

# Simulation of Stage-structured population growth of *Myzus persicae* (Suzler) (Hemiptera: Aphididae) based on age-stage, two sex life table

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## ABSTRACT

The age-stage specific growth rate and fecundity of *Myzus persicae* obtained from an age-stage, two-sex life table analysis were used to simulate the growth of stage-structured population under two scenario of initial population structure for five temperature regimes. The first scenario was started with a newly born nymph and the second scenario was started with the youngest female. In both scenario, the population growth increased with shorter life cycle in the respective order: 17°C < 20°C < 23°C < 26°C < 29°C. In this study, computer simulation based on the age-stage, two sex life table demonstrate it's advantages for revealing stage-structured population growth. Information on the growth of a stage-structured population is critical for deciding the timing of intervention in integrated pest management approach.

**Keywords:** *Myzus persicae*, Insect-days, Life table, Population projection, Simulation

## 1. INTRODUCTION

*Myzus persicae* (Suzler) (Hemiptera: Aphididae) is one of the most notorious polyphagous insect pest of agriculture. It feed on more than 500 species of host plants from at least 40 different plant families which include several economically important agricultural crops (van Emden & Harrington 2007). It is an efficient vector of large number of plant viruses (Bhat & Rao 2020). It is characterized of rapid population development due to a high reproductive capacity.

Suppression of insect pest population reaching economically damaging level is the major strategy of integrated pest management approach (Kogan, 1998; Bajwa & Kogan, 2002; Prokopy & Kogan, 2003). Stage differentiation and overlapping are two critical features of insect population ecology that are embedded into their demographics. Demography of an insect population emphasizes its characteristics particularly in relation to the patterns of population growth, survivorship, and reproduction. Demography of an insect population dictates its population dynamics. Population dynamics emphasize the causes and effects of these demographics (Price 1997). Thus, it is very crucial to understand the pattern of population growth for designing an ecologically sound pest management program.

The use of stage-structured population models has increased in recent years. The vital rates in such models are often estimated using a life table analysis by converting age-structured vital rates estimated from a life table parameters for a stage-structured population model. Such conversion introduces potential bias. The age-stage, two-sex life table theory, developed by Chi and Liu (1985), includes stage and sex differentiation and incorporates a variable developmental rate among individuals and accurately estimates population parameters to project the stage-specific population growth of a pest based on its life table characteristics without any conversion. The practical applications of life tables by including the age-stage and two-sexes in a life table construction is highlighted in Gutierrez (1996). A considerable number of published and unpublished (thesis and dissertations) studies by many researchers such as Jha *et al.* 2012a; Gao *et al.* 2012; Akca 2015; Chang *et al.* 2016; Hai *et al.* 2018; Huang *et al.* 2018; Liang *et al.* 2018; Tang *et al.* 2019; Baral *et al.* 2020 have used the age-stage, two-sex life table to study the life table characteristics of arthropods under varying food and environmental conditions and simulate the stage-specific population growth of a pest.

In general, two types of information can be obtained from life-table study. First is the basic life table data which is directly calculated from the life history data of a cohort. Such data includes the age-stage specific growth rate ( $g_{xj}$ ), age-stage specific developmental rate ( $d_{xj}$ ), age-stage specific survival rate ( $s_{xj}$ ) and age-stage specific fecundity ( $f_{xj}$ ). Second is the life table parameters such as the intrinsic rate of increase ( $r$ ), finite rate of increase ( $\lambda$ ), and mean generation time ( $T$ ), which is derived from the basic life table data. The life table parameters are applicable only to a population with a stable age distribution, which is unlikely to occur under changing environmental conditions. The intrinsic rate of increase has frequently been used as an important parameter to evaluate the growth potential of insect populations under varying conditions. However, any projection based on this parameter will have limited application in pest management (Jha *et al.* 2012b). The age-stage, two-sex life table offers a way to simulate population growth based on the basic life table data without assuming a stable age distribution (Chi & Liu 1985) and can reveal the stage structure in a pest population at any time (Chi 1988; 1990; Tsai & Chi 2007; Huang and Chi 2012 & Jha *et al.* 2012b).

In the present study, the age-stage, two-sex life-table theory was applied to simulate the population growth of *M. persicae* based on its life table characteristics under five temperature regimes. Population growth patterns under different temperature showed the comparative fitness of an insect at the particular temperature. The cumulative insect-days and weighed insect-days were also calculated. This study demonstrates the advantages of an age-stage, two-sex life table by revealing the stage structure and for projecting population growth.

