A MICROCOMPUTER BASED SIMULATION PACKAGE FOR TEACHING AGRICULTURAL PEST MANAGEMENT*

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Abstract

Simulations play an important role in the study of agricultural pest management. Several microcomputer-based simulations have been developed for this purpose. They range from basic population growth to the real-time management of complex agricultural systems consisting of pests, natural enemies, chemicals, and weather. Descriptions of the models and example simulations are described in this paper.

I. INTRODUCTION

The ever-increasing restrictions on chemicals used for pest and disease control are motivating factors for implementing complex management techniques in agriculture. These techniques systematically integrate chemicals, biotic, and abiotic factors into holistic systems for managing agricultural pests. Agricultural students need to understand the underlying principles and the process of developing these techniques, while growers need to be educated on the rationale and, ultimately, the use of these complex techniques. Computer-based simulations can play an important role in these educational areas.

The purpose of this paper is to describe several microcomputer-based simulation models that were developed at Michigan State University. The models were developed on a microcomputer because (1) the cost of acquiring and operating the equipment is minimal and is affordable by many universities despite shrinking budgets, and (2) a recent survey conducted by Farm Computing News shows that growers are purchasing microcomputers at an increasing rate.

II. EQUIPMENT REQUIRED

Figure 1 is a representative system of the minimal equipment requirements to run the simulation models. The equipment consists of:

1. an Apple II$^+$ microcomputer with 48K,
2. 5¼" floppy disk drive,
3. an EPSON MX80 printer, and
4. a color television.

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This simulation package, written in BASIC, can be adapted to run on any other microcomputer system with very little effort.

III. DESCRIPTION OF SIMULATION MODELS

An important area in the study of modern pest management is population ecology. Therefore the initial development of the simulations focused on population dynamic models. The dynamics of insect populations that have a single generation per year as well as many seasons per year are considered.

A. Single Generation Models

The first class of models study the multi-year population dynamics of an insect with one generation per year (growing season). Many agricultural insects exhibit this behavior. Basically, insect activity starts in the spring and stops at the end of the summer. Adult insects emerge from their overwintering sites, feed, mate, lay eggs, and die of natural causes in a few weeks. The eggs laid by the adults hatch in a few days and go through two other developmental stages called larva and pupa before becoming adults. The number of adults that emerge at the end of this developmental cycle is determined by the survival potentials of these immature stages (eggs, larvae, and pupae). Usually these survivals depend on weather, resources, naturally occuring biological controls such as parasites and predators, etc. At the end of the summer, the newly emerged adults disperse to their overwintering sites. These adults do not lay eggs until the following spring. Furthermore, the number of adults returning the next spring is determined by these newly emerged adults and their overwintering survival potential.

In summary, the long-term population dynamics of an insect is determined by (1) egg-laying capacity of the spring adults (fecundity rate), (2) survivals of eggs, larvae and pupae during the season, (3) overwintering survival of summer adults, and (4) effects due to natural enemies. Four models are developed to investigate these effects.

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POPSIM I. In this model, all the survivals and the fecundity rates are assumed to be constant. No effects due to natural enemies are considered. The mathematical model used is:

$$N(t+1) = F\,S_E\,S_L\,S_P\,S_O\,N(t) \qquad (1)$$

where F = fecundity rate (constant),

S_E = egg survival ($0 \leq S_E \leq 1$),

S_L = larval survival ($0 \leq S_L \leq 1$),

S_P = pupal survival ($0 \leq S_P \leq 1$),

S_O = overwinter survival ($0 \leq S_O \leq 1$).

POPSIM II. In this model, the density dependent effects on the larval survival are included. The form of the model is the same as in Eq. (1) except S_L is a function of time and is given by:

$$S_L(t) = S_{LN} + \left(\frac{.1 - S_{LN}}{L_2 - L_1}\right)(L(t) - L_1) \qquad (2)$$

where $L(t)$ = larval density in year t,

L_1 = larval density at which the density effects start to appear,

L_2 = larval density at which the survival is reduced to 0.1,

S_{LN} = density independent survival.

