COTTON AND INSECT MANAGEMENT (CIM) MODEL: PAST, PRESENT AND FUTURE

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Abstract

The Cotton and Insect Management (CIM) model was developed at Mississippi State University during the 1970's as a simulator to study cotton insect management strategies. CIM includes interacting models of the cotton crop (COTCROP), boll weevil (*Anthonomous grandis*) (CIM-BW), and heliothine (*Heliothis virescens* and *Helicoverpa zea*) populations (CIM-HEL). Variable effects of insecticides on boll weevil and heliothine populations and variable effects of beneficial insects on heliothine populations are included in the insect models. CIM has recently been revised to run in a Windows environment on personal computers (PC's). Typical simulation time is ~ 3 seconds on a pentium computer. In the early 1980's, a single simulation on the mainframe UNIVAC 1100/80 at Mississippi State University required 2 - 5 minutes. The new PC version of CIM uses a spreadsheet format for manipulating input and output data. The increased speed of simulation, the user friendly interface, and the experimental flexibility of the spreadsheet approach makes the model more accessible to researchers and pest managers interested in simulation experiments of the interaction between cotton and cotton insects. Future plans are to sophisticate the simulation capabilities of CIM by adding routines for generalized herbivores and increasing the detail of the insecticide, damage, and natural mortality subroutines that can be manipulated via the spreadsheet interface. Experiments can then be conducted with a broader pest complex exposed to a wider range of management options. We expect this refined CIM to be an important component of our research planning and management.

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Introduction and Historical Background

The Cotton and Insect Management (CIM) model evolved from an earlier effort to simulate cotton growth and development (Hesketh et al. 1972a, 1972b, McKinion et al. 1975). During the 1970's, interest in applying simulation techniques to agricultural problems developed. This increased awareness of management science and the availability of main-frame computers at land grant universities fostered the development of several multi-discipline teams of agriculturalists, economists, and engineers interested in modeling the cotton production system. Major research efforts with cotton were launched with USDA/ARS laboratories in Mississippi and Texas, and university scientists became involved through the support of the "IPM or Huffaker" project. Multi-discipline teams of researchers were formed at Mississippi State University, North Carolina State University, Texas A&M University, and the University of California system to develop a range of different models associated with cotton and cotton insects. The IPM project was jointly funded by the EPA, NSF, and the USDA and supported research on the development of IPM technologies from 1972-1978. Many of the current IPM programs at land grant universities were influenced by this national emphasis on IPM research. Wagner et al. (1996) provides a detailed description of the evolution of simulation models and expert systems related to cotton and cotton insects.

The research group at Mississippi State University emphasized the development of interacting population models to study the impact of major insect pests on cotton. COTCROP (Jones 1980, Brown et al. 1985) was the cotton model that was used as the central foundation for CIM. COTCROP makes daily simulations of cotton growth and development based on weather, nutrients, and management practices. Model projections are for a population or group of plants within a unit of a square meter. Other models, designed to study more mechanistic components of plant growth, commonly use a single-plant approach. The population approach of COTCROP was important to the goal of studyinginsect management options since insect pest problems on cotton are largely viewed as population related phenomena.

CIM was conceptualized as an integrator of several different models. This followed the objective of creating a unique modular system to study insect-plant interactions at the population level. The modular design of the system was intended to facilitate changes to an evolving data base. It is this modular approach that makes CIM a viable tool today, more than 20 years after its initial development. Just as COTCROP evolved from research on more mechanistic models of cotton, the boll weevil and heliothine (i.e. *Heliothis*) models in CIM evolved from more specific models of boll weevil (Jones et al. 1977) and *Heliothis* spp. (Hartstack et al. 1976). Adapting these models to Midsouth cotton production and sophisticating their design as control strategy testers for boll weevil (Brown et al. 1979) and heliothines (Brown et al. 1976) required an organized approach to model design and additional research on the interaction of cotton, insects, and management practices.

