ENGINEERING-BASED COPMUTER SIMULATION FOR MODELING GREENHOUSE WHITEFLY POPULATION GROWTH

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Abstract - Mathematical simulation model is very suitable to understand insect dynamical systems. This system is nonlinear and it is hard to deal with by pure mathematical models only. It offers a possibility to recognize possible gaps in our knowledge. A simulation model of immature stages development of greenhouse whitefly *Trialeurodes vaporariorum* (westwood) population is presented. The parameters, variables, selection of data used for the model and the formulation of equations are discussed. A network form and a program listing are provided with technical details on modeling with SLAM II software. To validate model there were two data sets available to compare the model result with. The data came from experiments that were carried out in greenhouse environment. In first experiment there were followed and recorded the numbers of developmental stages of two sets of 106 and 115 whitefly eggs on tomato leaves daily. In second experiment there were followed and recorded the numbers of empty pupa of two sets of 100 and 115 whitefly eggs on tomato leaves in 80 and 90 days respectively. Numerical results and graphs from model and greenhouse condition are compared presented.

Keywords - Mathematical model, Greenhouse Whitefly, Population.

1-INTRODUCTION

The greenhouse whitefly (*T. vaporariorum*) is one of the well-known pests on several greenhouse crops [11]. In this paper we show how mathematical models help in order to anticipate the immature stages development of this pest. Development of mathematical model is very suitable in this way. It offers a possibility to bring together the results of the extensive research conducted and recognize possible gaps in our knowledge. Once the model has stood verification and validation test, it can be used to obtain qualitative and quantitative information on the importance of certain relations or parameters. As the plant has a main influence on the population growth rate of greenhouse whitefly [10]. We decided to restrict the model to one plant species, from which the most experimental data were available, so we used tomato leaves as a plant in this research.

A simulation model was constructed since dynamic model was desired. SLAM II is used as an engineering-based computer simulation language. This simulator originally developed for modeling industrial manufacturing processes. We use this software to simulate the population growth of greenhouse whitefly. There are three main mathematical forms used to describe the dynamics of the distribution function.

2-MATERIALS AND METHODS

Life History of Greenhouse Whitefly - Immature whitefly periods can be subdivided to several stages (eggs, four larva stages and pupa). The eggs are laid by female whitefly under surfaces of host leaves(EGG). The first instar larvae that hatches from the egg is initially mobile, till it settles down with its mouth parts inserted in the leaf tissue (L1). There are three molts leading to respectively the second, thirds and forth instar larva (L2, L3, L4) and then thickened forth larval instar with visible pigmented eyes can technically be regarded as a pupa(PU). Finally the adult emerges through a slit-like opening in the pupa skin. Based on these knowledge on the life history of whitefly, relational diagram is constructed in figure 1.

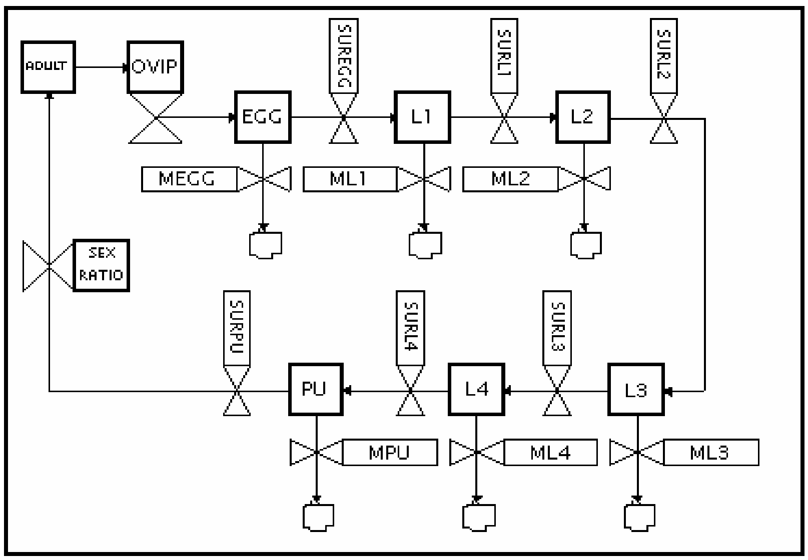

Fig 1: Relational diagram of *Trialeurodes vaporariorum* life history (M = mortality, SUR = survival, ovip = oviposition).For example, ML1 mean mortality of L1 and SURL4 means number of forth larval stage survive to pupa