POPSIM III. This model combines the adult density effects in their ability to lay eggs to the density dependent larval survivals given in Eq. (2). The model form is the same as in Eq. (1) except S_L is modified by Eq. (2) and F is modified by the following:

$$F(t) = F_N + \frac{.9F_N}{N_2 - N_1}(N(t) - N_1) \qquad (3)$$

where $F(t)$ = fecundity rate in year t,

F_N = density independent fecundity rate,

N_1 = population at which the density dependent effects begin to appear,

N_2 = population at which the fecundity decreases to 10% of F_N.

POPSIM IV. Two more features are added to the model described in POPSIM III. These are (a) habitat effects on the overwintering adults and (b) natural enemies. For part (a), Eq. (1) is modified as follows:

$$N^1(t) = F(t)\,S_E\,S_L(t)\,S_P\,N(t) \qquad (4)$$

$$N(t+1) = \sum_{i=1}^{4} S_{oi}(t)\,A_i\,N^1(t) \qquad (5)$$

where $S_{oi}(t)$ = survivals in the habitat i (i=1, 2, 3, 4),

A_i = proportion of overwintering populations in the habitat i,

$N^1(t)$ = population of adults leaving for overwintering habitats in the year t.

$S_L(t)$ and $F(t)$ are given by Eq. (2) and Eq. (3), respectively. For part (b), these equations are further modified to include the effects of natural enemies along with all the features mentioned above. They are given as follows:

$$N^1(t) = F(t)\,S_E\,\beta_1\,\beta_2\,S_L(t)\,S_P\,N(t) \qquad (6)$$

$$N(t+1) = \sum_{i=1}^{4} S_{oi}(t)\,A_i\,N^1(t) \qquad (5)$$

$$P_E(t+1) = G_1\,(P_E(t), E(t)) \qquad (7)$$

$$P_L(t+1) = G_2\,(P_L(t), L(t)) \qquad (8)$$

where $\beta_1 = 1 - \alpha_P(t)$, and $\beta_2 = 1 - \alpha_L(t)$,

$P_E(t)$, $E(t)$, $P_L(t)$, and $L(t)$, are number of egg parasites, number of eggs, number of larval parasites, and number of larvae in year t, respectively.

The parameters α_P and α_L are percent egg and larval parasitism, respectively. Explicit functional relationships are not shown in Eq. (7) because of the variety of theories proposed in the literature. The student has the flexibility to explore different formulations. A sample output for POPSIM I and POPSIM II are shown in Figures 2-3. Other models have similar output, except they require more inputs.

B. Single Season Model

In all of the above models, the within-generation dynamics of the insect are neglected. From the management point of view, knowing the changes within the season is as important as knowing the long-term dynamics of the insect. If $N_1(t)$, $N_2(t)$, $N_3(t)$, $N_4(t)$, and $N_5(t)$ represent the population of overwintering adults, eggs, larvae, pupae and summer adults, respectively, then a simple within-generation model can be given as follows:

$$\begin{bmatrix} N_1(t+1) \\ N_2(t+1) \\ N_3(t+1) \\ N_4(t+1) \\ N_5(t+1) \end{bmatrix} = \begin{bmatrix} a_1 & 0 & 0 & 0 & 0 \\ f & c_1 & 0 & 0 & 0 \\ 0 & s_e(1-c_1) & c_2 & 0 & 0 \\ 0 & 0 & s_l(1-c_2) & c_3 & 0 \\ 0 & 0 & 0 & s_p(1-c_3) & a_2 \end{bmatrix} \begin{bmatrix} N_1(t) \\ N_2(t) \\ N_3(t) \\ N_4(t) \\ N_5(t) \end{bmatrix}$$

where $c_i = e^{-1/D_i}$, i = 1, 2, 3,

D_i = development rate,

s_e, s_l, s_p = egg, larval, and pupal survivals, respectively,

a_1 = overwintering adult survival,

a_2 = summer adult survival.