Evolution of the model created a need for specific research data. As a result, CIM became an important component in the prioritization of research projects. This resource management aspect of CIM has application to management of current research conducted in an environment of stable or declining resources. As CIM evolved, the need for new information was addressed by numerous graduate student projects, both in engineering (Akbay 1979, Escarra 1979, Murphey 1980, Qayum 1980 and others) and in entomology (McDaniel 1976, Nicholson 1975 and others). Aubrey Harris, Gordan Andrews, David Hogg, Ed Pieters, John Schneider, Henry Pitre, William Scott, Jimmy Smith, Ed Lloyd, and entomologists at other universities and USDA laboratories provided data to support the development of CIM. Engineers instrumental in the development of CIM included Larry Brown, Jim Jones, Wayne Parker, and Ron McClendon. The effort was also supported by a wide range of scientists from a diversity of different scientific disciplines. David Parvin, J. Hesketh, J. Hartsog, and Frank Whisler contributed to the development of CIM.

Brown et al. (1977) presented predictions of cotton yield loss due to insects. This was one of the first examples of the use of CIM to study cotton insects. Harris et al. (1976) described in detail the potential use of CIM and the validation data collected to test model predictions. During the late 1970's and early 1980's, focus on research with CIM changed from development to application. Brown et al. (1976), Brown et al. (1977), Brown et al. (1979a), Harris et al. (1976), McClendon et al. (1979), McClendon and Brown (1983), and McClendon et al. (1977) describe much of the experimental use of CIM during this period. The shift in emphasis on model use rather than model development was stimulated by a change of financial support from the initial IPM project to the "CIPM or Adkisson" project in 1978. The CIPM (Consortium for Integrated Pest Management) project followed the IPM project in purpose and scope. CIPM was funded by EPA from 1979 to 1981 and by the USDA, CSRS from 1981 to 1985. The earlier IPM project focused on development of new technology. CIPM maintained this development interest, but allocated more resources toward technology transfer and demonstration of integrated management practices. As a result, most modeling efforts began to emphasize high visibility applications that engendered grower support. The value of CIM as a simulator and experimental tool was truly important to production agriculture, but its direct utility in the hands of farmers was unclear. Changes in personnel and the changing focus of research priorities for funding sources resulted in a decline in research associated with CIM during the 1980's. This trend in reduced support for simulation models was not unique to the CIM project (Wagoner et al. 1996).

An important contribution of the CIM modeling effort was the impact on students. As mentioned above, numerous graduate students contributed directly and indirectly to the design, development, and testing of CIM. An additional educational application of CIM was the development of COTGAME (Akbay 1979). COTGAME was a user interactive version that was tailored toward instruction of entomology students (McClendon et al. 1979, Pieters et al. 1981). This user interactive version was incorporated into the curriculum of a course on principles of insect pest management from 1979 through 1988, and it was a common demonstration medium to growers, consultants, government officials, and others interested in our research at Mississippi State University. Continued use of COTGAME decreased with the shift from main-frame to personal computers. A PC version of COTGAME has not been created, partially because the revised version of CIM described below is user friendly and applicable to student educational needs.

Although continued development of CIM slowed during the 1980's, research with the model continued in some laboratories. Brown and McClendon (1982) proposed a dynamic threshold for control of heliothines that intensified insecticide use at critical periods of crop susceptibility. This strategy was tested by entomologists in independent simulations (Luttrell et al. 1983) and field experiments (Kitten and Luttrell 1983). It became the threshold recommended by the Mississippi Cooperative Extension Service in the mid-1980's. Other innovative uses of CIM were explored in the 1980's. Andrews et al. (1984) used CIM in a real-time decision-making process to manage cotton insects on field plots in the Mississippi Delta. On-site weather data and insect scouting information were telephoned to Mississippi State University where CIM simulated the potential impact of relevant information using current observed data. Future weather predictions were based on 20 years of historical data. Results of these different simulations produced probabilities of different outcomes (yield) to assist the decision maker. Schneider et al. (1984) used CIM to study the value of removing cotton fruiting structures of different ages at different times during the season. McClendon et al. (1983) used CIM to estimate the expected harvestable mass of cotton fruiting structures appearing on the plant at different times during the growing season. Thead et al. (1984) collected information to sophisticate the beneficial insect subroutines of the heliothine model (CIM-HEL).