## 2. MATERIALS AND METHODS

### 2.1 Host Plant Materials

In this study, cabbage (*Brassica oleracea* L. var. capitata) was selected as host plant as it is one of the most preferred hosts of *M. persicae* and

being one of the most popular vegetables in the world. It is also an important commercial vegetable grown in Nepal. To prevent aphid infestation, cabbage seedlings were grown inside a net house at Vegetable Development Center Khumaltar, Lalitpur, Nepal. Such seedlings were grown in 24-well-plastic tray filled with coco peat-compost nursery mixed in 3:1 ratio in batches of 15 to 20 days interval to maintain a regular supply of tender leaves for aphid (*M. persicae*) rearing.

## 2.2 Colony of *M. Persicae*

The colony of *M. persicae* was established inside a net cage in Central Agricultural Laboratory with the help of apterous adults collected from pesticide uncontaminated cabbage field and was periodically supplemented with nymphs collected from such fields to maintain its genetic heterogeneity. Before starting experiment, insects were reared for 2-3 generations to maintain healthy stock.

## 2.3 Life - Table Study

The procedure of Baral *et al.* (2020) was followed to study the life tables of *M. persicae*. Life table was studied in the laboratory by rearing *M. persicae* on cabbage at five different temperature regimes, i.e. 17°C, 20°C, 23°C, 26°C and 29°C. Prior to the life-table study, a colony of *M. persicae* was reared on these respective temperature for one generation in a growth chamber at 65±5% RH and a photoperiod of 16:8 (L:D). The survival and fecundity were recorded daily for each individual until death. The raw data were analyzed by the computer program, TWSEX-MSChart which is available at <http://140.120.197.173/Ecology/prod02.htm> (Chi 2020a) which is based on the theory of the age-stage, two-sex life table (Chi & Liu 1985) and the method described by Chi (1988),

## 2.4 Population Projection

Population projection based on age-stage, two-sex life table analysis includes the the age-stage-specific growth rate matrix (G), age-

stage-specific development rate matrix (D) and the age-stage-specific fecundity matrix (F) for estimating life table parameters using life history data. Projection of the age-stage structure of a population at time t+1 is obtained from the operation of these matrices:

$$N_t \xrightarrow{G,D,F} N_{t+1} \quad (1)$$

In G matrix, element  $g_{xj}$  is the probability that an individual of age x and stage j will grow to age x+1 but will remain in stage j after one age unit. In D matrix, element  $d_{xj}$  is the probability that an individual of age x and stage j will survive and develop to age x+1 and stage j+1, respectively. Element  $f_{xj}$  of F matrix, is the number of offspring produced by an individual in age x and stage j. The detailed calculation procedures are discussed in Chi & Liu (1985).

The population growth for 30 days under two scenarios of initial population structure projected by using the age-stage specific growth rate, and fecundity obtained from an age-stage, two-sex life table analysis. One newly born nymph (zero day age) was used as initial population structure for each temperature condition in scenario A. In scenario B, one female of age 9 days, 8 days, 7 days, 6 days and 5 days were used as initial population structure for 17°C, 20°C, 23°C, 26°C and 29°C temperature condition, respectively. In both scenarios, the designated age is counted from the first instar nymph and indexed from 0. As the survival rate and fecundity used for the population projection were collected from the whole population, so initializing the simulation with an individual is appropriate. No management strategy applied for simulating both projection scenarios.

As the potential of a pest population to damage plants varies according to the stage-specific duration, we assigned a weighing coefficient ( $w_j$ ) to each stage based on its duration for each temperature condition separately (Table 1). The weighing coefficient of each stage was calculated as follows:

$$w_j = \frac{d_j}{d_h} \quad (2)$$

Where  $d_j$  is the duration in stage  $j$ , and  $d_h$  is the longest stage specific duration. Because the adult

stage has the longest duration, the value of  $w_5$  is set to unity.

