obtained for the above data show that pest infestation in the field increases linearly throughout the growing season of the crop (Fig. 1). For the whole field the RLF count starts with the value, 0.014 (average number of pests per hill) on the first date of observation (i.e., 40 days after sowing of the crop which is equivalent to 14 DAT) and ends with the value, 0.833 on the last date of observation (i.e., 115 days after sowing of the crop which is equivalent to 89 DAT).

Table 2: Pest counts on different DAT (2015).

No of Observations	DAT	Pest Count	No of Observations	DAT	Pest Count	No of Observations	DAT	Pest Count
1	14	0.014	12	47	0.412	23	80	0.777
2	17	0.056	13	50	0.438	24	83	0.808
3	20	0.061	14	53	0.489	25	86	0.833
4	23	0.118	15	56	0.524	26	89	0.833
5	26	0.136	16	59	0.555	27	92	0.833
6	29	0.178	17	62	0.589	28	95	0.833
7	32	0.212	18	65	0.632			
8	35	0.245	19	68	0.661			
9	38	0.288	20	71	0.695			
10	41	0.318	21	74	0.733			
11	44	0.364	22	77	0.758			

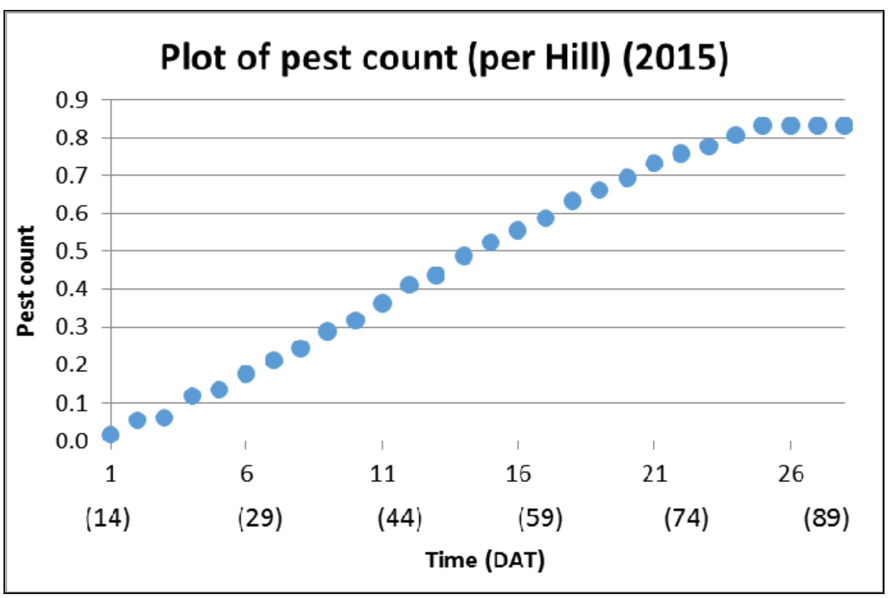

Fig 1: Scatter plot of the RLF population over time.

Identifying the best fitted non-linear Model
Eight (8) models (Table 1) were fitted on the data and the values of the precision coefficients were given in Table 3. Table 3 reveals that all eight models are almost equally precise, however, out of the eight models investigated, the cubic model (ARPE/MAPE) value is equal to 4.710/0.047 which is minimum among all ARPE/MAPE values) scores slightly better than the rest. Thus cubic model has been selected (among all models) for further analysis.

Table 3: Fitted R^2 values, Error mean square (EMS), Mean absolute error (MAE) & Mean absolute percentage error (MAPE) for different models.

Models	R^2 value	ESS	EMS	MAE	MAPE	AIC	BIC	ARPE values
Cubic	0.999	0.001	0.00004	0.006	0.047	-279.72	-273.39	4.718
Gompertz	0.998	0.004	0.00016	0.009	0.098	-276.98	-237.91	9.785
Logistic	0.996	0.009	0.00036	0.014	0.202	-218.20	-215.20	20.244
Richards	0.996	0.009	0.000375	0.014	0.202	-215.46	-211.87	20.244
Monomolecular	0.994	0.013	0.001	0.019	0.144	-207.90	-204.90	14.395
Quadratic	0.994	0.012	0.00048	0.018	0.147	-210.14	-207.14	14.672
Linear	0.987	0.027	0.001	0.024	0.097	-189.96	-187.77	9.695

Table 4: Best Fitted Model.