With more changes in personnel and the end of the CIPM project in 1984, research with CIM essentially stopped. Brown et al. (1983) developed a detailed description of CIM and its individual models of cotton (COTCROP), boll weevil (CIM-BW), and heliothines (CIM-HEL) that serves as a good historical record of CIM and the collective CIM project. A brief effort to make CIM usable on personal computers was initiated in the late 1980's but was abandoned. The emphasis on technology transfer and grower use of models led the research group to focus on the development of expert systems. CIC-EM (Cotton Insect Consultant for Expert Management) (Bowden et al. 1991, 1992) and PIC-EM (Pesticide Information Consultant for Expert Management) (Bowden et al. 1991) were expert systems developed in the late 1980's and early 1990's. These systems were tested against the opinions of experts (Luttrell et al. 1991), and they gained general acceptance among scientists (Wagoner et al. 1996). However, they have never been fully accepted and used at the production level. The conceptual development of these new decision tools was closely aligned with the modular organization and strategy-testing design of CIM. We are continuing efforts to improve the decision aids, and we are working to revitalize CIM as a simulator of cotton insect management strategies and a guide for prioritizing research.

Recent Changes to the CIM Model

The unique applications of CIM that continued in the 1980's and the development of the CIC-EM and PIC-EM expert systems closely aligned with CIM were funded by several small grants from the Southern Region IPM program, various agricultural chemical groups, commodity funds, and special support from the Mississippi Agricultural and Forestry Experiment Station. While these funds were important to the success of each specific project, there was not enough general support to continue a focused research effort.

In 1994, a research project was initiated with special funds ("Research Initiative") from the Mississippi Legislature and with the direct encouragement and support of the Director of the Mississippi Agricultural and Forestry Experiment Station to study cotton insect management strategies. The reasons for this project were declining profits from cotton production and increasing insect control problems (Reed et al. 1996, Luttrell et al. 1997). The project was organized by experiment station entomologists responsible for research on cotton insect management strategies. The project included small plot experiments and large, on-farm validation tests at several locations in Mississippi. The group recognized the importance of decision-making tools and the potential value of a good experimental simulator. As a result, a major component of this new research initiative was focused on completing the CIC-EM expert system developed in the early 1990's and revitalizing the CIM model as a simulator of insect management strategies. We are making progress with both.

CIM was modified to run in a Windows environment on personal computers. Any IBM compatible personal computer with Windows 95 can run CIM. A typical simulation of a growing season requires ~ 3 seconds on a pentium processor. This compares to a run time of 2-5 minutes on the older main-frame version during the 1980's. The structure of the model is essentially the same as the original version created to run on the UNIVAC 1100 at Mississippi State University. However, to facilitate the transfer of CIM to a personal computer platform, the GASP-IV simulation language that organized and controlled the processing of the FORTRAN routines was removed and rewritten in FORTRAN. A user interface to CIM was developed using the BASIC language. Most recently, an Excel spreadsheet was created to guide users through the process of conducting experiments with CIM (running the model, generating and printing output reports, and cleaning up files in memory) (Figure 1).

From the Excel spreadsheet, the main program of the user interface to CIM (Figure 2) is accessed. The main program controls the overall simulation process including which models are used and the parameters for the variables of interest. The insect models include offset and multiplier options (Figure 3) which allows the user to change colonizing densities of insects (Figure 4) in both CIM-HEL and CIM-BW. This option also impacts beneficial insect densities, which interact with the CIM-HEL model. Historical data files that can be manipulated are based on field data described by Brown et al. (1983). Specific simulations are controlled in the run program (Figure 5) which allows a user to choose weather files for two different times during the crop growing season. For example, a simulation could use the file Stonvle.82 (weather data for Stoneville, MS during 1982) for daily simulations until 7/15 (15 July) and then change to Stonvle.83 (weather data for Stoneville, MS during 1983) for daily simulations between 7/15 and crop harvest. The run file also controls output files. As with the initial CIM model, simulations are made on a daily basis from crop emergence to harvest (Figure 6). Running CIM produces a tremendous amount of data that represents a rich source of information about the interactions between cotton and insects. The spreadsheet aids the decision-maker by tabulating these data in their raw form, providing summary reports, and generating graphs. In addition to the eight standard reports in the spreadsheet, users can easily create different reports by sorting and transforming the data using common spreadsheet functions.