COMPONENTS, PARAMETERS, VARIABLES AND EQUATIONS - A model consists of components, parameters, variables and equations. The components are parts that make system. All immature stages (egg, four larvae stages and pupa) and adults are components of model. The mortality of these stages as parameters of model has been determined bu assessing the percentage of individual of certain stage that reached the next stage. Data of mortality duration are given by [2][5][6][7][8][9] and [13]. Data showed no correlation between mortality with temperature fluctuating between 16 and 25 degree centigrade. Mean value of collected data on different stages from above references is included in the model, as shown in table1.

Table 1- Mean values of the mortality of *T. vaporariorum* immature stage

Life stage	Percent
Egg	6.1
Larvae 1	3.7
Larvae 1	2.3
Larvae 1	3.3
Larvae 1	1.6
Pupa	1.9

Oviposition rate as a parameter was introduced 5 egg per female per day in model (average of table 2). We also introduced a 1:1 sex ratio as another parameter.

Table 2- Daily fecundity of *T. vaporariorum* in different temperature between 21-24 C°

Reference number	Daily fecundity
[1]	0.96
[6]	2.74
[3]	2.84
[12]	4.4
[1]	4.5
[12]	4.9
[8]	5.8
[8]	6.15
[11]	6.7
[1]	6.8
[2]	7.5
[2]	8.4

In the model, developmental periods and individual numbers of all life stages were considered as variables. Data on development periods of immature whiteflies on tomato are collected from following references: [1], [2], [5], [6], [8], [9], [13] and [14]. The second-degree polynomial is used to find the best fitting for corresponding data obtain from above references in order to use in SLAM II (table 3).

$$\mathrm{Dp} = \alpha t^2 + \beta t + \gamma \quad (1)$$

TABLE 3 -coefficients of equations to calculate life stages of *T. vaporariorum*

Life stage	α	β	γ	P-value			r^2
				α	β	γ	
Egg	0.0191	-1.3361	27.774	0.0415	0.02717	0.0339	0.70
Larvae 1	0.0209	-1.3208	23.626	0.0043	0.0004	0.0000	0.85
Larvae 2	0.0124	-0.6372	16.015	0.0492	0.0218	0.0007	0.71
Larvae 3	0.0106	-0.6706	12.972	0.0478	0.0105	0.0002	0.72
Larvae 4	0.0243	-1.6370	29.717	0.0419	0.0100	0.0010	0.93
Pupa	0.0291	-1.5209	22.624	0.0147	0.0059	0.0011	0.95

Longevity of adult as another variable is equal in male and female [4] and[6]. Longevity of 100 adults on tomato in greenhouse condition (27 ± 2 degree centigrade and 16 hours light and 8 hours dark) is measured. The second-degree polynomial was used to find the best fitting for corresponding data obtain from table 4 and greenhouse experiment in order to use in SLAM II.

Table 4- Longevity of *T. vaporariorum* in different temperature C°

Reference number	Temperature C°	Longevity
[2]	12.5	36
[2]	15	50
[8]	16	32
[2]	18	43
[11]	21	58
[2]	21	28.5
[6]	22	33
[12]	22.5	23
[1]	22.5	28
[8]	24	18
[2]	27	8
[2]	30	5
[2]	33	4

$$Y = 0.0827x^2 + 1.7085x + 35.302 \quad (2) \quad r^2=0.83$$

3- MODEL'S PROGRAM DETAILS

Figure 2 shows SLAM II network model of greenhouse whitefly dynamics. The relational diagram of model listing SLAM II is considered. The model is initiated by allowing whitefly females to lay the eggs on the plant. We used temperature be one of the abiotic parameters. Whiteflies female is then given a value for daily fecundity equal to 5. At this point, the female is checked and if her lifetime is finished she is routed to a death or termination node. If she is not terminated, she is allowed to lay her complement of eggs and is then routed back to fecundity node. So she continues in this cycle until her death.