Model name	Equation form
Cubic	$y = 0.000 + 0.020^{*}t + 0.002t^2 - 0.00005t^3$

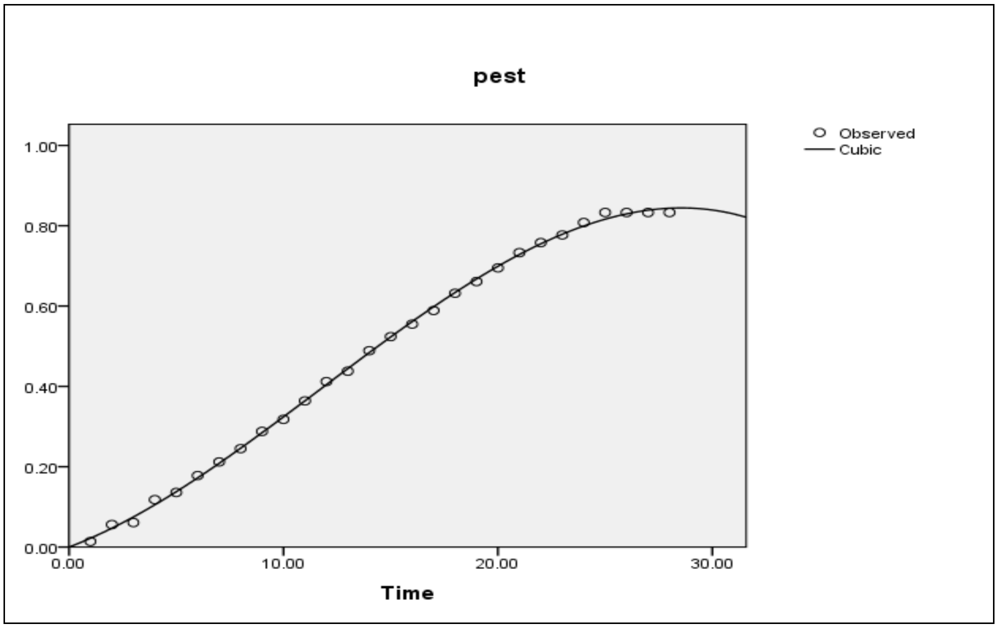

Fig 2: Plot of the observations and the fitted cubic equation.

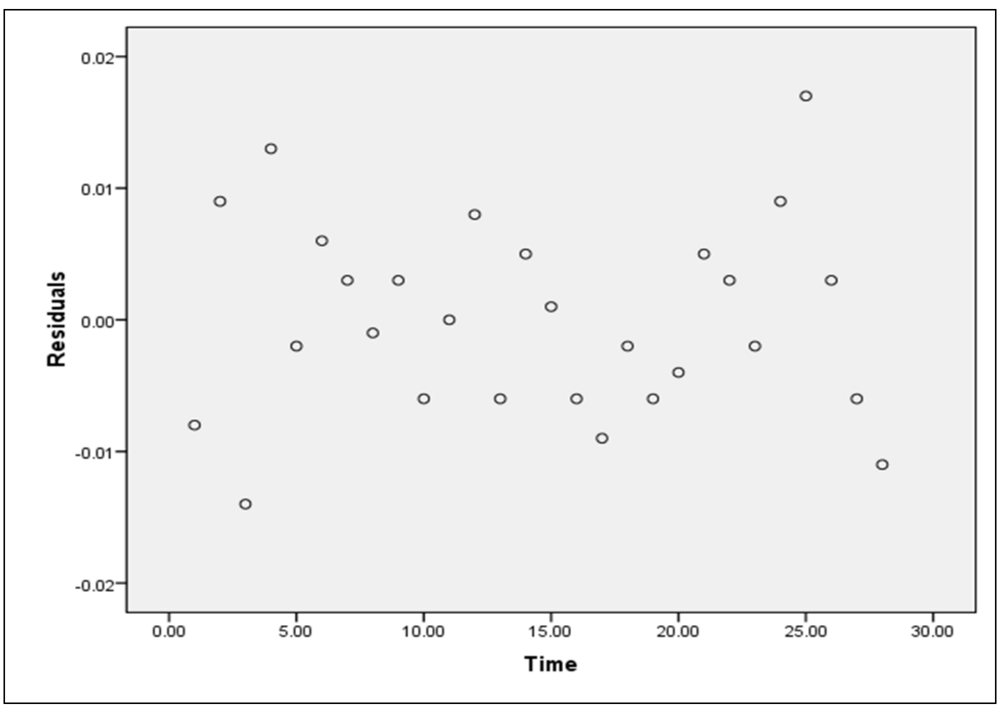

Fig 3: Residual plot for cubic model.

The nature of the above residual plot (cubic model) spells unambiguously that the residuals are random (the residuals are distributed randomly around the line drawn at the point (residual = 0.00) and that there does not exist any systematic pattern around the said line). Run test has also been done to examine the randomness of the residuals. The following Table presents the results obtained after application of the run test.