To illustrate the use of the new version of CIM as a simulator, we conducted a simple experiment to compare the impact of different densities of heliothines colonizing cotton on yield, cost of insect control, and net returns ($). The model was initialized with moderate densities of heliothines and the multiplier option was set at 0.25, 1.0, and 4.0 for three separate simulations. Results of the different simulations are summarized in Table 1. Insecticide applications were made when larval densities were higher than those of the dynamic threshold. When the model was initialized with low densities (0.25 multiplier), three applications were made and the crop yield was 855 lb of lint per acre (Table 1). When the model was initialized with high densities (4.0 multiplier), seven applications were made and the crop yield was 770 lb of lint per acre. Control costs and returns per acre were also influenced by the level of heliothines colonizing the crop. Figures 7, 9, and 11 show example summaries of output generated from CIM for low, moderate, and high colonizing densities of heliothines, respectively. Note that the output summary records important simulation data about weather, date of emergence, plant population density, rooting depth of soil, residual nitrogen, residual water, nitrogen fertilization, irrigation, rainfall, solar radiation, crop developmental time, and date of harvest in addition to the simulated information on insecticide applications, yield, and profit. Several other pages of output data are also generated with each simulation. CIM includes several graphs of important seasonal data. Figures 8, 10, and 12 are plots of the collective number of heliothine eggs (*Heliothis virescens* and *Helicoverpa zea*), small larvae, and large larvae per acre throughout the growing season. These results are essentially the same as those generated by the older version of CIM (described in numerous publications above), but they are available in more practical and user-friendly format.

Conclusions and Future Applications of the CIM Model

The conceptual strength of CIM as an experimental tool and its modular design have preserved its utility for more than 20 years. While it is important to show applicability of modeling research to real world problems, the actual simulation does not have to be made at the farm level. CIM has unique value as an experimental tool. We believe that one of the most important advantages of simulation is that of organizing research and identifying priorities. Our experiment station research can be more efficiently conducted if we consider a wide range of simulation results prior to conducting expensive field research. To achieve this objective, CIM needs to be accessible and valued by a larger number of researchers, especially entomologists interested in developing insect control strategies. To this end, the new version of CIM was designed.

We are currently working to sophisticate some of the subroutines and make CIM more robust in its application to real world problems. We hope to create a generalized herbivore that can mimic most phytophagous insects, sophisticate the management options including more detailed insecticide subroutines, and educate our key researchers on the potential use of CIM. To help in our quest to identify optimal insect control strategies, we plan to add an optimization feature to CIM based on Bowden's research that produced the first widely successful commercially available simulation optimization software package (Hicks and Bowden, 1996). We are also working to finalize the CIC-EM expert system, which was conceptualized within the CIM modeling group. The new version of CIM and the expert systems will become an important component of the insect pest management curriculum for agricultural pest management students this year. If the model is successful in educating students and stimulating creative ideas about insect management, it will again take on a dynamic form with annual changes. Its initial design and purpose as a simulator of the interactions between cotton and insects will continue to fuel its utility into the next century. Computer capabilities and the general skill of most agriculturists have increased to the point that ownership of these types of systems can be transferred from the engineers to the agriculturalists with some continued design and optimization assistance from the engineers. Broad use of CIM among the agriculturists will foster more creative management strategies.

Acknowledgments

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Table 1. Results of simulation experiment using CIM to describe impact of different levels of heliothines colonizing cotton.

Heliothine Population[1]	Number of Applications	Yield (lb lint/acre)	Cost of Insect Control ($/acre)	Returns ($/acre)[2]
Low	3	855.3	$20.50	$614.97
Moderate	6	821.6	$37.00	$573.44
High	7	770.3	$42.50	$529.80

[1]Low, moderate, and high densities were created by using 0.25, 1.0, and 4.0 multipliers of colonizing insect numbers (Figures 3 and 4).
[2]Returns above cost of insect control are based on a cotton price of $0.65 per pound. CIM also computes return values for a range of prices (See Figures 7, 9, and 11).