Table 1. Stage-specific weighing coefficients used in the simulations

Stage code ( $j$ )	Stage Title and Symbol	Temperature regimes									
		17°C		20°C		23°C		26°C		29°C	
		$n$	$w_j$	$n$	$w_j$	$n$	$w_j$	$n$	$w_j$	$n$	$w_j$
1	Firs nymphal instar ( $N_1$ )	37	0.06	47	0.09	41	0.07	41	0.1	56	0.1
2	Second nymphal instar ( $N_2$ )	37	0.06	47	0.09	41	0.09	41	0.12	56	0.13
3	Third nymphal instar ( $N_3$ )	37	0.07	47	0.12	41	0.09	41	0.11	56	0.1
4	Fourth- fifth nymphal instar ( $N_{4,5}$ )	37	0.1	47	0.15	41	0.13	41	0.17	56	0.19
5	Adult female (F)	37	1	47	1	41	1	41	1	56	1

In table 1,  $n$  denotes the number of individuals in the cohort that reaches to adult stage. The weighed size of the *M. persicae* population on day  $t$  was then calculated as follows (Chi, 1990):

$$n_w(t) = \sum \sum n_{ij}(t) w_j \quad (3)$$

Insect-days are the summation of the number of pests over the number of days that they survive and cause damage to a crop, which could be used as an index of crop damage (Ruppel 1983). As the age-stage, two-sex life table takes into consideration the variable developmental rate among individuals, and the stage-specific duration, so the cumulative insect-days (CumSD) and weighed cumulative insect-days estimated by using an age-stage, two-sex life table could generate a more rational index of the overall damage caused by a pest population. These indices can be calculated as follows Chi (1990):

$$CumSD = \sum_{t=0}^T \sum_{j=1}^5 n_{xj}(t) \quad (4)$$

$$CumWSD = \sum_{t=0}^T [\sum_{j=1}^5 (n_{xj}(t) \cdot w_j)] \quad (5)$$

Where  $T$  is the simulation time, and  $j = 1$  to 5 are the stages that cause damage (Table 1). The program Timing-MSChart is available at <http://140.120.197.173/Ecology/prod02.htm> (Chi 2020b).

### 3. RESULTS

Starting with an initial population of one pair of the youngest adults, the population growth of *M. persicae* at five different temperature regimes i.e. 17°C, 20°C, 23°C, 26°C and 29°C were simulated for 30 days and compared with each other. (Fig. 1-5). The starting individual could properly represent the population as the survival rate and fecundity used in population projection were calculated from the whole population. The figures from simulation result revealed the change in the age-stage structure of *M. persicae* under the given conditions. The populations growth under these five conditions are shown in Fig. 6. The weighed population growth is depicted in Fig. 7 which shows the damaging potential of the pest population.

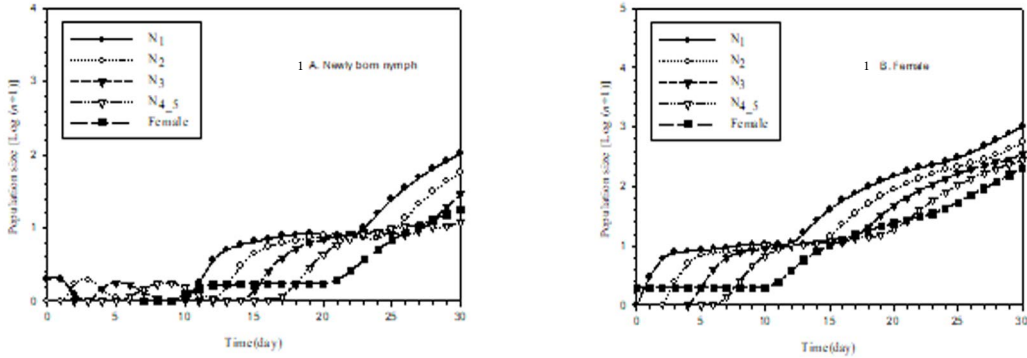


Fig. 1. Stage-specific population projections of *M. persicae* reared on cabbage at 17°C using a newly born nymph (1 A) and a female (1 B)

