A SIMULATION OF FIELD POPULATIONS OF INSECTS (HELIOTHIS IN COTTON)[1]

M. W. Parker*, L. G. Brown*, F. A. Harris+, and G. L. Andrews+

*Department of Industrial Engineering, Mississippi State University
Mississippi State, Mississippi

+Department of Entomology, Mississippi State University
Mississippi State, Mississippi

The Heliothis species is an economically important pest on a number of crops, including cotton, corn, tobacco, and soybeans. This paper describes an extensive effort to model field populations of Heliothis and to correctly model the interaction of these populations with simulated cotton populations.

The models were structured according to principles of Systems Dynamics and written in FORDYN. Basic results indicate:

1. Field Populations of insects can be accurately predicted.
2. The most important variable affecting the population is predator presence.
3. Limited interfield migration occurs.

Additionally, the paper presents a description of the problems and results associated with interaction between the insect model and cotton. The results of runs in which insecticide effect was modeled are presented.

Introduction

The species known to entomologists as Heliothis is a significant pest on several important crops. These include corn, cotton, and soybeans. The inroads on these crops made by this pest have led to extensive investigation of the species. This investigation is proceeding at several different universities and experiment stations. The research at several locations includes a modeling effort, wherein digital simulation models of the Heliothis species have been written. Noteable are the efforts at Texas A&M (1), North Carolina (2), the University of Arkansas (3), and Mississippi State University. At each of these locations, different modeling philosophies and approaches have been used. This paper is a description of the approach and results at Mississippi State University.

Model

The seasonal life cycle of the Heliothis can be outlined as: 1) emergence from over-wintering, 2) egg laying, 3) egg, 4) larvae, 5) pupae, 6) emergence as adult, and 7) preparation for over-wintering, with steps 2) through 6) repeated one or more times as separate generations through the season. This process can be represented with the partial Systems Dynamics network of Figure 1. This is to be considered only a partial representation since several information flows and constants are omitted from the figure as given.

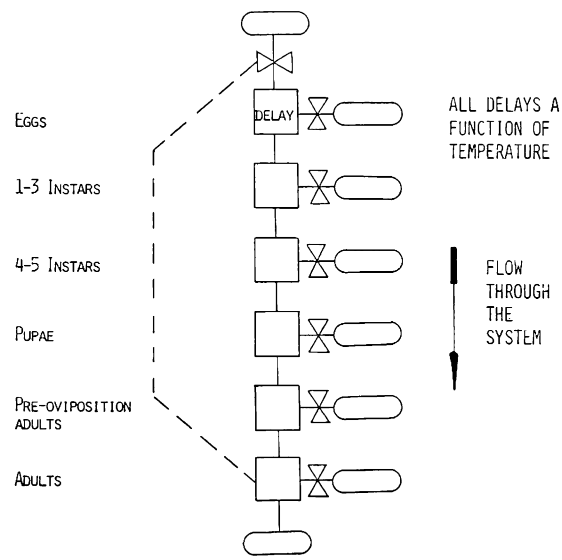

Figure 1

The model was written in FORDYN, developed by Llewellyn (4). This choice was made for what is perhaps the most common reason for FORDYN selection, the non-availability of Dynamo on the computer system being used. Nevertheless, FORDYN offered its usual advantages of FORTRAN flexibility and capability. When combined with a cotton fruit model, the FORDYN Heliothis model required about 12,000 words of core, with run time for a single season calculation of 20 to 34 seconds of CPU time on a UNIVAC 1106, depending on the options exercised. About 1/3 to 1/2 of this time was required for the cotton model.

The single most important exogeneous variable connected with this model was ambient temperatures. The selection of the calculation interval of 1/2 simulated day relates to this variable. The insect lives in the close environment of the cotton plant, which has the capability of moderating its immediate environment. Consequently, selection of the half day interval and use of an average ambient temperature for this period, approximates this moderating effect.