The eggs that she has oviposited are each assigned the current simulation time as their "birth day". Next 6.1% of eggs population is routed to termination node corresponding to egg mortality. The remainders are sent via activity 5 to another assignment node which assigns egg development time from equation (6). The model continues in this manner until all eggs change to become pupa. After finishing the pupa duration adult whitefly emerged. The adults that emerged were each assigned the current simulation time as adult birthday. Next 50% of them are routed to termination node corresponding to adult male. The remainders are sent to another assignment node, which assign adult longevity from equation (7). Then adult females go to fecundity cycle.

4- VERIFICATION AND VALIDATION

The program of the whitefly model was run and accurate controlling its operation (active TRACE parameter of SLAM II) revealed that it operated as intended.

To validate the model that describes the developmental stages, there are two data sets available to compare the model result with. The data came from an experiment that was carried out in greenhouse condition. In this experiment there were followed and recorded the numbers of developmental stages of two sets of 106 and 115 whitefly eggs on tomato leaves daily at average 18 C temperature and %65±5 relative humidity. The average of developmental period of immature whitefly eggs in the experiment (106 eggs) took 52 days, while it last 56 days in the simulation (Figure 3).

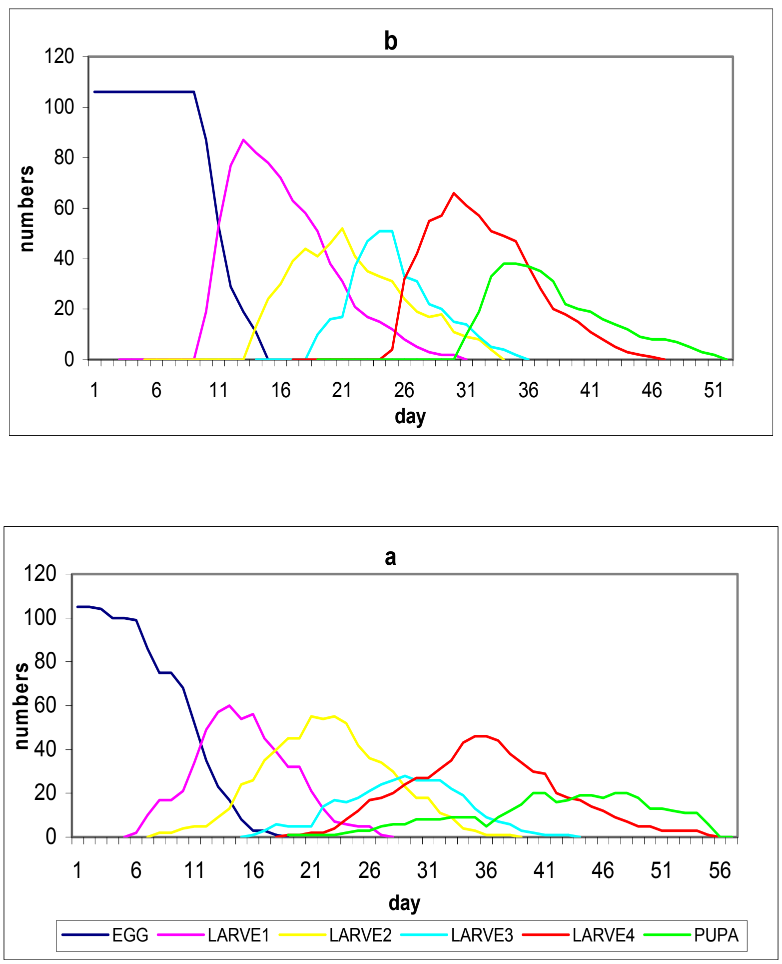

Fig3- Number of immature greenhouse whitefly stages From 106 eggs (a) observation (b) simulation

The average of developmental period of immature in the experiment (115 eggs) took 52 days, while it last 58 days in the simulation (Figure 4).

