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Modelling and its perspectives in entomology

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1. INTRODUCTION

Mathematical modelling is the major tool for predicting population dynamics of insect pests. The changes in pest management objectives should be followed by a change in modelling methodology. Ecosystems with limited diversity are vulnerable to the rapid colonization of the host by some biological organisms. The task of many IPM (Integrated Pest Management) practices is to increase the diversity of an agroecosystem as well as the pest management. To this end, IPM very much encompasses and makes use of the cultural control tactics and practices that were also identified. It also embraces the practice of using biopesticides[15].

2. Model

A model is a representation or abstraction of a system in some form other than the original[28,29].

Smith[24] indicates that a model is a description of general ideas that includes as little detail as possible.

Manetsch and Park[16] indicate a model is an abstract representation of a system that behaves like the real-world system in certain respects.

Jeffers[9] defines a model as any formal expression of the relationship between defined symbols.

3. System

A system is defined as something that has a set of characteristic common to all systems and lacking in things that are not systems[18].

Manetsch and Park[16] defined system as a set of interconnected elements organized towards a goal or set of goals separate from the environment and are determined by factors completely independent or external to the system.

Teng[29] indicates that the whole of the system is more than the sum of its parts.

4. How can model be useful ?

1. To predict the pest population will behave in relation to some expected changes in the prevailing environmental condition.
2. To seek general conclusion about how organisms interact with each other and their environment.
3. To decide the pest managers how the agro-ecosystem should be changed to favour economy and conservation and not to favour pests.
4. Models have been used whenever a scientist wanted to explore as well as understand the complexities of agro-ecosystem.
5. Where data is not available, a model can be more useful.

4.1. Examples

Biological agents are to be sought for the control of introduced pest. How can we predict which is likely to be the most effective agent?

Little information about new pest on the factors attacking the level of attack, critical informations should be collected?

5. Modelling process

Modelling process can be involved in two phases. Phase I consist of conception of model, the construction of the model and sensitivity analysis. Phase II is the implication of model.

5.1. Phase I[9,29]

5.1.1. Defining and bounding the system that is to be modelled

The objectives of this step should include the identification of how resolute the modelling process should be in order to address the stated problem, as well as the breadth of scale that should be considered for developing and applying the model.

5.1.2. Evaluating the historical and current knowledge about the system

After these questions are answered, it is always good to conduct a thorough review of the literature and find out from a historical perspective, what is known about the system of interest.

5.1.3. Developing an initial conceptual (system) model

For this, we can use flow charts with writing computer programs. However, just about any system of ‘boxes’ and arrows will be sufficient to show the variables and their relations to one another.

5.1.4. Collecting data and constructing equations to describe the system

After constructing a conceptual diagram, collect some data through either a series of designed experiments or observational studies or both. This is not necessarily so, as for some problems, constructing an elegant word model or perhaps a knowledge-based system may prove satisfactory.

5.1.5. Structuring a detailed system model for computer modelling

A system is sufficiently constructed for detailed analyses, as well as simulations, to be needed.

5.1.6. Translating the model into a selected language for computer performance

The constructed model is translated into a computer language for its use. Again, it is assumed that the model is mathematical in nature, is very complex or both and should be embedded in a computer program for ease of use. However, if the model is not of a mathematical nature, it may be represented by a knowledge-based system. Further, if the model is non-mathematical and simple in its depth or breadth, a decision TABLE or decision tree may be sufficient.

5.1.7. Verification

Some errors are obvious and harder to detect. It is necessary to check every part of the programme carefully for such errors and to run the whole program on sample values for which the output is known.

5.1.8. Validation

Once a model has been verified it is necessary to compare the output from the model with independent field measurements of this variable for a range of places and time.

5.1.9. Sensitivity analysis

Sensitivity analysis is to know which element or parameter of the system has the greater impact on the output. A sensitive parameter is one which has a large impact on model output for a relatively small change in its own value. A sensitive parameter may actually show very little variation in nature.