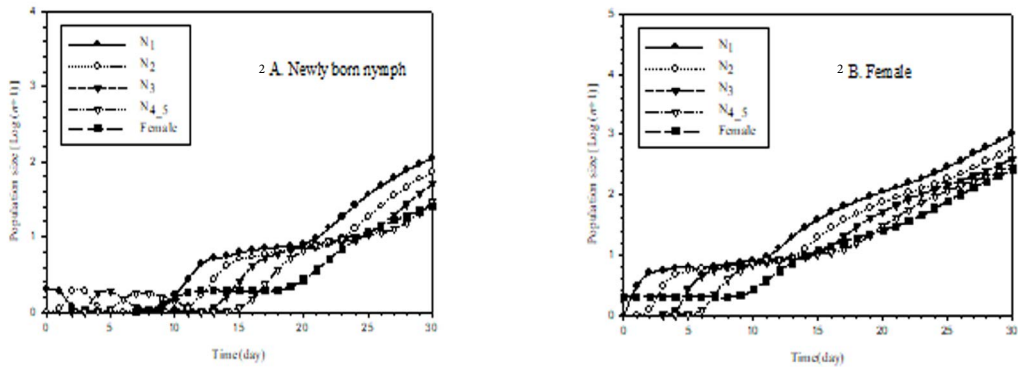


Fig. 2. Stage-specific population projections of *M. persicae* reared on cabbage at 20°C using a newly born nymph (2 A) and a female (2 B)

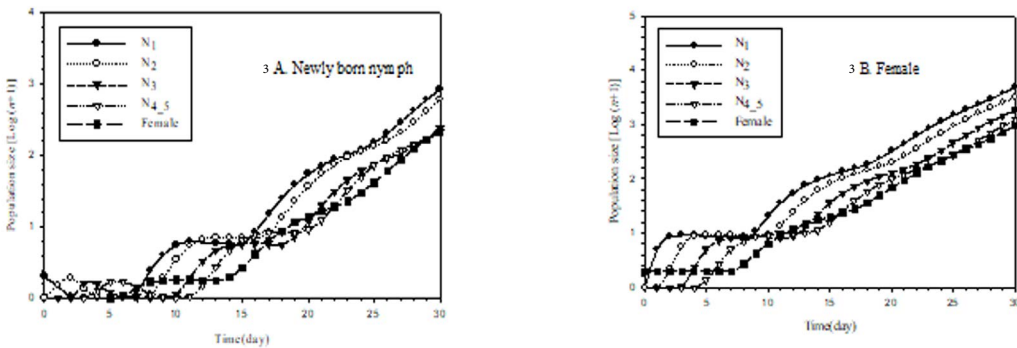


Fig. 3. Stage-specific population projections of *M. persicae* reared on cabbage at 23°C using a newly born nymph (3 A) and a female (3 B)

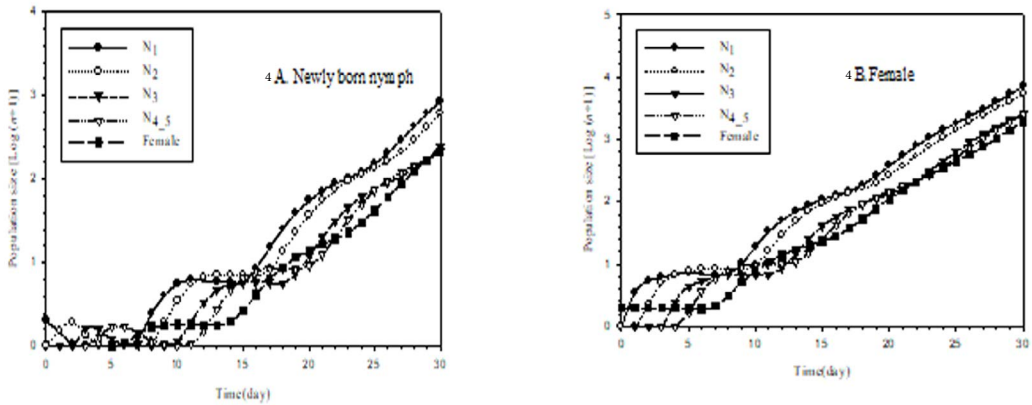


Fig. 4. Stage-specific population projections of *M. persicae* reared on cabbage at 26°C using a newly born nymph (4 A) and a female (4 B)