C. PRED-PREY Models

So far we have considered insects that have only one generation per year. However, there are many insects whose generation time is very small compared to the growing season and thus have several generations every year. Interplay between the biological controls and chemicals can be observed more effectively with these populations in a given growing season. To illustrate these principles, a predator/prey model developed by Leslie and Gower (1960) has been used and modified to include chemicals and weather in the following simulations. If H(t) and P(t) represent the number of pests and predators present at time t, respectively, then the model suggested by Leslie and Gower (1960) is given by:

$$dH/dt = (a_1 - b_1 P)\, H \tag{10}$$

$$dP/dt = (a_2 - b_2 P/H)\, P \tag{11}$$

where a_1 = intrinsic rate of growth of pests in the absence of the predator,
a_2 = intrinsic rate of growth with unlimited supply of pests,
$b_1 P$ = decrease in growth rate of pests in the presence of predator,
$b_2 P/H$ = decrease in the growth rate when the pest supply is limited.

The discrete equivalents of these equations are given by Pielou (1977):

$$H(t+1) = \frac{\lambda H(t)}{1 + \alpha_1 P(t)} \tag{12}$$

$$P(t+1) = \frac{\lambda_2 P(t)}{1 + \alpha_2 P(t)/H(t)} \tag{13}$$

where $\lambda_i = \exp(a_i)$; $i = 1, 2$

$$\alpha_i = (\lambda_i - 1)\frac{b_i}{a_i}$$

To illustrate the basic principles of predator-prey interactions, three separate simulations have been developed for convenience. They are:

PRED-PREY I. This program simulates Eqs. (12) and (13) where the growth rates are known and no weather effects are present. Each simulation time interval represents one generation time of the population. Effects of varying the parameters, a_i and b_i, on the population can be studied.

PRED-PREY II. This model uses the daily temperature information to determine the generation time for the population. The user inputs the seasonal information, such as beginning of the season and length of the season. Since the number of generations is affected by all of the above factors, the student can determine the effects of varying weather, length of season, etc., on the population.

PRED-PREY III. This is a simple variation of PRED-PREY II. The basic difference is in the output from the simulation. In PRED-PREY II, the output is population vs. generations. In PRED-PREY III, the output is given as population vs. days from April 1. Apart from the teaching perspective, this has some practical applications as well. It is easier to relate to the population numbers in the field on a day-to-day basis than on a generation-to-generation basis.

The daily temperature in the above models is obtained as follows:

$$T_M(i) = K_1 + K_2 \sin\left(\frac{\pi}{180}\, i\right) \tag{14}$$

$$T_D(i) = T_M(i) + \sigma * X \tag{15}$$

where $T_M(i)$ is the mean temperature on a given day i, which is used to determine the daily temperature $T_D(i)$ in Eq. (15). In Eq. (15), X is the random number obtained from a normal distribution with mean of 0 and standard deviation 1.

A sample session of the model is given in Figure 4.

D. Management Models

Decision-making in modern pest management involves controlling the pest trajectory during the season, utilizing all the biological and abiotic controls available at one's disposal (Tummala and Haynes 1977). Abiotic inputs to the system are usually weather and chemicals. The weather essentially determines the speed of development of the pest populations. Chemicals induce mortality of a given value. Biological controls also determine the rates of a change of the pest population. To provide experience in this real time decision making, a simulation model MANAGEMENT MODEL I has been developed. This model allows the user to manage the pest population on a weekly basis using any of the following three management options:

1) biological control by introducing new predators in the system,
2) application of chemicals with low or high mortalities, and
3) no action

In the second case, the chemicals applied also induce mortality to the predator, if it is present in the system. Crop damage is computed based on the population of the pests and the susceptibility of the crop in that period. Finally the user learns the success or failure of the chosen management strategy by the amount of revenue or loss earned at the end of the season. By varying the parameters, such as length of the season, beginning of the season, weather patterns, and crop growth functions, the user can gain experience with the complex decision-making needed for pest management. A sample session is shown in Figure 6.