5.2. Phase II (Kraemer, 1984)

5.2.1. Introduction

Model introduction refers to a period during which the model is considered for adoption/ during this step, some early initial testing may be conducted and the results, along with the introductory information that was presented with the model, are used to make the decision on model adaption.

5.2.2. Adaptation

Model adaptation refers to the period after model introduction during which broader support for the model is developed and plans are made for instructing and training practitioners on its use as well as the interpretation of its output. During model adaptation, the model begins to be widely used.

5.2.3. Incorporation

Model incorporation is the step at which the model is no longer a new entity but, rather, becomes a routine part of the user’s operations. Research has shown that the successful implementation of a model is influenced by at least three factors: (i) The inherent technical characteristics of the model itself (ii) The social setting in which the model is used (iii) The used and impacts of the model as experienced by the user. Interestingly, it has been hypothesized that ‘user’ will not implement a model unless the model also serves some political interests.

6. Types of models

6.1. Statistical models

Statistical models, including various forms of regression analysis, offer a means of determining the value of a response variable using a small number of explanatory variables. Theses models are purely based on empirical observations.

6.2. Mechanistic models

Mechanistic models are constructed to represent knowledge concerning the biological and ecological processes that underline pest population dynamics, damage and control[6].

6.2.1. Analytical models

Analytical models are those for which explicit formulae are derived for predicted values or distributions. They include regression and multivariate models, experimental designs and the standard and theoretical, statistical distributions. This model provides general information about the system by describing the characteristics in a handful of relationship and parameters[11]. Analytical models have been used in developing host-parasitoid relationship for sustainable biocontrol strategies and for determining population changes. Analytical models have been used as a tool for developing pest management principles and ecological theory.

6.2.2. Simulation models

Simulation is the process of designing a model of a real system and conducting experiments with the model for the purposes of understanding the behaviour of the system or of evaluating various strategies for the operation of the system[25]. Simulation modelling is used in pest management mainly in relation to the population dynamics of crop, pests and their natural enemies. In pest management, decision-making simulation models are used for forecasting of pest population changes and for testing the wide range of management options of the modelled pest population. An example is the simulation model of rice brown plant hopper (BPH), used to account for the role of different mortality agents in BPH population dynamics, and to investigate the causes of BPH outbreaks in tropical rice systems[7]. It has also been used to determine the best time for application of insecticides for BPH control based on reduction peak density of the pest[3].

6.2.3. Rule-based models

Rule-based modelling is qualitatively equivalent to conventional simulation modelling[6]. Without the need to represent relationships between components of system using mathematical equations, a rule-based approach provides a means by which subjective knowledge about a system can be used to build models. In rule-based models, subjective knowledge about a system can be used to build a model. Any computer language, which incorporates logical operations and if-then statements and capacity for interaction can be used to build a model. This includes the conventional programming languages (Basic, Pascal, C etc), database (dBASE, FoxPro etc.), spreadsheets (Supercalc, Lotus 123, etc.,) and some expert system shells.

6.2.4. Spreadsheet based models

Spreadsheets are widely used for the storage and management of biological data. In pest management, spreadsheet models are ideal for quick, exploratory models to get a feel for the range of likely outcomes from possible control options. They are particularly useful in a workshop setting where ideas can be tested immediately on a spreadsheet model. A simple spreadsheet model can be designed and built by participants during the course of a few hours during a workshop session. The result of a simple model can then from the basis for further discussion, analysis and experimentation. Examples of the spreadsheet software are LOTUS, Quattro Pro and Excel, etc.

6.2.5. Inferential model

They have been proposed for modelling development of an insect population that passes through a series of discrete developmental stages. The relationship between an insect, its hosts and predators is often dependent upon the relative phenologies of each other[8]. Understanding insect host phenology is useful in understanding ecological interactions as well as in managing insect populations. Control of the insect population can be made much more effective, if control measures can be timed to coincide with the occurrence of the most susceptible life stage of the insect. This technique has been successfully used to describe the phenology of post-diapause of spruce budworm, *Choristoneura fumiferana* (Clemens) larvae. Phenological data on the budworm are collected annually and the information is used to determine the timings of insecticidal sprays[8].