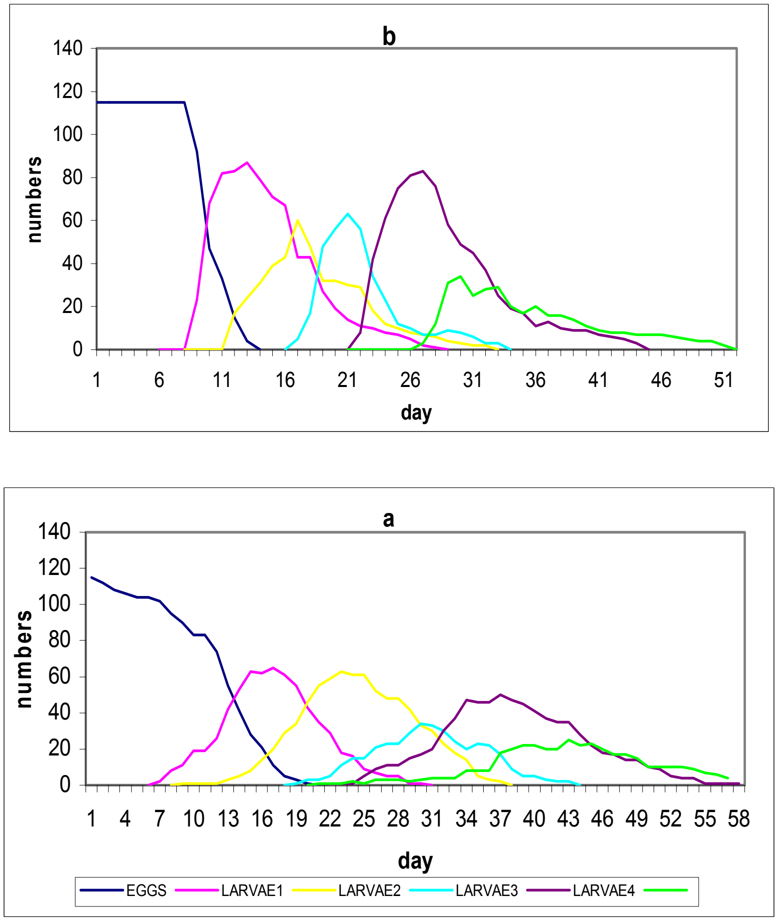

Fig4- Number of immature greenhouse whitefly stages From 115 eggs (a) observation (b) simulation

The mortality was lower than simulated particularly during egg and second larval stages. The average of mortality in greenhouse was 21.2% and in model was 24%.

To validate the population growth model with real world experimental results we counted and recorded the numbers of empty pupa two sets consists (series A) 100 whitefly eggs on tomato leaves in 80 days (in average 24 degree centigrade and 65% humidity) and (series B) 106 whitefly eggs in tomato leaves in 90 days (in constant 18 ± 2 degree centigrade and 65% humidity). Then run the model program with SLAMII software in the same conditions.

SERIES A

Output of the model resulted the average 71.7 and maximum 286 empty pupa per day and total 1542 empty pupa at the end of simulation plot of population growth of model and observation are given in figure that shows the points of observation placed on the curve of model (Figure 5).