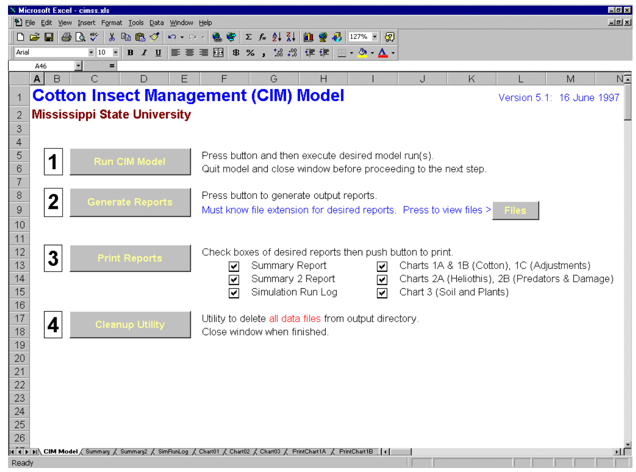

Figure 1. Spreadsheet interface to CIM that controls runs and simulation data.

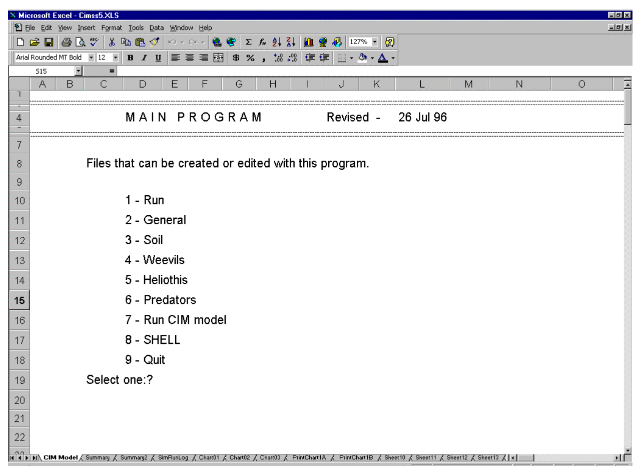

Figure 2. Main program for manipulating individual models and desired simulations in CIM.

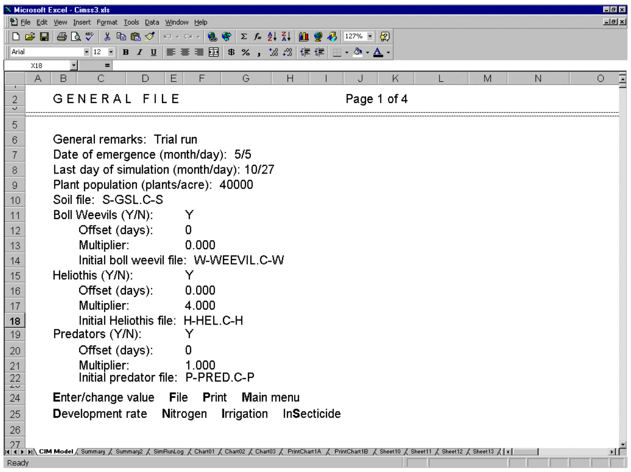

Figure 3. General file used to define major parameters for the cotton (COTCCROP), boll weevil (CIM-BW), and heliothine (CIM-HEL) models within CIM.

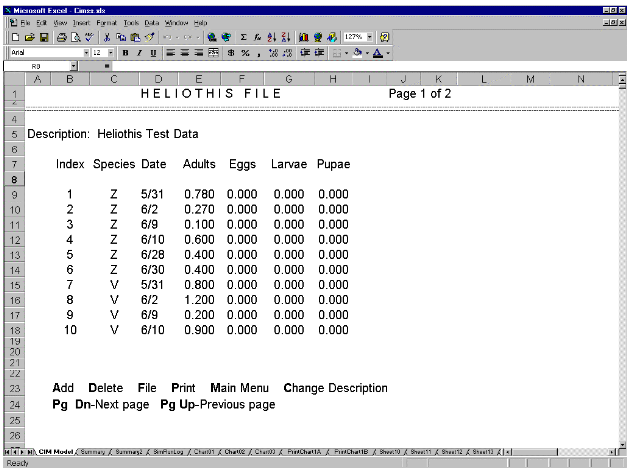

Figure 4. Insect data used to initialize insect populations within CIM.