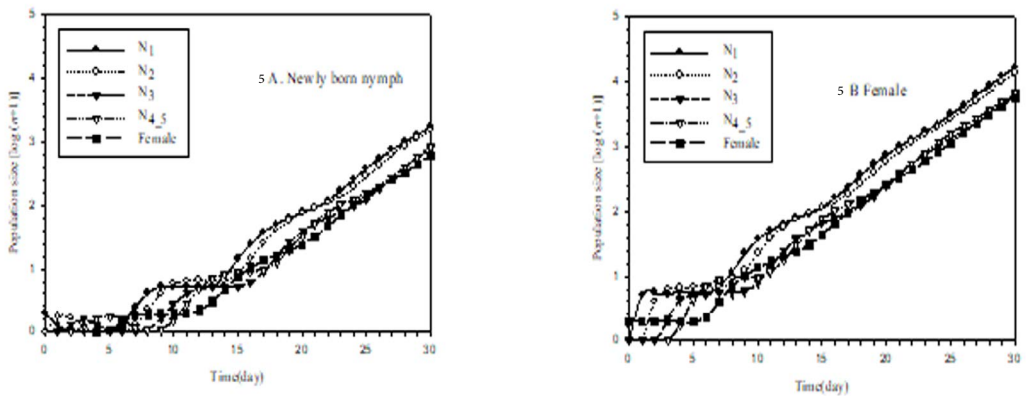


Fig. 5. Stage-specific population projections of *M. persicae* reared on cabbage at 29°C using a newly born nymph (5 A) and a female (5 B)

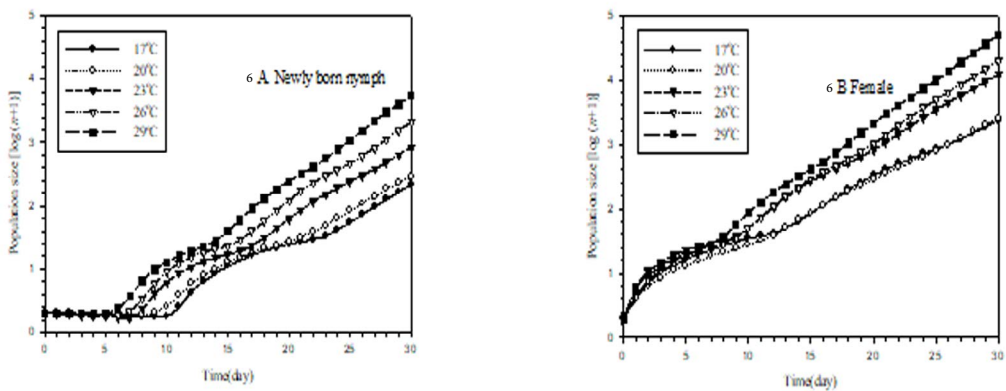


Fig. 6. Population growth projections of *M. persicae* at five temperature regimes using a newly born nymph (6 A) and a female (6 B)

The growth curves of the all stages in fig. 6 were compiled for making a comparison. The simulation curves based on the weighed stage size represent the damage potential of *M. persicae* under respective scenarios (Fig. 7).

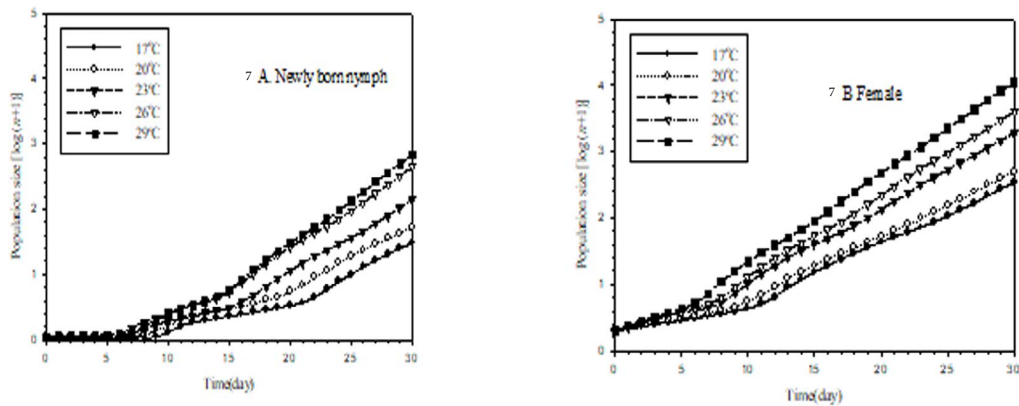


Fig. 7. Weighed population growths of *M. persicae* at five temperature regimes using a newly born nymph (7 A) and a female (7 B)

The curve of the weighed insect-days at 29°C was the highest compared to the other curves due to a faster development. In contrast, the weighed insect-days curve at 17°C was the lowest compared to the other curves due to a

slower development. This result shows that the *M. persicae* population grew slowly at 17°C. All of these details can only be observed by using a computer simulation based on the age-stage, two-sex life table.