E. Output Format

For all the models described above, the output can be presented in many forms, such as output on a video screen or printer output. A special graphics package is used on our system (Tummala 1982) to facilitate graphic output on the screen as well as on the printer. The user who wishes to know more details about this package may contact the first author. However, it should be pointed out that the models described here do not depend on this graphics package.

IV. SUMMARY

Simulation models play an important role in explaining complex phenomenon. Agricultural students and growers who are less quantitatively prepared can benefit from the inexpensive microcomputer based simulations to learn the implications of the complex dynamics of pests in the ecosystem. Furthermore, models such as MANAGEMENT MODEL I can be used by growers to experiment with various management strategies by actually inputting the counts of pests, parasites, etc., and weather information. Although, space limitations prevented us from giving complete listings of the programs, anyone interested in the listings and more details may contact the authors.

Figures

Figure 1. Representative microcomputer system: (1 & 2) Apple II+ microcomputer with 48K, (3) 5¼" floppy disc drive, (4) EPSON MX80 printer, and (5) color television.

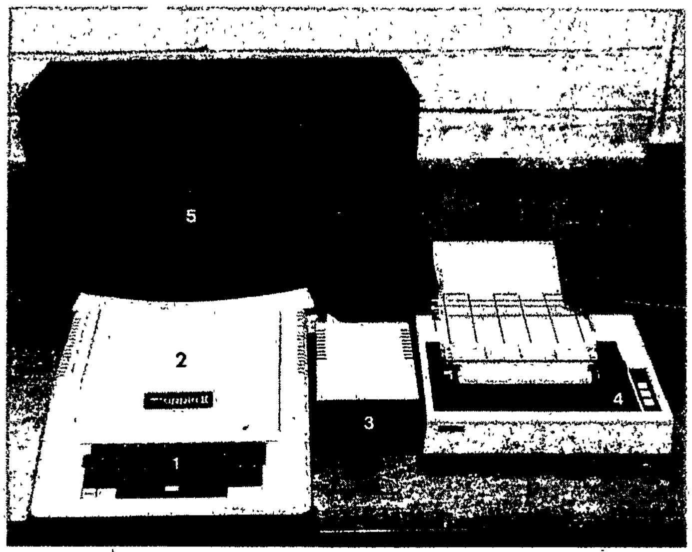

Figure 2. A sample simulation of POPSIM I.

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* * * * * * * * * * * * * * * * * * * * * * * * *

You have selected POPSIM I. This model simulates
the population dynamics of an insect with one
generation per year. No density effects are
considered. Percent survivals are assumed to be
between 0 and 1 where 0 = zero percent and 1 = 100
percent. Follow the directions.