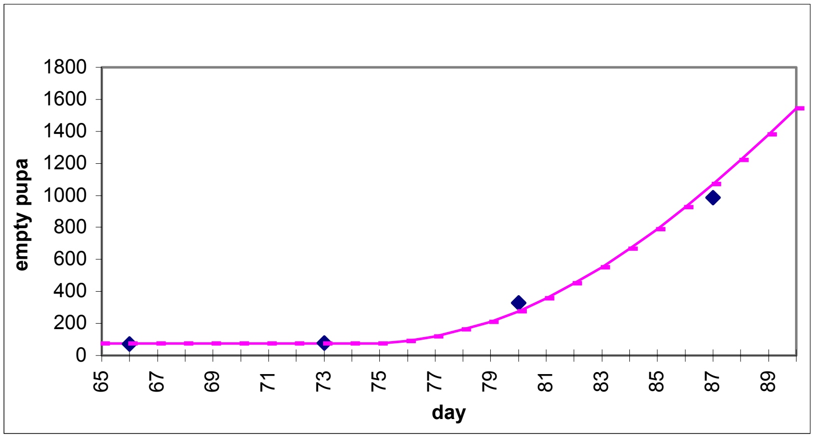

Fig 5. Population growth (number of empty pupa) of greenhouse whitefly 18 C° (------model, • observation)

SERIES B

Output of the model resulted the average 380 and maximum 1635 empty pupa per day and total 8177 empty pupas at the end of simulation. Plot of population growth of model and observation are given in figure that shows the points of observation placed over the curve of model. Difference between model and observation maybe related to temperature situation. In model we consider average of temperature but in greenhouse experiment we had natural tolerance of temperature in spring in Tehran. So high temperature maybe have more influence in speed of population growth (Figure 6).

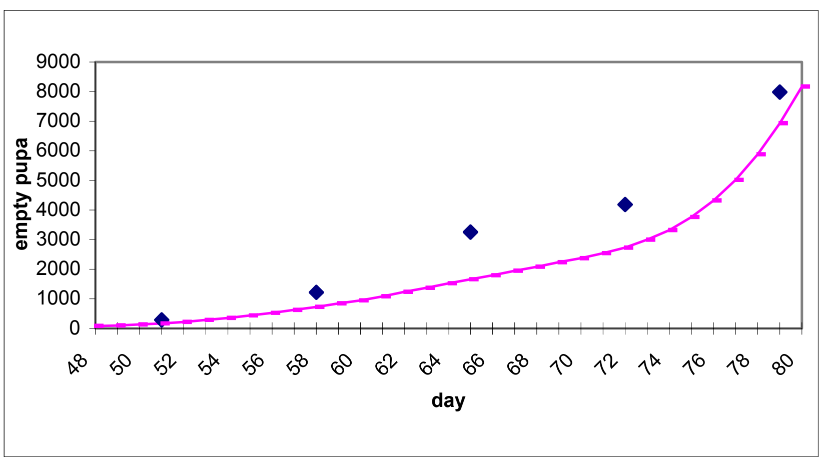

Fig 6. Population growth (number of empty pupa) of greenhouse whitefly in average 24 C° (------model, • observation)

The mortality was lower than simulated particularly during egg and second larval stage. The average of mortality in greenhouse was 21.2% and in model was 24%. The survival curve of model and observation were third type as showed in fig 7. This kind of survival curve describe that the mortality in all life stages are equal.