6.3. Optimization models

Optimization techniques, as name suggests, are primarily concerned with prescriptive decision problems in pest management. In Optimization decisions can be made for the whole of growing season at once or stepwise within each optimization period[34]. Simulation and optimization are complementary tools in pest management.

7. Utility of modelling in insect pest management

7.1. Rice leaf folder

Prediction of leaf folder damage and yield loss in susceptible rice cultivar IR 50 at different larval populations and crop periods under natural conditions were studied by Pandi et al.[31] in two field experiments during Kharif season.

7.1.1. Damage and yield loss with ensured infestation of leaf folder without plant protection

Second instar larvae (3-4 day old) were released at 30, 40, 60 and 80 days after sowing (DAS). The treatment variants were one to seven larvae per hill, with a control. Ten hills were maintained for each treatment. The treatments were replicated three times. The plants were unprotected after the release of larvae, which allowed them to multiply freely. The damage was assessed 15 days after larval introduction. In order to assess the cumulative damage, the subsequent counts were taken on the same plants, which were marked at the first count. Damage assessment was carried out at 20 day intervals, starting 15 days after larval release. i.e., counts were made at 45, 60, 80 and 100 DAS for infestation at 30 DAS. For larval introduction at 40 DAS, assessment was made on 55, 80 and 100 DAS. The counts were made at 75 and 100 DAS for infestation that was introduced at 60 DAS and for the 80 day larval introduction only one count was taken at 95 DAS. Finally, the hills were harvested separately and the grain yield was assessed. The yield loss at different larval populations and crop periods was assessed based on uninfested control yield (TABLE 1).

7.1.2. Damage and yield loss with ensured infestation of leaf folder with plant protection

The design and procedure for ensuring infestation of the hills were similar to that described in the leaf folder without plant protection experiment. One spray using monocrotophos 36 WSC was given, based on the economic threshold (ET). The ET at the vegetative stage is 10 per cent and at the reproductive stage it is 5 per cent of leaf damage. The damage and yield assessment were carried out in a similar manner to that of the unprotected group.

7.1.3. Mathematical model

7.1.3.1. Prediction of damage

The Mitscherlich's model was used for the prediction of damage, because it was found to be the best, based on correlation coefficient and goodness of fit[15] and this model is of the form:

$$D(l,t) = D_M(1-\alpha c \beta \alpha)$$

Where, D (l,t) = leaf damage at various larval loads and crop Periods; l(t) = larval at the t^{th} crop period; D_M = maximum damage at given larval loads and crop periods; α and β are parameters to be estimated.

7.1.3.2. Prediction of yield

The rectangular hyberbola model was used for the prediction of yield obtained, because it was found to be the best, based on R^2 value and the prediction ability of the yield due to damage[17] and this model is of the form:

$$Y(l, t) = \alpha + \beta D(l, t)^{-1}$$

Where, y (l,t) = yield obtained after the infestation of various larval loads at different crop periods; D (l,t) = leaf damage at different larval loads and crop periods; α and β are parameters to be estimated. The above models were estimated using the non-linear methods of ordinary least squares (OLS).

7.1.4. Results

7.1.4.1. Yield loss

The damage on 40 DAS contributed for greater fall in yield levels, the infestation at 30, 60 and 80 DAS contributed for lesser yield levels. However, the fall in yield increased with increasing larval population.

7.1.4.2. Unprotected crop

TABLE 1: Experimental design for damage and yield assessment with plant protection

Crop age at infestation (DAS)	Days on which ETL reached (DAS)	Days on which spray given (DAS)
30	35	35
40	46	46
60	65	65
80	85	85

Pandi et al.,[21]

TABLE 2:. Predicted yield loss due to leaf folder infestation at vegetative stage (unprotected crop)

