9-1-1988

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Published version. *Applied Engineering in Agriculture,* Vol. 4, No. 3 (September 1988): 201-206. DOI.

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ABSTRACT

AN interactive version of the Cotton and Insect Management (CIM) model was developed to aid individuals in improving their insect pest management decision making skills. This version, COTGAME, allowed the user to encounter situations and make decisions during the simulated cotton crop growing season. The intermediate results of these decisions were immediately delivered in the form of a report on the current status of the crop and insect populations. Based on the information presented in this status report, the user would make additional management decisions and take tactical actions. Once the harvest date had been reached, the economics of the simulated production season was presented to allow the user to evaluate the decisions. The use of COTGAME has been a way to apply the technology in a detailed crop growth model to improving insect pest management skills.

INTRODUCTION

In 1986, 3.75 million ha of cotton were harvested in the U.S. Insect pests caused losses totaling $219 million and $228 million was spent on insect control (King et al., 1987). The bollworm and budworm complex (*Heliothis* spp.) and boll weevil (*Anthonomous grandis* Boheman) were responsible for most of the losses and control costs. Insecticide applications have environmental costs as well as economic costs. Moreover, there is evidence that the use of insecticides is not always a desirable way to manage insect pests. For example, an early insecticide application which reduces a boll weevil population also destroys the natural predators of the boll/budworm (Harris, 1972). With this reduction in the beneficial insect population, the boll/budworm find a better environment for their development. However, if the boll weevil population is not controlled by an early season insecticide application, high boll weevil damage may result later in the season. This complex biological system of an agricultural crop, multiple insect pests, and beneficial insects thus poses conflicting alternatives for farm management (McClendon et al., 1977).

Feldman and Curry (1982) presented a survey of the role of operations research in agricultural pest management. They stated that the complex interactions involved in many biological systems can be fully understood only through mathematical modeling. Unfortunately, when the model contains sufficient biological realism, an optimization approach to decision-making is not practical except under certain conditions. Shoemaker (1982) has applied dynamic programming to the optimization of alfalfa weevil (*Hypera postica*) control. However, this approach was effective for this case because the alfalfa weevil has only one generation per year and only one insecticide application per year was considered. The cotton ecosystem has multiple insect pests with several generations requiring insecticide applications throughout the season. An optimization approach therefore would not be practical.

Computer simulation models of crop ecosystems have been developed for most of the major crops in the U.S. including cotton. These models have been useful in understanding the physiology of the crops and insects and in gaining insight into selecting research priorities. However, detailed crop growth models are usually understood only by those who are involved in their development. Incorrect interpretation of the results can occur when the user does not understand the limitations of the model. Crop growth models have therefore seen only limited use as teaching tools and as direct aids to crop producers.

Two approaches have recently been pursued to allow detailed growth models to be more applications oriented. In one approach, expert systems encompassing crop models have been developed to aid in decision making. For example, the COMAX model is an expert system in which the GOSSYM cotton crop growth model was included as part of the data base (Baker et al., 1983; Lemmon, 1986; McKinion and Lemmon, 1985). The COMAX expert system can then use rules as in the traditional expert system and also have the advantage of a crop growth model. The user communicates through the user interface in COMAX and not directly with GOSSYM. In this manner the results of the simulation are interpreted and then provided to the user in a manner which would be understandable.

The other approach has been to restucture the crop growth model such that it runs interactively with the user. Crop growth simulation models typically run from planting to harvest before delivering results. With modifications, the model can produce daily crop status information allowing the user to experience the decisions facing a farm manager. In this mode, the user would run the model with a year of weather selected from a historical weather data file. Through repeated runs over a season, the user could improve decision making skills, develop strategies, and gain a better understanding of

Article was submitted for publication in October, 1987; reviewed and approved for publication by the Power and Machinery Division of ASAE in March, 1988.

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  0883-8542/88/0403-0201$02.00

the crop growth model. This approach to transferring the technology incorporated in a detailed crop growth model to farmers and extension personnel is the subject of this paper.

The objectives of this research were to (a) modify a cotton crop growth and insect population model such that it could be used in a management game form, (b) evaluate the model as an aid to insect pest management by producers, extension personnel, and consultants, and (c) demonstrate its capabilities with examples of typical pest management decisions as case studies.

MANAGEMENT GAMES

The development of early management games was closely associated with military operations. Military games were introduced in the British Army in 1872 and were copied shortly afterwards in the United States (Kalman and Rhenman, 1961). By the beginning of the twentieth century, knowledge of war games was widespread throughout the world, and Germany and Japan made extensive use of such games during their preparations for World War II (James, 1959). In 1956, the American Management Association (AMA) introduced "Top Management Decision Simulation" for the business community (Eilon, 1963). This grew out of experience with military war games. The development of games of this type was also dependent upon advances in the field of operations research and computers.