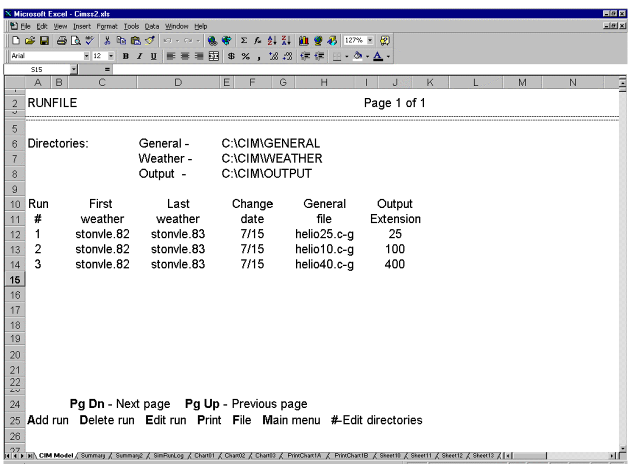

Figure 5. Run file that controls all input and output information in a simulation including weather data, change in weather data, general file information, and output files.

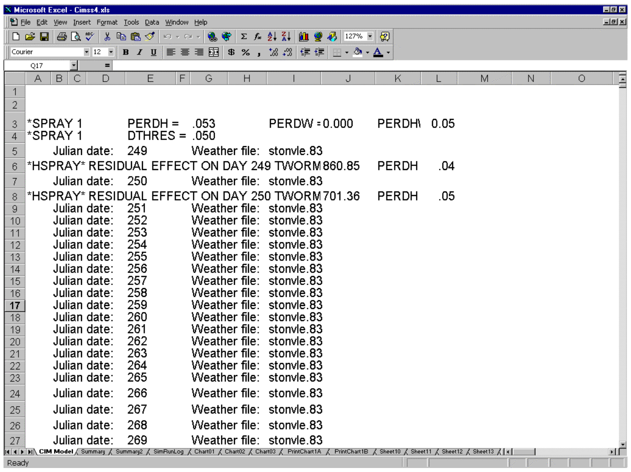

Figure 6. Day by day output results of CIM simulation.

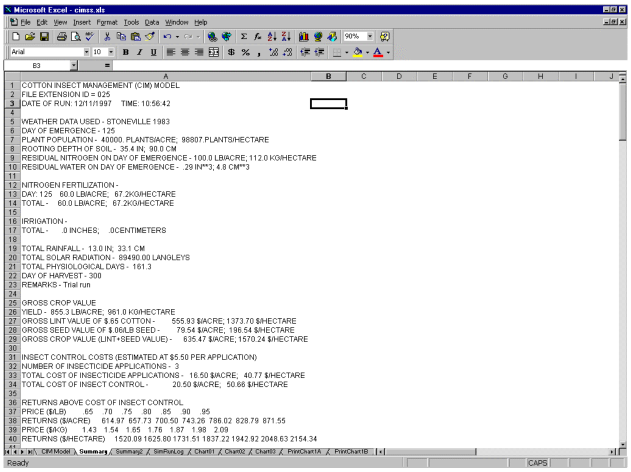

Figure 7. Output summary from CIM simulation using low colonizing densities of heliothines (multiplier of 0.25).

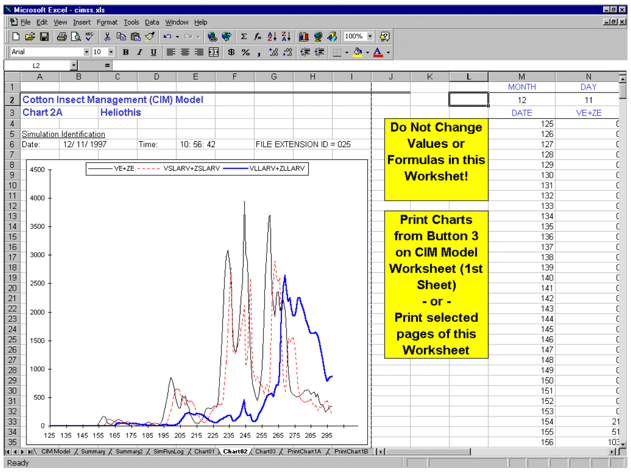

Figure 8. Output chart of seasonal heliothine populations when CIM was initialized with low densities of heliothines (0.25 multiplier).