No. of larvae/hill	Damage (%)	30 DAS Yield obtained (%)	Yield loss (%)	Damage (%)	40 DAS Yield obtained (%)	Yield loss (%)
1	20.13	96.88	3.12	10.18	94.33	5.67
2	32.88	84.82	15.18	20.30	72.29	27.71
3	43.15	80.22	19.78	29.79	66.00	34.00
4	51.42	77.91	22.09	37.39	62.93	37.07
5	58.09	76.56	23.44	43.83	61.21	38.79
6	63.45	75.61	24.39	49.27	60.10	39.90
7	67.78	74.93	25.07	53.88	59.36	40.64
Control	0.00	100.00	0.00	0.00	100.00	0.00

$D(l,t) = 85.7(1-0.9498e^{-0.2162l(t)})$(r=0.9850) t=30DAS; $Y(l,t) = 4.8500+47.2600D(l,t)^{-1}$(r=0.9541) t = 30 DAS; $D(l,t) = 79.2(1-1.0299e^{-0.1671(t)})$(r = 0.9950) t = 60 DAS; $Y(l,t) = 4.1624+35.5700\,D(l,t)^{-1}$(r = 0.9113) t = 40 DAS

TABLE 3: Predicted yield loss due to leaf folder infestation at reproductive stage (unprotected crop)

No. of larvae/hill	Damage (%)	60 DAS Yield obtained (%)	Yield Loss (%)	Damage (%)	80 DAS Yield obtained (%)	Yield loss (%)
1	4.80	100.00	0.00	1.78	100.00	0.00
2	11.42	92.62	7.38	8.50	96.61	3.39
3	16.78	89.00	11.00	13.65	93.39	6.61
4	21.12	87.47	12.53	17.61	92.26	7.74
5	24.64	86.63	13.37	20.65	91.61	8.39
6	27.48	86.07	13.93	23.00	91.29	8.71
7	29.79	85.65	14.35	24.78	90.97	9.03
Control	0.00	100.00	0.00	0.00	100.00	0.00

$D(l,t) = 39.6(1-1.0852e^{-0.2110l(t)})$(r=0.9931) t=60DAS, $Y(l,t) = 5.8450+9.1807D(l,t)^{-1}$(r=0.8535) t = 60 DAS, $D(l,t) = 30..7(1-1.2273e^{-0.2644l(t)})$(r = 0.9883) t =80 DAS, $Y(l,t) = 5.4650+4.4286\,D(l,t)^{-1}$(r = 0..8964) t = 80 DAS

TABLE 4: Predicted yield loss due to leaf folder infestation at vegetative stage (unprotected crop)

No. of larvae/hill	Damage (%)	30 DAS Yield obtained (%)	Yield Loss (%)	Damage (%)	40 DAS Yield obtained (%)	Yield loss (%)
1	9.43	100.00	0.00	5.28	100.00	0.00
2	20.14	97.25	2.75	12.78	94.24	5.76
3	28.85	92.73	7.27	18.94	88.47	11.53
4	35.93	90.79	9.21	24.01	85.98	14.02
5	41.68	89.66	10.34	28.17	84.58	15.42
6	46.36	88.85	11.15	31.59	83.80	16.20
7	50.16	88.37	11.63	34.41	83.18	16.82
Control	0.00	100.00	0.00	0.00	0.00	0.00

Pandi et al.,[21] : $D(l,t) = 66.7(1-0560e^{-0.2070l(t)})$(r=0.9434) t = 30DAS; $Y(l,t) = 5.1080+18.3160D(l,t)^{-1}$(r=0.8671) t = 30 DAS; $D(l,t) = 47.4(1-0810e^{-0.1960l(t)})$(r = 0.9643) t = 40 DAS; $Y(l,t) = 4.9180+14.5100\,D(l,t)^{-1}$(r = 0.7173) t = 40 DAS

The yield loss was 3.12 to 25.07 per cent in the 30 day old crop and between 5.67 and 40.64 per cent in 40 day old crop for the larval populations ranging from one to seven per hill (TABLE 2). It was found that, although the damage suffered by the 40 day old crop was comparatively less than that of the 30 day old crop, the yield suffered by it was nearly twice that of the younger crop. Older crops of 60 and 80 DAS were found to have less damage than the 40 day old crop. The yield loss was 7.38 to 14.35 per cent in the 60 day old crop and 3.39 to 9.03 per cent in the 80 day old crop for damage and yield loss in rice due to leaf folder (TABLE 3).