Table 2. Cumulative insect-days and weighed insect-days of each simulation result

Temperature	Scenario A- Newly born nymph		Scenario B- Female	
	Insect-days		Insect-days	
	Cumulative	Weighed	Cumulative	Weighed
17°C	984	142	12569	1723
20°C	1350	259	12513	2412
23°C	3676	584	53509	8373
26°C	8220	1689	79598	15998
29°C	20239	2455	181367	41239

The values of the total cumulative insect-days and weighed insect-days corresponding to the population curves are given in Table 2. The total number of cumulative insect-days was the lowest at 20°C, while the number of weighed stage days was the lowest at 17°C. The greatest number of insect-days and weighed insect-days were at 29°C.

#### 4. DISCUSSION

Cabbage aphid, *M. persicae* is a hemimetabolous insect with two clearly distinguishable life stages: nymph, and adult. The production of nymphs varies with maternal age. The nymphal stage undergoes 3 to 4 molts, depending on the food and environmental conditions. The growth, and development rates vary among individuals in a

cohort which affect the demography of this insect and create complications in evaluating its fitness and damage potential under different conditions. These fascinating biological variations are also reported in Tang *et al.* (2019). The intrinsic rate of increase is considered to be a most appropriate life-table parameter for comparing the fitness of populations across diverse climatic and food-related conditions (Southwood 1966; Smith 1991; Kingsolver & Huey 2008). However, the intrinsic rate of increase ( $r$ ) is only applicable to a population with a stable age distribution, while survival rate and fecundity can be applicable to contemporary population. Thus, a population projection based on an age-stage-specific survival rate and an age-stage-specific fecundity rate provides a more realistic and reliable insight into the ecological fitness and damage potential of an insect population. The age-stage, two-sex life table analysis make it possible to simulate population growth with stage differentiation which reveal the short-term growth of a pest population by depicting the stage structure and can be applied to the timing of pest management (Chi 1990). Such simulation reveals overlaps in the stage curves (Fig. 1-5) and thus demonstrate the advantage of taking the variable development into account. On the other hand, if the variable development is ignored, it results into inaccurate simulations and generates a single curve representing the total population only.

The population grew faster despite the lower fecundity observed at 29°C. This result is due to the shorter developmental duration of each stage at 29°C. The order of population growth was 17°C < 20°C < 23°C < 26°C < 29°C. The intrinsic rate of increase calculated for these conditions followed the same order.

Ruppel (1983) proposed that the insect-day is an index of arthropod abundance over time and particularly useful when yield loss results from an accumulation of feeding injury over time (Rhains *et al.* 2010). This index can be used to estimate damage potential. However, the insect-day is not gaining as much attention as it deserves due to the difficulties of computer simulation based on life table theories. This study also demonstrated that the simulation of population growth based on weighed stage size in combination with insect-

day techniques enables to assess the damage potential under given conditions and incorporates the damage potential estimate as shown in Jha *et al.* 2012b. For example, the higher weighed insect-day value was obtained at 20°C despite the relatively high cumulative insect-day values at 17°C in this study (Table 3). This is due to the combined effect of two distinct phenomena: a longer nymphal duration due to slower development and more nymph due to higher fecundity at 17°C. Slower development occurred due to a longer feeding period and more nymphal instars.

## 5. CONCLUSION

In this study, the computer simulation of population growth is limited to five conditions. Such simulations are based on life table data which is a useful, comprehensive, and efficient for predicting and comparing the growth of populations. If survival rate and fecundity data are known, this study demonstrated a technique that can be applied to compare the growth of populations across diverse climatic and food-related conditions. In addition, a better timing for pest management decisions can be taken if the growth characteristics of a pest population under different conditions could be understood properly. This study showed the advantages of revealing stage-structured population growth in a manner relevant to integrated pest management (IPM) as the age-stage, two-sex life table takes the variable developmental time, and stage differentiation into consideration. As insect life tables vary significantly with food, temperature and other environmental factors, it is a difficult task to project populations in the field precisely. An insect pest management expert or scientists should not overlook the importance of life table despite its difficulties. Further efforts and such studies are needed to make ecologically sound pest management a possible task.

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