Journal of Entomology and Zoology Studies 2017; 5(5): 1773-1777

Journal of Entomology and Zoology Studies

Available online at www.entomoljournal.com

E-ISSN: 2320-7078
P-ISSN: 2349-6800
JEZS 2017; 5(5): 1773-1777

Received: 15-07-2017
Accepted: 16-08-2017

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Role of modeling in insect pest and disease management

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Abstract

Successful integrated pest management (IPM) control programmes depend on many factors which include host–parasitoid ratios, starting densities, timings of parasitoid releases, dosages and timings of insecticide applications and levels of host-feeding and parasitism. In devising strategies for the control of pest populations, pest management specialists have attempted to make use of mathematical theories of population dynamics to aid in their task. Manetsch and Park defined model as an abstract representation of a real-world system that behaves like the real-world system in certain respects. Modeling in pest management not only helps in forecasting of pest populations but it also give answers to problems like strategy selection, tactics selection and state selection. One such model is FRUTFLY, which has been successful in predicting the fruit fly emergence. Likewise, weather variables also play significant role in initiating the plant diseases. Extensive studies involving favourable weather variables with respect to wheat rust, bacterial blight of rice, etc. have helped researchers to anticipate the future plant disease problems.

Keywords: modeling, insect pest, disease management

Introduction

Uncertainty ridden agriculture requires reliable and well-timed forecast (Agrawal and Mehta, 2007). Pests and diseases are the prominent causes of reduction in crop yield. To reduce the yield-loss, timely and need based application of remedial measures are indispensible which is possible with the prior knowledge of the time and severity of the outbreak of pests and diseases. Thus, factors affecting crop yield and infestation of pest and diseases need to be looked in to. Therefore, models can provide reliable forecast of crop yield in advance of harvest and also forewarning of pests and diseases attack so that suitable plant protection measures could be taken up timely to protect the crops. Successful pest and disease control programmes requires efficient monitoring of pest populations, host–parasitoid ratios, starting densities of parasitoid, timing of parasitoid releases, dosages and timing of insecticides application and level of host feeding and parasitism. Modeling is an effective mathematical tool that can help in the design of appropriate control strategies and assist in management decision-making (Tang and Cheke 2008) [26]. In devising strategies for the control of pest populations, pest management specialists have attempted to make use of mathematical theories of population dynamics to aid in their task (Plant and Mangel 1987) [24]. Forecasting of insect-pests attack considered to be an indispensible component for sound implementation of integrated pest management. Pest forecasting assist in knowing the actual timing of pest incidence. Forecasting of pest incidence has been meticulously made by certain mathematical models designed for the forecasting purpose. This can achieve quality results in terms of effective pest control at a time when most susceptible stage of pest is prevailing in the environment; need based use of pesticide application, prevention of resistance, resurgence and residue and producing quality food product. Models apart from forecasting, has been exemplary in terms of decision making regarding actual time of pest control by chemical methods. This decision making process can lead to sustainable pest control with little or negligible hazards to non-target organisms and environment. The present write up reviews the concept of model, system, simulation and their role in insect pests management. Classification of modeling given by (Jeffers 1978) which fits well in pest management setting has also been given due emphasis.

Model and System

Manetsch and Park (1982) [19] defined a model as an abstract representation of a real-world system that behaves like the real-world system in certain respects whereas system is something that has a set of characteristics common to all systems and it has parts called units or components, which are interdependent and interact with one another (Miller and Miller 1984) [21]. Models are ascribed from the real world system, models follows and involve similar components of real world system which help in giving clear details of functioning of different components of system. Since desired results regarding future pests number or actual time of applying pest control methods in a given situation cannot made from real world system hence after studying the effect of each and every component of system on natural phenomenon. These components are then expressed in mathematical functions and suitable mathematical expression is formulated on the basis of the relationship between these components. This is why these models act as a reliable tool in prediction and decision making.