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A unique feature of the model is the representation of the length of time in each life cycle stage as a pipeline delay. However, since the time in each stage is heavily temperature dependent, it was necessary to speed or slow flow through these delays as appropriate. This was accomplished by moving a calculated fraction of the insects in each stage forward or backwards in the arrays which FORDYN uses to represent such delays. The fraction was calculated to result in the average time in a stage appropriate for the average temperature experienced during the half day under consideration.

The model accepts as input, counts of any life stage of the bollworm. Typical are egg counts, larvae counts, or light trap catches of the adult moth. Given 30 to 45 days of such counts, the model projects subsequent generations across the seasons.

Results

Two significant analyses were made with this model. The first dealt with analysis of population composition; the second with comparisons against field larvae counts.

The model actually projects population counts during the season for two species of Heliothis, H.zea and H.virescens. These species have the common names of corn earworm and tobacco budworm, respectively, or earworm and budworm. These species are very similar, requiring expert inspection for differentiation. Nevertheless, there are significant differences in fecundity, host preference, and mortality, and the relative proportions of the two species in a field count of bollworms is of interest to entomologists. Therefore, the model was run with identical patterns of emergence from over-wintering in order to observe the pattern of subsequent generations over the season.

Figure 2 shows the results of this run. Due to greater fecundity, the earworm showed larger numbers in subsequent generations. However, generation peaking for the two species occurred at not significantly different times.

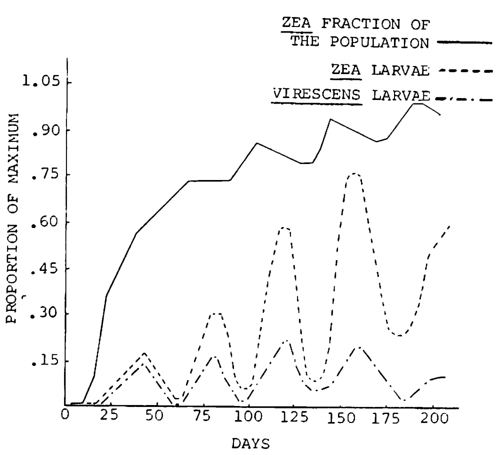


Figure 2

As a second run, the over-wintering emergence patterns were modified for each species to that thought to actually occur. With this input, the results were as shown in Figure 3. The budworm populations retain distinct peaks, while the earworm population generations are considerably smoothed with only slight peaking effects.

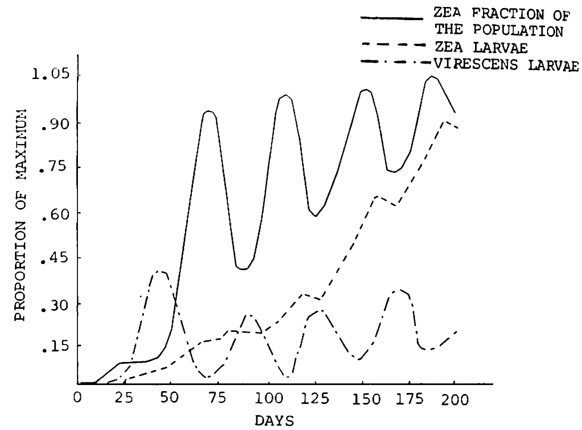


Figure 3

Note that there is pronounced oscillation in the composition of the population, with the earworm fraction oscillating from a high of almost 1.0 to lows of 0.4, 0.55, and 0.77, even though the predicted earworm population was showing a relatively stable rate of increase. Field data showing such oscillations in species composition of larval samples might be interpreted as the result of local movement between alternate hosts or of long range immigration, when in fact it is as easily (or more so) interpreted as a function of the spring emergence patterns. Although these data are not proof that such variations are caused by spring emergence patterns, they do indicate that over-wintering populations and their emergence patterns are key variables in predicting subsequent population patterns.

The model was then initiated by actual 1973 field counts and the projection across the season compared to larval populations found in this field. No insecticide was applied in this field.