* * * * * * * * * * * * * * * * * * * * * * * * *

Initial overwintering population = 10
Seasonal egg production per female = 5
Egg survival = .9
Larval survival = .7
Pupal survival = .8
Overwinter survival = .5
Number of years to be simulated = 10
Migration = 0
Are you happy with the above values? (Y or N) Y
   1. line graph
   2. point graph
   3. bar graph
Which type of graph would you like to see? 1
   1. adult population
   2. time
What would you like the X axis of the graph to be?
   2
How many variables do you wish plotted vs. time?
   1
Enter the number of a variable to be displayed. 1
Would you like to do any scaling? (Y or N) N
```

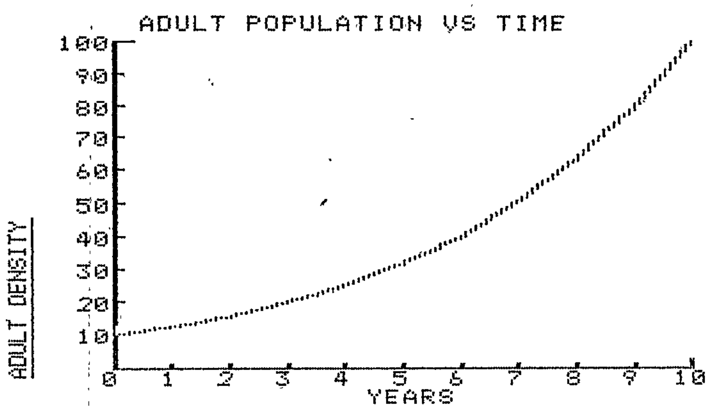

Figure 3. A sample session with POPSIM II.

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* * * * * * * * * * * * * * * * * * * * * * * * *

You have selected POPSIM II. This model simu-
lates the population dynamics of an insect with
one generation per year. Density dependent
mortality in the larval stage is considered.
Survivals are assumed between 0 and 1 where 0 =
zero percent and 1 = 100 percent. Follow the
directions.

* * * * * * * * * * * * * * * * * * * * * * * * *

Initial overwintering population = 10
Maximum seasonal egg production per female = 5
Egg survival = .9
Density independent larval survival = .7
Density at which density dependent effects start
   appearing = 25
Density at which the larval mortality is .99 = 100
Pupal survival = .8
Overwintering survival = .5
Number of years to be simulated = 30
Migration = 0
Are you happy with the above values? (Y or N) Y

                 * Wait for the graph *
```

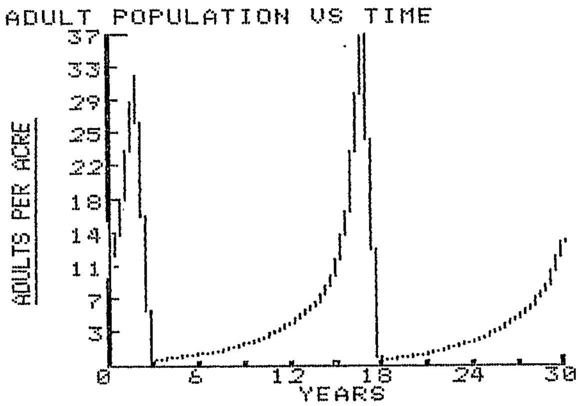

Figure 4. A sample session of PRED-PREY III.

* *

Generation index = exp (A1), input A1 = 1
Generation index = exp (A2), input A2 = 1
Number of degree days required to complete a generation = 100
Give season starting date in number of days from April 1 = 0
Give the length of the season in days = 100
Threshold temperature = 45
B1 = .1
B2 = 2.5
Are you happy with the values? (Y or N) Y
The initial density of the prey = 50
The initial density of the predator = 30

Day from April 1	Prey	Pred
10	22	23
17	12	11
23	11	6
27	15	5
31	22	6
35	30	7
39	37	10
42	38	12
45	33	14
48	26	13
51	22	11
54	20	10
57	21	8
60	23	8
63	25	9
66	28	10
69	28	10
72	27	11
75	26	11
78	24	11
81	23	10
84	23	10
87	24	9
90	25	10
93	26	10
96	26	10
99	26	10

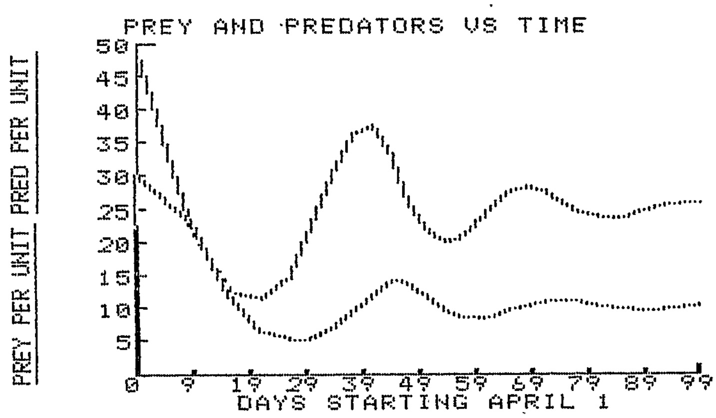

Figure 5. A sample session for MANAGEMENT MODEL I.