Modeling in insect pest management

Mathematics has been capable enough to model the pest population. Agricultural crops which are considered to be managed ecosystems require the timely management of insect pests. In this regard pest control experts have given due emphasis to the mathematical theories of population dynamics to aid them in their task (Plant and Mangel 1987) [24]. The agricultural pest management faces three primary problems such as, what control strategy is to selected for pest management (Strategy selection)? If at all the strategy has been made how these strategies are to be applied into the field (Tactics selection)? What state of population of pest is suitable for control tactics (State estimation)?. Strategy selection involves determining, in a general way, the appropriate mix of chemical, biological, and cultural practices to be used I controlling the pest. Tactics selection follows strategy selection and consists of determination of the specific way in which pest control will be applied in response to a particular state of pest infestation. State estimation involves the attempt by the grower or his agents to determine whether the pest population has reached a level where active pest control is appropriate. This level is called the economic threshold (Stern *et al* 1959). In actual application, all these three problem such as strategy selection, tactics selection and state estimation is actually related the same problem. So, for Strategy selection anything like combination of chemical control with the sterile insect technique for the suppression or eradication of an insect population is very effective. Similarly, tactics selection is discussed in the context of determining the appropriate schedule for application of a pesticide. Finally, State estimation can explain by the two examples. The first being the estimation of the population of a pest species in a particular field and second is the rapid delimiting of the extent of infestation of an invasive pest.

Strategy selection: The IPM concept

The strategy selection is generally done in the context of an integrated pest management (IPM) plan. The primary ideas are first that chemical control should be used to complement, not replace, biological and cultural control, and that no control action should be taken until the level of insect pest infestation surpasses a level, economic threshold, at which cost of treatment becomes justifiable. The role of mathematical modeling in strategy selection in the IPM context is to aid in determining the optimal strategy for a given strategy of releasing of sterile insects (generally males when separation by sex is possible). In addition to helping in circumstances in which this method is appropriate, mathematical analysis show how chemical controls can best be used in conjunction. In 1955, E. F Knipling published a landmark paper (Knipling, 1955) [13] on eradication or control using sterile insect technique (SIT)

Tactics selection: The scheduling of pesticide application

After selecting the particular strategy for dealing with a insect pest, the farmer must next determine the tactics to be used in implementing this strategy. So, here also mathematical modeling plays a prominent role in tactics selection. We assume that the farmer has selected the strategy of complete dependence on single pesticide, and that he plans to apply pesticide in advance, without monitoring the pest population. The problem is than to determine the best time or times to apply the pesticide. We assume that the grower wishes to maximize his net profit, subject to discounting, over a fixed time horizon. It may be a possibility that a tiny fraction of population has conferred resistance to the pesticide. Since, resistant individuals are more likely to survive the pesticide applications hence the succeeding generations has a higher number of resistant individuals and eventually pesticide will no longer remain effective.

Pest Forecasting

Pest forecasting guides the farmers regarding the timing of pest incidence to eliminate any possibility of blanket application of pesticide and reduce pesticide amounts along with achieving effective pesticide results (Mahal *et al* 2011) [18]. Pest forecasting models are very helpful in these predictions which involve using statistical procedures like ANOVA, factorial analysis, regression and multiple regression. For a pest management expert, prediction of pest pressure along with its timing and level is important for planning and decision making (Maelzer and Zalucki 2000) [17]. Mahal *et al* (2011) [18] describes about pre-requisite for the development of pest forecasting models which require following basic information

1. **Quantitative seasonal studies** which involves seasonal abundance and sampling of population
2. **Life history and pest biology** which involves life span, survival rate, food , intrinsic growth rate in field and laboratory
3. **Ecological studies of the pest** which includes life studies of the pest which is important for better understanding of pest population build up, natural mortality factors and critical stages
4. **Crop Phenology** which includes different crop cultivars, fertilizer dosages, irrigation and plant spacing which influence the phenology of the crop
5. **Natural enemies** which involves the population of natural enemies present on various time intervals in the crop
6. **Agro-ecosystem** which involves changing cropping pattern and crop diversification involving different crops with a wide range of varieties of different maturity groups serve as suitable niche for supporting the buildup of *Helicoverpa*