Initial results showed a wide discrepency between model data and field data. This was expected, since the initial run of the model incorporated a constant mortality across the season. While the actual mortality pattern was unknown, there was confidence that it was not constant.

At this point the value of the model began to show. Day-by-day mortality of eggs and larvae was adjusted until there was a reasonable close fit between model results and field data, as shown in Figure 4. This mortality pattern, as derived from the model, was then plotted against the total number of parasites and predators in the field, with the results as shown in Figure 5. The strong correspondence between the data sets is obvious.

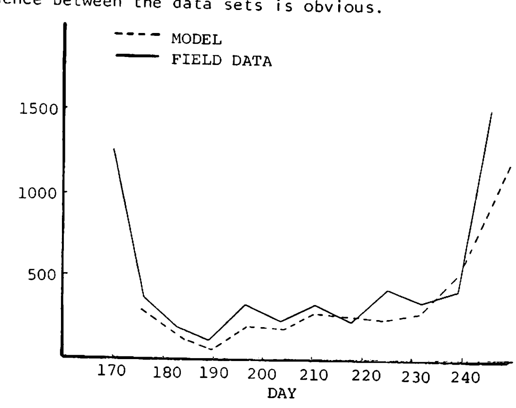


Figure 4

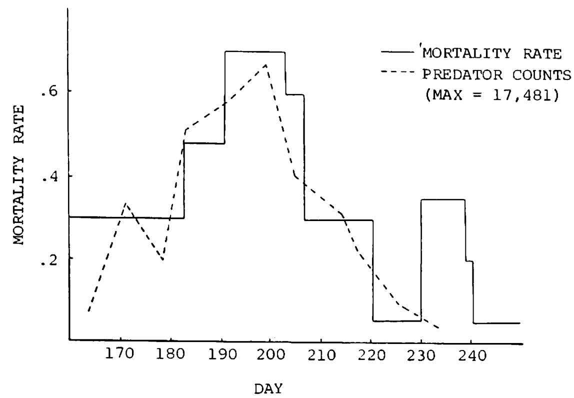
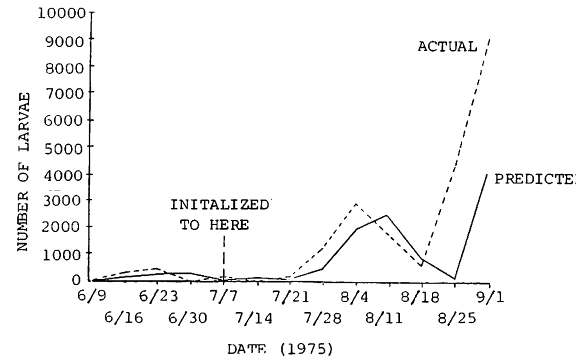


Figure 5



DATA COLLECTED BY DR. G. ANDREWS IN MISSISSIPPI DELTA

Figure 7

Further manipulation of the model produced results as shown in Figure 6. Mortality of eggs and larvae was taken as directly proportional to total predators less two species (Coccinellids and Chrysopids) thought to have little effect on bollworms. The model is predicting the number of larvae very closely. This same procedure was used against 1974 and 1975 counts, also from the Mississippi Delta. These results are shown in Figures 7 and 8. Again the model predicts actual numbers very well.