7.1.4.3. Protected crop

The protection of the crop with monocrotophos 36 WSC avoided more yield loss. The yield loss suffered by the 30 day old was 0.00 per cent for one larva and 11.63 per cent for seven larvae (TABLE 4). The yield loss suffered by 40 day old crop was between zero and 16.82 per cent, which was much less compared with the unprotected crop of the same age. The yield loss was only 5.43 per cent in the 60 and 2.44 per cent in the 80 days infested crop for the highest larval load of seven per hill (TABLE 5).

The damage caused on the 40 day infested crop accounted for more yield loss. It has been reported that the flag leaf is the main source of photosynthates for the formation of grain and damage to this leaf might result in a greater yield loss. The crop may coincide

TABLE 5: Predicted yield loss due to leaf folder infestation at reproductive stage (protected crop)

No. of larvae/hill	Damage (%)	60 DAS Yield obtained (%)	Yield loss (%)	Damage (%)	80 DAS Yield obtained (%)	Yield Loss (%)
1	0.00	100.00	0.00	1.20	100.00	0.00
2	7.93	96.65	3.35	6.52	99.84	0.16
3	13.81	95.37	4.63	10.68	98.37	1.63
4	18.33	94.89	5.11	13.94	98.05	1.95
5	21.80	94.73	5.27	16.49	97.72	2.28
6	24.46	94.57	5.43	18.49	97.72	2.28
7	26.5	94.57	5.43	20.01	97.56	2.44
Control	0.00	100.00	0.00	0.00	100.00	0.00

$D(l,t) = 33.3(1-2910e^{-0.26371(t)})(r=0.9371)$ t = 60DAS; $Y(l,t) = 5.8600+1.5240D\ (l,t)^{-1}(r=0.7173)$ t = 60 DAS; $D(l,t) = 25.7\ (1-2177e^{-0.2447(t)})(r = 0.9789)$ t = 80 DAS; $Y(l,t) = 5.9300+1.3871\ D(l,t)^{-1}(r = 0.6400)$ t = 80 DAS

with later tillering/panicle initiation/heading (40-60 DAS) and the compensation ability of the plant is reduced. Therefore the grain crop needs insecticidal protection at panicle initiation to heading stage alone (40 to 60 DAS). A seed crop may also warrant protection both at early growth, tillering (25-40DAS) as well as panicle initiation to heading stage (40-60 DAS).

7.2. Sesame pod bug (SPB)

Assessment of yield loss caused by sesame pod bug, *Elasmolobus sordidus* Fab. using simulation model was developed by Kalaiyarasan and Kailasam[12]. Estimation of yield loss caused by both adults and nymphs of sesame pod bug was studied under caged condition in the field during Kharif and Rabi on sesame cv. TMV3. Fifteen sesame plants were selected at random and one branch with mature pods from each plant was enclosed in a tubular mylarfilm cage (45× 6 cm). The other pests, if any, were mechanically eliminated from the selected branches before caging. In each cage, only 10 capsules were retained and the rest were removed. Dried sesame leaves were placed inside the mylarfilm cage to provide shelter to the bugs during day time. Female bugs/nymphs at 1,2,3,4,5,6,7,8,9,10,15,20,25 and 30 per cage were introduced into the cages for feeding on the capsules. A check with no bugs was also maintained. The treatments were replicated thrice. The required bug populations were maintained in each treatment up to harvest, the infested pod, in each treatment were counted and the severity of damages was also worked out using a scale of 0-9 as mentioned below.

Surface area score	Damaged	(%)
No damage	-	0
1-15	-	1
16-30	-	3
31-50	-	5
51-75	-	7
>75	-	9

The percent damage was worked out using the formula

Pod damage (%) = Sum of score/Maximum score × No. of pods observed ×100

The data on per cent pod damage and the seed yield obtained from each treatment was recorded and used for estimating the pod damage, yield loss, pod damage rate and rate of yield loss using simulation model.