* *

Gen. index is exp(A1), give A1 = 1
Gen. index is exp(A2), give A2 = 2
Number of degree days required to complete a generation = 100
Give season starting date in number of days from April 1 = 30
Give the length of the season in days = 70
Threshold temperature = 45
B1 = .1
B2 = 2.5
Are you happy with the values? (Y or N) Y
The initial density of the prey = 50
The initial density of the predator = 6

Day from April 1	Prey	Pred
30	50	6
31	55.1	7.2
32	59.1	8.5
33	61.5	10.3
34	61	12.1
35	57.9	13.9
36	52.7	15.5

Want to manage? (Y or N) Y
Do you want to see the management options? (Y or N) Y

* *

Management Options

Code (cost)	Effect (mortality)
BC(1$/10pred)	Variable
P1($15)	Pest = .45, Pred = .1
P2($40)	Pest = .95, Pred = .7

* *

Management Strategy = P2

37	2.3	5
38	2.7	2.2
39	3.3	1.7
40	4.4	1.6

Microcomputer Simulation (continued)

```
    41          5.7         1.6
    42          7.5         1.8
    43          9.9           2
Want to manage?  (Y or N)  N
    44           13         2.4
    45         16.8         2.8
    46         21.2         3.4
    47         26.8         4.2
    48         32.3         5.1
    49         38.4         6.3
    50         43.2         7.7
Want to manage?  (Y or N)  Y
Do you want to see the management options?
  (Y or N)  N
Management Strategy = P2
    51          2.3         2.8
    52            3         1.7
    53          4.2         1.5
    54          5.7         1.6
    55          7.8         1.7
    56         10.7           2
    57         14.5         2.5
Want to manage?  (Y or N)  Y
    58         19.1           3
    59         25.1         3.8
    60         31.7         4.8
    61         38.6         6.1
    62         44.4         7.6
    63         48.4         9.5
    64         49.2        11.5
Want to manage?  (Y or N)  Y
Do you want to see the management options?
  (Y or N)  N
Management Strategy = BC
Number of predators to be released = 30
    65         23.1        29.7
    66         13.8        16.9
    67         11.2         9.9
    68         11.2         6.8
    69         12.7         5.7
    70         14.9         5.5
    71           18         5.7
Want to manage?  (Y or N)  N
    72         21.5         6.1
    73         25.1         6.9
    74         28.5         7.8
    75           31         8.9
    76         32.4         9.9
    77         32.5        10.8
    78         31.5        11.5
Want to manage?  (Y or N)  Y
Do you want to see the management options?
  (Y or N)  N
Management Strategy = P1
    79         16.4        10.7
    80           16         8.7
    81         16.9         7.7
    82         18.5         7.3
    83         20.7         7.3
    84         23.1         7.7
    85         25.3         8.2
Want to manage?  (Y or N)  Y
Do you want to see the management options?
  (Y or N)  N
Management Strategy = BC
Number of predators to be released = 20
    86         15.1        16.9
    87         11.9          10
    88         11.9         7.2
    89         13.3           6
    90         15.7         5.7
    91         18.8         5.9
    92         22.2         6.5
Want to manage?  (Y or N)  Y
Do you want to see the management options?
  (Y or N)  N
Management Strategy = BC
Number of predators to be released = 20
    93         13.5        14.9
    94         11.4           9
    95         11.9         6.6
    96         13.6         5.7
    97         16.1         5.6
    98         19.2         5.9
    99         22.7         6.5
Want to manage?  (Y or N)  N
   100         26.2         7.3
Your net revenue is $26,971.
Do you want a plot?  (Y or N)  Y
```


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