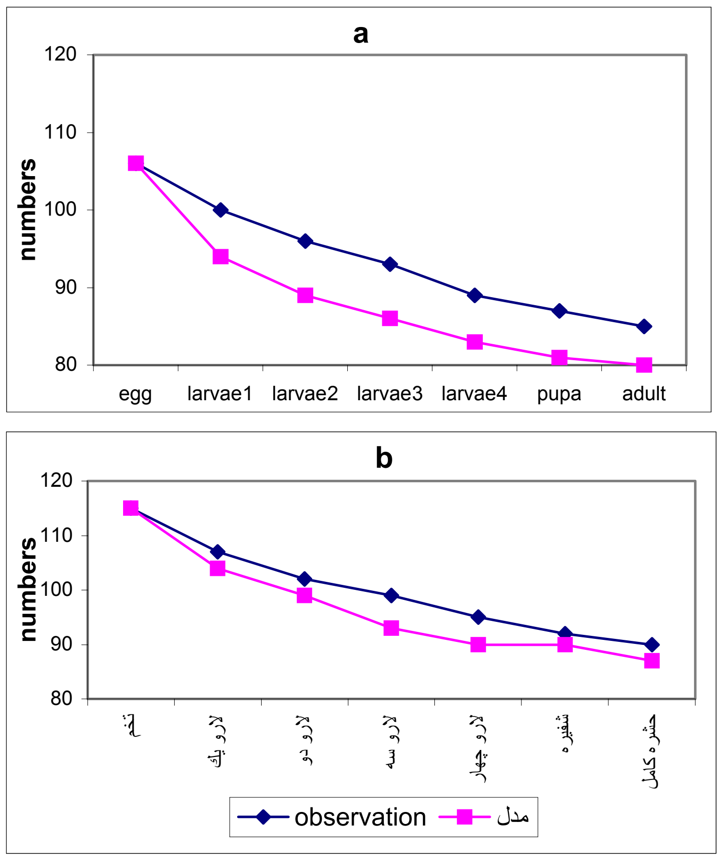

Fig7. survival curve of greenhouse whitefly life stages (a)from 106 eggs (b) from 115 eggs

5- SENSITVE ANALYSIS

For a preliminary evaluation of the relative importance of various life history components for the population growth rate, a limited sensitivity analysis was done. We determine the effect of a 10% increase or decrease of several life history components on the end result of the sumulation. The simulation of experiment was used as reference, because this fittes the experimental data best.

The following components were varied: development period (from egg to adult), fecundity, and relative mortality rate of the developmental stages, adult longevity. The results are shown in figure. On the over of the zero-line we see the relative change I total population size after days, when the component concerned was seer to 90% of the value used in the reference model. On the below of the zero-line the same is for 110% of the reference value. A10% decrease of the developmental pried thus led to a 1% increase of the total population size. A10% increase of the developmental time led to a total population size that was 2% smaller than the reference value. Bu decreasing the fecundity with 10%, the total population size was decreased with 3%, qhilt increasing the fecundity with 10% led to a total population size that was 4% larger than the reference value. As can be seen fro, figure, changing of the developmental period has far the greatest effect, followed by a proportionally equivalent change in fecundity (figure 8).

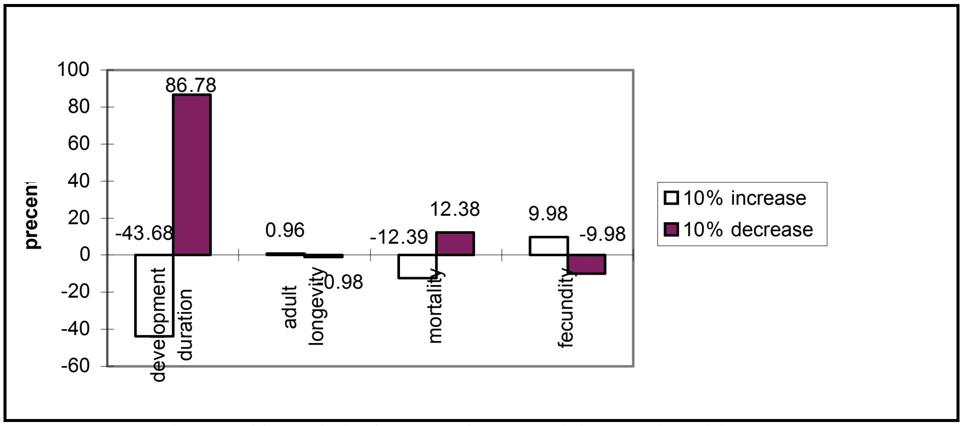

Fig 8. Sensitive analysis of T. vaporariorum population growth-model

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