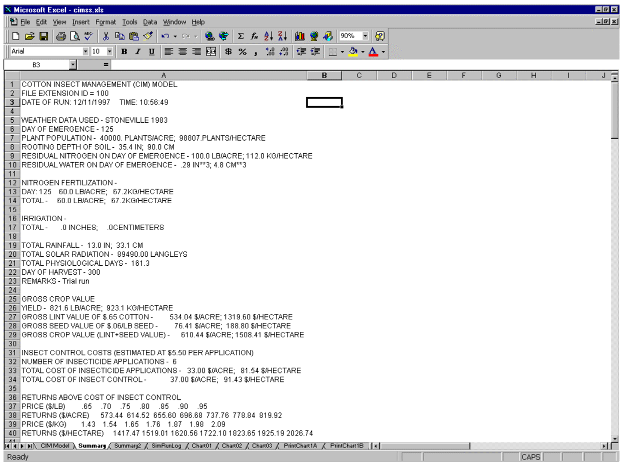

Figure 9. Output summary from CIM simulation using moderate colonizing densities of heliothines (multiplier 1.0).

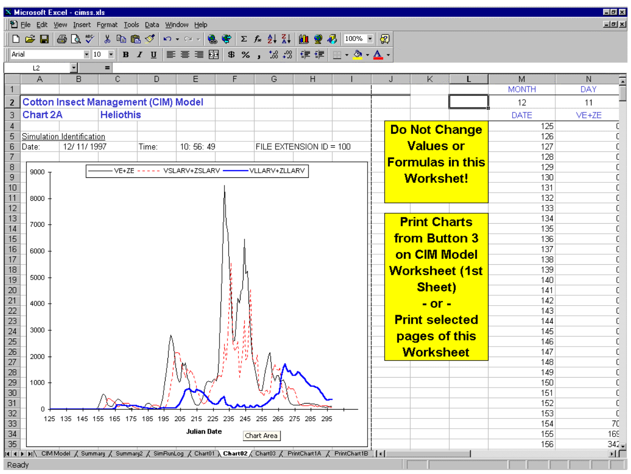

Figure 10. Output chart of seasonal heliothine populations when CIM was initialized with moderate densities of heliothines (1.0 multiplier). Note that scale of Y-axis is two-fold that of Figure 8.

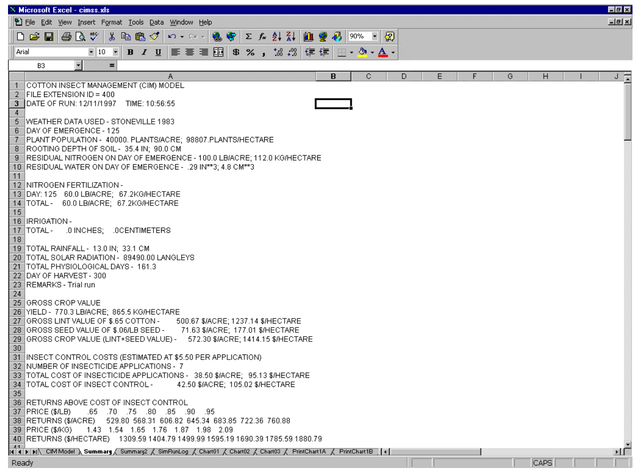

Figure 11. Output summary from CIM simulation using high colonizing densities of heliothines (multiplier 4.0).

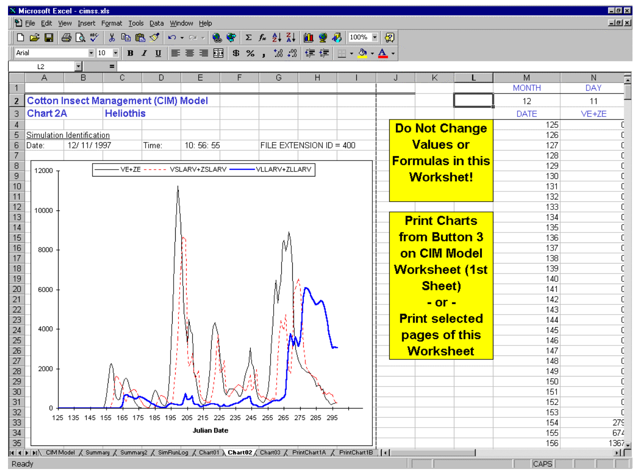

Figure 12. Output chart of seasonal heliothine populations when CIM was initialized with high densities of heliothines (multiplier 4.0). Note that scale of Y-axis is two-fold that of Figure 10 and four-fold that of Figure 8.