Pest forecasting models

Forecasting mustard aphid in Punjab

Dhaliwal *et al* (2005) [7] conducted study in Ludhiana from 1988-89 to 1997-98 to evaluate the use of agro meteorological indices for forecasting mustard aphid on Raya, *Brassica juncea*. A formula for measuring the relationship between weekly aphid population and humid–thermal ration was provided. The year 1992-93 and 1996-97 were characterized with high infestation, with aphid populations ranging from 700 to 1300 aphids/plants. The growing degree days accumulated from 1 December for the all the years. A pest weather diagram constructed during the high infestation years shows that low minimum temperature, high morning relative humidity, and reduced solar radiation or sunshine hours favoured aphid population. The historical data on mustard aphid and mean temperature were analyzed from 1988-89 to 2003-04. Mean temperature during January for both low and high aphid attack years was compared. Mean temperature during January remained below 13 ^{0}C during high aphid attack years. The years of aphid attack were comparatively warmer than the years with high aphid attack. Similarly, other models are listed in the table below.

Table 1: Various Pest forecasting models around the world

Forecasting Models	Insect	Parametres	Country	Reference
Ordinal logistic Model	Whitefly, Pyrilla and Fruit fly	Max temp. , Min temp. and RH	India	Agrawal and Mehta (2007)
CLIMAX	*Helicoverpa* sp.	Temperature and humidity	Australia	Zalucki and Furlong (2005)
SOPRA	*Dysaphis plantaginea* and *Grapholitha lobarzeweskii*	Air and soil temperature	Switzerland	Graf *et al* (2002)
FLYPAST	*Aphis fabae*	Suction trap data	UK	Knight *et al* (1992)
NAPPFAST	*Scirtothrips dorsalis*	Degree days and cold temp. survival	USA	Nietschke (2008)

MOTHZV-computer based simulation model

A computer based simulation model MOTHZV has been developed for predicting the population dynamics of *Helicoverpa* species (Witz *et al* 1985). The model uses early season number of eggs, larvae or adults to forecast the timing and size of later potentially damaging population. Pheromone trap has provided the means for measuring early season numbers of *Helicoverpa* adults. This trap data along with climatic variability and crop phenology are used to the MOTHZV model to predict the timing of future *Helicoverpa* generations.

Degree Day Model of *Helicoverpa armigera*

Dalal (2014) conducted experiment on *Helicoverpa armigera* at different alternating temperatures varying from 25: 10 to 30:16 ˚C to estimate the exact time of development of different immature stages of this insect which include egg stage, larval stage and pupal stage. Under this experiment the observation related to time of development of different immature stage was recorded. The development of immature stages was found to be inversely proportional to the mean development temperature. Since the experiment was conducted on alternating temperature regime so step 1 involved the calculation of mean value of temperature which utilized formulae

Mean temperature = [(maximum temperature x No. of hrs) + (minimum temperature x No. of hrs)]/ 24

Step 2 involved the calculation of development threshold temperature in which linear regression equation (y=a+bx) is formed for every immature stage of insect , which is a relationship between development rate(y) and temperature (x) which estimate development threshold temperature for different immature stage. The values for lower threshold temperature can be estimated as per the equation by Campbell et al. (1974). Dalal and Arora (2016) has predicted more food consumption by *H. armigera* on tomato crop leading to more damage.

Non-linear models

As linear models can only estimate the lower threshold temperature (T_{min}) for insect development but not the upper threshold temperature (T_{max}) and optimum temperature threshold (T_{opt}) limits. So, various workers (Lactin et al. 1995; Briere et al. 1999) have come up with various temperature dependent development rate non-linear models to estimate these temperature limits. Optimum threshold temperature, T_{opt} is the temperature where the development rate of the insect is highest whereas at both T_{min} and T_{max} the development rate ceases to zero. Several workers have fitted the development rate to non-linear models which furnished the details of estimates like $T_{min,}$ T_{max} and $T_{opt.}$. Recently, Noor-Ul-Ane (2017) have been able to successfully estimated the temperature threshold estimates of both *H. armigera* and its parasitoid *Habrobracon hebetor* using non-linear models.

FRUFLY Model

A dynamic population model, FRUFLY, for complete life cycle of fruit fly, *Ceratitis capitata* (Messousi *et al* 2008). The model determines an optimal behavior of different system components during the life cycle with an adjustment by a limiting factor like temperature, humidity, parasitism and predation. The effects of the temperature on immature stage developmental times of medfly, *Ceratitis capitata* were used to study the dynamics of population with FRUFLY degree day model. To test the model in the field, flight activity was studied using para-pheromone traps. The FRUFLY model simulations agree with experimental data results of the insect collected by para-pheromone traps and predicts the appearance of the various generations of adults with time. FRUFLY simulation modeling is an important tool for identifying insect pests population size and can help to determine the exact time of taking the management options.