7.2.1. Mitscherlich's curve

The Mitscherlich model for pod damage is in the form

$$D = A\,(1-e\beta+^{k\ SPB})$$

Where, D = Pod damage per 10 pods measured in per cent, SPB = Sesame pod bug levels of adults and nymphs in numbers per 10 pods, A, β and k are the parameters to be estimated.

The Mitscherlich's model for yield loss is in the form

$$Y\,(L) = M\,(1-e\alpha^{+SPD})$$

Where, Y (L) = Yield loss in grams per 10 pods, M, α and δ are the parameters to be estimated

The rate of yield loss at different levels of pod damage level in per cent and pod damage rate by different levels of SPB population were estimated using the above damage function and yield loss function.

To conclude, the assessment of yield loss caused by SPB, three points are clear that is (1) the pod damage and yield loss increased with increase in bug population (2) the pod damage rate of an individual was higher at low levels of bug population and lower at high levels of bug population (3) the rate of yield loss was higher at low level of pod damage and lower at high level of pod damage. From this, it is imperative that control measures have to be taken up even at low levels of bug population to avoid the yield loss.

7.3. Development of *Helicoverpa armigera* forecasting models

A computer based simulation model MOTHZV has been adopted by Trivedi et al.[30] for predicting the population dynamics of *Helicoverpa* species. The model uses early season number of eggs, larvae or adults to forecast the timing and potentially damaging population. Pheromone trap has provided the means for measuring early season number of *Helicoverpa* adults. This pheromone trap data along with climatic variable and crop phenology were used as inputs to the MOTHZV model to predict the timing of future *Helicoverpa* generations for a pilot test on the management of *Helicoverpa* species.

The main peak was during March-April and the second peak was during October every year. During March-April peak, chickpea was the main crop and during October, cotton was grown almost over entire area. The peak population of *Helicoverpa* moth during March-April and October can be predicted in advance by multiple regression models using different weather parameters along with previous season's population of *Helicoverpa*. The population density during March-April (P M-A) has been regressed with different weather parameters as well as pest population density of previous five months separately and cumulatively. It has been found to depend on total moth catch per trap during previous October to February (Po-F), mean monthly relative humidity recorded in the afternoon during previous February (RHEF) and mean monthly minimum temperature of previous February (T minF) as follows:

$$\mathbf{P_{M\text{-}A} = -1032.65+2.06P_{O\text{-}F} - 34.26RHE_F + 516.74T\ min_F\ (R^2 = 0.75)}$$

Apart from weather parameters, the total population cumulated from October to February is another important parameter. The population, which uses to undergo diapause from October due to severe winter, is emerged again after February.

Similarly, the population density during October (Po) can be predicted in advance with multiple regression using weather parameters as well as pest population of preceding months as follows:

$$\mathbf{P_o = -5.39+12P_{M\text{-}A} + 1.28\ P_J - 0.51_{J\text{-}J}\ (R^2 = 0.87)}$$

$P_{M\text{-}A}$ = Pest population density of March and April; P_J = Pest Population density of June; $R_{J\text{-}J}$ = Total amount of rainfall during June and July

7.4. Fruit fly, *Bactrocera dorsalis* model

A model from methyl eugenol trap catches was developed by Verghese[31] for fruit fly, *Bactrocera dorsalis*.

The mean weekly trap catch data were subjected to statistical analysis and it was found that the best relation existed between two consequent week catches *i.e.*, the current week's catch seemed to depend on the previous week's catch. The best fit was obtained with a polynomial model (order 4):

$$\mathbf{Y = (-2\times10^{-8})x4 + (2\times10^{-5})x^3 - 0.0051x^2 + 1.173x + 4.989.\ (R^2 = 0.74)}$$

Here a polynomial order 4, with a coefficient of determination of 74%, gives the second weeks (y) population trend from the first week's (x). It should be noted that such models do not reflect a cause and effect relationship rather it gives a trend. Using such trends judiciously will help in decision-making.