Table 5: Run Test statistics for examining the randomness of the residuals.

	Test Value[a]	Number of Cases < Test Value	Number of cases > = Test Value	Total Number of Cases	Number of Runs	Z	Asymp. Sig. (2-tailed)
Residuals	0.00	14	14	28	17	0.578	0.563

a = median

In a sequence of 28 observations consisting of 14 + signs (= N_1) and 14 − signs (= N_2), the critical values of runs at the 0.05 level of significance are 9 and 21 as shown in the Tables on run test statistic. The null hypothesis is nothing to be rejected (or accepted) if the number of runs lies between 9 and 21. Here as it is found that the number of runs (equal to 14) is greater than 9 and less than 21, we accept (at the 0.05 level of significance) the null hypothesis that the observed sequence of residuals is random. We next proceed to test for the normality of the residuals.

KS Test has been performed and the calculated value of the test statistic is $D_{n(Cal.)} = 0.116$ and as the calculated value of $D_{n(Cal.)} < D_{n(Tab.),0.05} = 0.24993$, the null hypothesis (that the observed distribution is normal) is accepted. Thus it is concluded that the residuals are independent and follow normal distribution.

Determination of Optimum time of spray using Cubic model

Based on cubic model as presented in Table 1, it is possible to determine the point of time when the rate of growth of the pest is at its peak. Similarly, the point of time (when the pest infestation is at its maximum) can be determined. The results are given below:

$t_{opt} = -\frac{\gamma}{3\delta} = 13.33$ (Corresponds to 51 DAT), and

$t_{max} = -\frac{2\gamma \pm \sqrt{4\gamma^2 - 12\beta\delta}}{6\delta} = 27.157$, t_{max} corresponds to 92 DAT.

Table 4: Predicted values with respect to observed data on infestation due to rice leaf folder.

Time	DAT	Cubic(predicted)	Time	DAT	Cubic(predicted)
1	14	0.022	18	65	0.634
2	17	0.047	19	68	0.667
3	20	0.075	20	71	0.699
4	23	0.105	21	74	0.728
5	26	0.138	22	77	0.755
6	29	0.172	23	80	0.779
7	32	0.209	24	83	0.799
8	35	0.246	25	86	0.816
9	38	0.285	26	89	0.830
10	41	0.324	27	92	0.839
11	44	0.364	28	95	0.844
12	47	0.404			
13	50	0.444			
13.33	50.99	0.457			
14	53	0.484			
15	56	0.523			
16	59	0.561			
17	62	0.598			

From the above Table (using formulae given above), the maximum rate of growth of RLF pest in the field occurs at around 51 DAT when the forecasted pest population in the field is 0.457 which is much below the ETL level, and, in fact, throughout the growing season of the crop the pest population remains much below the ETL level. Hence, it is not economical to adopt any pesticide spray in the field during its life-term in such situations.

Discussion

The available literature reveals that a large no. of studies has been conducted dealing with the various biological aspects of aphids. Barlow & Dixon [9] has developed a detailed deterministic simulation model for aphid population. Application of various stochastic models to represent the growth of Aphid population over time is rife in the existing literature. The latest nonlinear aphid population model is due to Prajneshu [10].

The present study establishes the importance of the use of non-linear models as a means to describe the growth trend of the pest, RLF population over time in actual field condition. The other revelation is that even when the ETL level is not reached in a research field trial, the knowledge of the time-points, (a) when the rate of growth of the pest population assumes maximum and (b) the maximum number of pests, emerge as important information useful for propagation to farmers in general. An earlier reference in the context of (a) and (b) is available in the paper due to Prajneshu [10] (mentioned in the preceding paragraph). The data-set generated under the experiment considered in this paper points to the suitability of a non-deterministic model (cubic) which is found to be highly precise and the values of the parameters (time-point corresponding to the maximum rate of growth and the time-point corresponding to the maximum pest population) are found to be 51 DAT and 92 DAT respectively.

Conclusion

The above study reveals that the population growth dynamics of the pest, RLF on Boro rice can be very precisely modelled by cubic degree equation of pest population on time. Incidentally, in this case the ETL level for the pest population has not reached. The value of t_{opt} was 13 and hence the rate of RLF population growth touches its maximum on the 51st day (after the transplantation of Boro rice). Therefore, it may be the most opportune time (51 DAT) to adopt pest control measures; though the pest population at this time is much below the ETL level of RLF on Boro rice (needless to mention that in natural system, ETL levels are not always reached because of existence of temporal and spatial variation in case of pest infestation).

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