Area wide pest management (AWPM)

Lindquist (2001) defined Area Wide Pest Management as “An area -wide insect control programme is a long term planned campaign against an insect pest population in a relatively large pre-defined area with the objective of reducing the insect population to a non- economic status.”

Models to be followed for AWPM

A recurrent concern for pest managers is the minimum size of the target area that needs to be considered for an AWPM programme to be technically viable and economically justifiable. Due to the lack of adequate practical experience and the absence of models, decisions were sometimes based on educated guesses rather than on sound, scientific principles. Therefore, a conceptual mathematical model was developed that can assist with estimating the minimum area that needs to be considered to successfully apply a series of control tactics according to the AWPM approach against insect pests for which there are adequate biological input data. To make the model applicable to a series of pest species amenable to AWPM, it was developed in a generic way with a minimum of identified assumptions included. The prototype model creates a basis for a decision-support tool to assess the minimum dimensions of an intervention area required for the establishment of a pest-free area For the development of the model, two main situations were considered: (1) the control area is fixed in size (fixed-area model) and there is no advancing pest control front, and (2) the control area is expanding according to the "Rolling-carpet principle" as described in (Barclay *et al* 2011). Hendrichs *et al* (2005) describe the basic spatial elements of an AW-IPM program. The first is the core area, in which the aim is to reduce (in case of a suppression strategy) or eliminate the pest species. The core area may contain the actual resource of value, but in other cases, removal of the pest from the core area may simply have a strategic value by protecting crops situated elsewhere or by protecting humans or livestock against disease vectors (in case of a containment or a prevention strategy). The second is a buffer zone that borders the core area on one or more sides and within which control methods attempt to kill the target insects within that zone, including those that enter the zone from outside. The buffer zone is defined as the region of an AWPM program that is large enough to prevent the pest insect from moving from outside the buffer to the core area before being destroyed by the control methods operating within the buffer zone.

In the case of the fixed-area model, there is a core area to be protected and a buffer zone on all sides of the core area. This model was followed in Chile for fruit fly eradication (Gonzalez and Tronsco 2007). The Rolling-carpet model, there is a buffer on only one side and pest free zones on the other sides. The width of the buffer zone is central to determining the minimum area of an AWPM program, since it defines the smallest possible program. Both these models consists of two components such as a biological component (i.e., dispersal) and an economic component (break-even analysis). The dispersal part describes the movement of the insects across the buffer zone and will determine the width of the buffer zone. The eradication of the New World screwworm, *Cochliomyia hominivorax* Coquerel from Mexico to Panama is a large-scale example of an AWPM action program implemented according to this rolling-carpet principle (Wyss 1998).

Forecasting the plant disease incidence

As per disease triangle, favourable weather condition play important role in initiation and maintenance of plant disease. Several workers have studied the impact of weather variables with respect to diseases of wheat, rice, potato, etc. (Joshi *et al* 1985; Rehman *et al* 2016; Kumar and Gupta 2016). Joshi *et al* (1985) studied the temperature profile, incubation and disease gradient with respect to wheat rusts in India. They concluded that the cyclonic events in bay of Bengal contributed to the dissemination of leaf and stem rust caused by *Puccinia* spp. from Nilgiri and Pulney Hills situated in south India to north India. Rehman *et al* (2016) developed the step wise regression model for bacterial blight of rice caused by *Xanthomonas oryzae* pv. *oryzae*. The authors proved that wind speed and relative humidity in the morning was responsible in development of this bacterial disease. Similarly, Kumar and Gupta (2016) studied the impact of weather variables on incidence of potato apical leaf curl virus disease (PALCVD) transmitted by *Bemisia tabaci* and concluded that the mean *B. tabaci* population would remain at 24 to 85% whiteflies per plant. The pooled data showed that maximum temperature, minimum temperature, evening relative humidity and wind speed are important contributing factors which could predict vector population by 57 per cent.

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