It was also found that regressing the means of trap catches from first to seventh (x to x) week could predict the eighth weeks population with a coefficient of determination = 61%:

$$\mathbf{Y = 11.31 + 0.14x_1 - 0.13x_2 + 0.23x_3 - 0.27x_4 + 0.26x_5 - 0.22x_6 + 0.75x_7 : R^2 = 0.61}$$

Both the above models can be used for arriving at a decision.

7.5. Mango shoot borer, *Chlumena transversa* Walker model

Studies by Verghese and Devi[32] showed that the number of shoots damaged in the lower canopy (x) fitted to total infestation (y) on a tree by a simple linear model. i.e., $Y = 0.089 + 1.8x$: R^2: 0.9235

The variability in the total population is explained by the infestation in lower canopy to the tune of 92 per cent. This is fairly high precision and helps in quick estimation.

7.6. Rice brown plant hopper model

Mathematical model for population growth of buprofezin treated brown plant hopper was studied by Salin et al.[24]. Tests were conducted in glasshouse under controlled conditions of light (photoperiod of LD 13:11) and temperature (26±3). Laboratory reared *Nilaparvatha lugens* served as the test insect. Thirty insects each of first to fifth instars and adult stages were exposed to 0.1, 0.2, 0.5, 1.0 and 5.0 ppm buprofezin treated 35 days old TN-1 seedling for 2 days and transferred to untreated TN-1 plants of the same age on the third day for further development.

TABLE 6: R^2 values for different functions fitted

		R^2					
Types of function	Functional forms	0.1ppm	0.2ppm	1.0ppm	0.5ppm	5.0ppm	Control
Linear	$P_t = P_0 + \beta_1$	0.6833	0.6942	0.7023	0.7212	0.7507	0.7396
Quadratic	$P_t = P_0 + \beta_{1t} + \beta_{2t}^2$	0.7102	0.7342	0.6876	0.7542	0.7732	0.7032
Exponential	$P_t = P_0 + e^{\beta t}$	0.8432	0.7966	0.8242	0.7846	0.8233	0.8073
Negative Exponential	$P_t = P_m e^{-\beta t}$	0.8461	0.8266	0.8067	0.7942	0.6887	0.8298
Logistic	$P_t = P_m (1 + \alpha e^{-\beta t})^{-1}$	0.9828	0.9826	0.9807	0.9773	0.5699	0.9849

P_T= Population at time t; P_0= Initial Population; P_M= Maximum Population

Water sprayed plants served as control. Number of insects reaching adult stage, fecundity and per cent hatchability of eggs were assessed. From this, potential progeny production of the surviving individuals was worked out for each concentration tested. The assumptions made for calculating population growth were: (1) Population consists of 30 individuals of each stage in 1:1 ratio (male: female) (2) a predator feeds on 20 eggs/ day (3) a female lives for 15 days (4) life cycle completes in 32 days.

Various population growth models *viz*., linear quadratic, exponential, negative exponential and logistic were tried. Among the above models, the logistic model was found to be the best fit based on R^2 values (TABLE 6) and x^2 -test for different concentration levels. The logistic was

$$P_t = P_m (1 + \alpha e^{-\beta t})^{-1}$$

Where Pm = peak insect population; t = time measure in days; α and β are the parameters to be estimated. The model was fitted following the method of ordinary least squares (OLS). Using the above model relative growth rate at time t, the peak population (P_{max}) with varying initial populations subjected to different concentrations of buprofezin treatment were simulated. The relative growth rate was worked out using the formula RGR = $\alpha \beta (\alpha e^{-\beta t})^{-1}$

7.6.1. Results

The growth model tested gave a good fitting with highly significant R^2 as well as X^2 - test values. Using these models, potential growth rates of the first generation from the surviving individuals of buprofezin treatment were worked out and presented in TABLE 7. The models predicted maximum growth rates at the beginning and as the day advanced, the growth slowed down. On reaching maximum population, it remained stationary.

Using the above equation peak populations attainable with various initial population levels were simulated (TABLE 8).