The general management games were designed to teach decision making at the top management level. At this level all major functional organizational objectives were considered, such as profit, return on investment, sales levels or share of the market (Graham and Gray, 1969). Management games have also been developed to teach decision making in the agribusiness industry. Salisbury and Van Otten (1981) developed a simulation game to allow the user to attempt to maximize profits through land purchase, crop selection, capital input, and sale price agreements. Six crops were available to the user. Boehlje and Eidman (1978) developed a farm management game to be used in teaching and extension programs. This game was used to aid in understanding production economics principles and whole-farm planning procedures. Other examples of management games in the agricultural business industry include: "The California Farm Management Game", "A General Agricultural Firm Simulator", "The Poultry Farm Management Game", and "Purdue Farm Management Game" (Graham and Gray, 1969).

CIM MODEL DEVELOPMENT

An interdisciplinary team of engineers and scientists at Mississippi State University developed the Cotton and Insect Management (CIM) model (Brown et al., 1983). It is based on field data taken by several scientists in various fields of agricultural research. This model was created primarily for the purpose of research in studying insect pest management strategies. It was also intended to be used as a training aid for cotton growers, management consultants, cooperative extension personnel and students in related agricultural fields.

The CIM computer simulation model consists of three component submodels concerning the cotton crop, boll weevil, and boll/budworm complex. A brief description of the structure and characteristics of each component submodel is summarized in the following sections.

Cotton Crop Component Submodel

The cotton crop component submodel, COTCROP, maintains carbohydrate and nitrogen balances for the plants as well as water and nitrogen balances for the soil (Jones et al., 1980; Brown et al., 1985). The demands for carbohydrate and nitrogen are calculated on the basis of the organ initiation rate and plant growth rate. The available carbohydrate is then determined on the basis of carbohydrate reserves in the plant and photosynthate produced. Available nitrogen is determined from plant uptake on the basis of depth of roots and distribution of nitrogen in the soil.

The soil is divided into homogeneous 10-cm deep layers, each having distinct volumes of water and concentrations of nitrogen. Availability of water and nitrogen to the plant depends on root depth. If there is insufficient carbohydrate or nitrogen to meet daily demands, the rate of organ initiation and the growth rates of existing organs are reduced until the demand for nutrients is equal to the amount available. A surplus of either nitrogen or carbohydrate is stored in the crop for later use. A shortage of either nitrogen or carbohydrate causes fruit of different ages to be abscised after a certain period. Water stress also causes the abscission of fruit and retards the development of new organs for several days. The COTCROP model maintains the age distribution of the fruit in order to facilitate the inclusion of insect damage and to simulate the actual crop growth process.

Boll Weevil Component Submodel

The boll weevil component submodel used is the population dynamics Cotton and Insect Management-Boll Weevil (CIM-BW)model, which was a modification of the Boll Weevil Simulation (BWSIM) model developed by Jones et al. (1977). The boll weevil population is closely related to the growth dynamics of the cotton crop. The model is initiated with emergence of overwintering adult weevils into the cotton field. This may occur early in the season when the crop has no fruit (bolls or squares). The boll weevil must have cotton fruit for reproduction, therefore no reproduction occurs until the crop begins to produce squares. As the female adult encounters fruit, she oviposits into them. As the larvae develop, the fruit are abscised from the plants. This fruit loss causes a response in the growth and development processes of the plants. Both the development and survival of the larvae depend on temperature and quality of food.

The CIM-BW submodel maintains the model population densities for cohorts of each life stage (egg, larva, pupa, adult). Thus, age structure of each life form is explicitly considered.

Boll/Budworm Complex Component Submodel

The boll/budworm component submodel CIM-HEL was developed specifically for interfacing with the cotton model COTCROP and the boll weevil model CIM-BW (Brown et al., 1983). The model updates the status of the boll/budworm populations each day. The bollworm and budworm have different rates of development and ovipositioning. They also react differently to insecticide; consequently, they are considered individually in the model.

CIM-HEL maintains population densities for cohorts of egg, larva, pupa and adult stages for each species. The transition to the next stage of development on a given day is a function of the number of degree days that have been accumulated since entering the current life stage. If sufficient degree days have accumulated then a given cohort advances to the next life stage. In CIM-HEL, reproductive potential is a function of temperature and adult age. The functions that reduce the reproduction rate due to temperature and temperature/age effects are from MOTHZV-2 (Hartstack et al., 1976).

Coupling of the Model Components

Within CIM, the interaction between the cotton crop and insect pests occurs through the fruit. Crop damage done by the insect pests is calculated each day and transferred to the crop component model. The status of the fruit is also updated daily and transferred to the component models of the two insect pests.

Insect pest management strategies in CIM are concerned largely with insecticide applications. These applications are performed either on a predetermined fixed schedule or in response to scouting. Scouting provides the percentage of square damage, insect pest densities or both. The interval between simulated scouting reports of damage and density can also be varied to simulate different strategies.