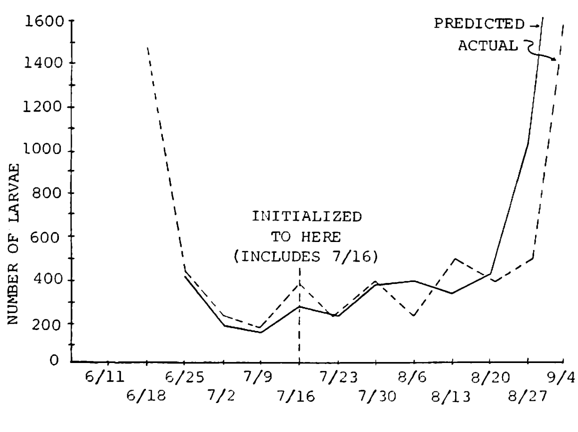


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Figure 6a

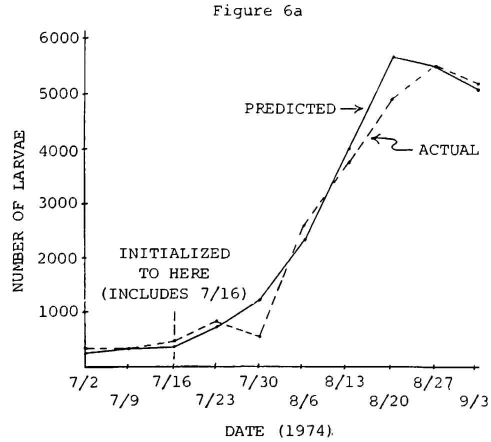

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Figure 6b

Integration of Insect and Plant Model for Insecticide Study

The Heliothis model and a modified version of SIMCOT II (a cotton plant model (5)) were used to study relative effects of two insecticide mixtures on populations of *Heliothis zea* (Boddie) and *H. virescens* (F.) on cotton yield (6). Toxaphene-DDT-Methyl parathion (Tox-DDT-MP) and EPN-Methyl parathion (EPN-MP) were the two insecticide mixtures. Their effects were tested by simulating insecticide applications to cotton under various simulated weather conditions, *Heliothis* spp. population levels, *Heliothis* spp. population initiation dates, cotton crop emergence dates, and insecticide resistance levels.

Some of the results of this simulation study are shown in Table 1. One result not shown in the table is yield with no infestation of *Heliothis*. This yield was 821 pounds of lint per acre. It is interesting to note that the yield with low infestation and insecticide treatments is larger than that with no infestation. This result has been duplicated by field experiments and is due to the early season pruning effect.

Table 1. Yield in pounds of lint/acre of simulated crop having different scenarios of insect population levels and insecticides. 1/

Copiah County, MS, 1972

	Population Levels		
Insecticide	low	moderate	heavy
No treatment	696(0)3/	267(0)	90(0)
EPN-MP	879(10)	562(13)	265(14)
Tox-DDT-MP	899(10)	612(13)	343(14)
Emergency Tox-DDT-MP	2/	570(13)	310(14)

1/ Crop emergence on May 5, insect initiation started on June 21, relative resistance levels of 0.65 and 0.55 for Tox-DDT-MP and EPN-MP, respectively, emergency spray level of 5000 larvae/acre.
2/ Emergency use not considered.
3/ Numbers in parenthesis indicate the number of insecticide applications.

Yields shown by the simulation closely resembled prior estimates by agricultural experts. However, Copiah County data were not available for detailed comparison. Further studies are planned for validation purposes.

Conclusions

First, the model is producing numbers which correspond closely to actual field counts. Previous insect population modeling has aimed at predicting patterns of populations, rather than numbers. It has been generally thought that the field situation was so complex, with many factors interacting that any reasonably simple model could not hope to predict numbers very well. The model described, however, has accomplished this goal without consideration of many variables previously thought to be of great importance. These variables include humidity, rainfall, and moon phase, among others.

Second, the model has indicated needed areas of research. Spring emergence patterns seem to be of interest.

Third, the process has isolated the predator effect as being of paramount importance. This implies that a model which will attempt to make long range predictions of bollworm populations must also make (or require as input) long range predator population predictions.

Fourth, the combination of the insect and plant model offers insight into this interaction. Further, the ability to model the insecticide effect on insect populations and plant production allows objective evaluation of the value of insecticide usage.

In summary, this model has demonstrated the classic benefits of simulation, including the ability to model complex situations and produce useful results not otherwise available, identification of important factors (sensitivity analysis), and the identification of areas of needed research.

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