Buprofezin has no lethal effect on the adult insect. However, it strongly suppresses the oviposition and subsequent hatching of eggs[1].

TABLE 7: Potential growth rates of *N.lugens* on different dates

Buprofezin treatments (ppm)	Relative growth rates on			
	7	14	21	28
0.10	0.2431	0.1777	0.0594	0.0116
0.20	0.2377	0.1568	0.0498	0.0094
0.05	0.2367	0.1475	0.0430	0.0077
1.00	0.2341	0.1286	0.0318	0.0052
5.00	0.1691	0.0305	0.0033	0.0003
Control	0.2518	0.1831	0.0653	0.0124

TABLE 8: Maximum attainable population of *N.lugens* with different levels of initial population treated with buprofezin

	R^2					
Initial	Peak population attained on day 32 at different ppm					
Population	0.10	0.20	0.50	1.00	5.00	Control
5	375.55	298.80	263.25	208.50	58.05	466.55
10	751.10	597.60	526.50	417.00	116.10	933.10
15	1126.65	876.40	789.75	625.50	174.15	1399.65
20	1502.20	1195.20	1053.00	834.00	232.20	1866.20

The chemical does not have any adverse effect on the natural enemy[5]. Hence, a population containing various stages of insect and its biotic agents, buprofezin, has the potential of bringing down the resulting population without adversely affecting the natural enemies.

8. Models in p[est management

8.1. PETE (Predictor extension timing estimator)

PETE was originally developed for the Michigan fruit pest complex but has now been applied to fruit and other crop pests in several countries[4,33].

8.2. EPIPRE(EPIdemic PREdiction and PREvention)

EPIPRE is for the wheat diseases[23,35,36]. In addition to providing information on *Puccinia striiformis*, EPIPRE includes advice on treatments for brown rust (*Puccinia recondita*), wheat powdery mildew (*Erysiphe graminis)*, *Septoria* spp. and aphids

(*Sitobion avenae, Metopolopium dirhodium* and *Rhopalosiphium padi*).

8.3. Blitcast

Blitcast is a computerized decision model based on identification of critical periods against *Phytophthora infestans* on potatoes[14]. BLITCAST was initially programmed on a large mainframe computer, but subsequently has become available on a microcomputer coupted with a weather data logger. This is a self-contained unit and can be placed in potato field. The model is field specific and is used in disease forecasting.

8.4. Phytoprog

This is also computerized but it is not field specific. The method of determining apple scab infection periods has also been programmed into computers. This program has been incorporated with a weather data logger into self-contained unit[10]. The simulation models predicting the timing of events in the population dynamic of the pest are termed phenological models. They are also referred as day-degree model because population development is based on the accumulation of heat. Simulation models of the crop coupled with the pest simulation models are known as crop-pest coupled models. They are useful when the damage relationship is complicated or when other factors(e.g. drought stress) interact with pest damage[2,22].

8.5. Sucros (simple and universal crop growth simulator)

Sucros is used for aphid damaging cereal crop. Such models are necessary to enable holistic assessment of the impact of climate change and variability in crops and the associated pests[27].

9. Advantages of modelling

1. To improve the perception of pest problem
2. To understand the pest population dynamics.
3. To asses the risk associated with introduction of a pest (where there is no data).
4. Integration of control methods for an economically optimal, long term and economically sound control strategy.
5. To understand the change of pest with respect to climate changes.
6. To develop the effective strategies.

10. CONCLUSION

The main requirements of the model should be simple and sustainable. Model should form an important component of IPM decision making. Models serve as a very useful trend indicator of either forecasting or estimating insect population or infestation. These will form a basis for IPM managers to be alert as well as take judicious decisions for IPM. Pest resistance to pesticides, residues and high cost of pesticides, emphasis on conservation of natural enemies is of greater concern. Therefore, it is mandatory requirement to develop early warning system to provide caution to the farmers regarding the occurrence of pest, peak activity and migration. The model will helpful in developing sustainable pest management system which may economically viable and socially acceptable. Further improvements in computer technology are likely to make the models more users friendly.

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