Three insecticides are currently included in CIM. EPN-methyl-parathion is an insecticide which differs in degree of effectiveness against boll/budworm, depending on the temperature and the age and species of the insect. The insecticide-induced larval mortality factors included are from laboratory data collected by McDaniel (1976). Each insecticide application affects *Heliothis* spp. for up to 3 days. The same application kills 90% of the adult boll weevils and 30% of *Heliothis* spp. eggs on the day of the application. For boll weevils it was assumed that the insecticide has no residual effect or temperature dependency. EPN-methyl-parathion kills 80% of the predator population on the day of application.

The second insecticide uses chlordimeform as an ovicide and larvicide as suggested by Campbell et al. (1979). Each application affects boll/budworm eggs for up to 6 days. It also kills 35% and 32% of the first and second instar *Heliothis virescens* larvae, respectively, on the day of application. It kills *Heliothis zea* egg and larvae at a slightly higher rate. Chlordimeform has no effect on boll weevil or predator populations.

The third insecticide choice included in the model uses chlordimeform as an ovicide and EPN-methyl-parathion as a larvicide to control boll/budworm populations. It also kills 90% of adult boll weevils and 80% of the predator population on the day of application.

COTGAME

The CIM model was modified by the authors to allow the user to select from two modes of operation. The first mode is a simulation of the cotton ecosystem based on given initial conditions with preset strategies consisting of thresholds for management actions such as insecticide application, irrigation, and fertilization. The results are provided to the user at the end of the simulation. The second mode is structured in game form and allows the user to interact with the simulation model by making management decisions based on the current status of the simulated crop system. COTGAME is the interactive version of the CIM computer simulation model. COTGAME aids in understanding the behavior of the system under varying conditions because the user can see the effects of actions selected. This mode is also more realistic in terms of the way a manager would make decisions on a farm.

COTGAME does not provide the user with an optimal pest management strategy; rather, it exposes the user to many field predicaments. The user can gain insight into the cotton ecosystem and thus be trained to make better decisions. Cotton growers, extension personnel, and cotton management consultants have used COTGAME to investigate pest management strategies and to test possible innovations based on their experience and intuition (McClendon and Brown, 1983).

COTGAME has been included in entomology and agriculture classes at universities because it is a relatively inexpensive way to study the cotton ecosystem from a source other than textbooks and lectures (Pieters et al., 1981). The user responds to questions asked by the program. The user can take actions, observe the results, and then make subsequent decisions based on these results. COTGAME was organized so that the game could be played with a minimum of user effort. The objective of the game, as in actual crop production, is to maximize returns. No computer programming knowledge is required to use COTGAME.

COTGAME was structured into three phases: initialization, management, and results. During the initialization phase, the user selects the agronomic, weather, and insect conditions. The user may select a value for any system parameter listed in Table 1. All of the parameters have a default value if the user does not enter a new value.

The users of COTGAME may select any combination of three populations (low, medium, and high) for predators, boll/budworm, and boll weevil. For example, with 1972 weather data from Stoneville, MS, the low, medium, and high populations would reach the following simulated peak values in the absence of insecticide applications: 18,300, 29,200, and 38,800 predators/ha,

TABLE 1. COTGAME PARAMETERS IN THE INITIALIZATION PHASE

Agronomic
Date of crop emergence
Plant population
Residual nitrogen in soil
Initial fertilization
Initial irrigation
Weather
Year of historical weather data
Insect
Initial boll/budworm population
Initial boll weevil population
Predator (beneficial insect) population

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                    SCOUTING REPORT 1 (7/17/1972)
CROP INFORMATION                          PER PLANT      PER HA

SMALL SQUARES               -               1.85         182943.
MEDIUM SQUARES              -               1.14         112433.
LARGE SQUARES               -               3.32         327956.
SMALL BOLLS                 -               1.54         152508.
MEDIUM BOLLS                -                .82          80762.
LARGE BOLLS                 -                .11          10838.
OPEN BOLLS                  -                .00              0.

INSECT INFORMATION -                    NUMBER PER HA  PERCENT DAMAGE
HELIOTHIS
  EGGS                          -           17685
  SMALL LARVAE (0-3 DAYS OLD)   -            6175
  LARGE LARVAE (4 DAYS OR OLDER)-            1243
TOTAL LARVAE                    -            7420          1.0
TOTAL BOLL WEEVILS              -             840           .3
    TOTAL PERCENT DAMAGE        -                          1.3
TOTAL PREDATORS                 -           23129

WEATHER: RAINFALL = .00 CM.  MAX TEMPERATURE  =  33°C (91°F).  MIN TEMPERATURE -
 22°C (72°F)
TOTAL RAINFALL FROM  CROP EMERGENCE TO 7/17/1972:  20.8 CM (8.20 IN)

PLEASE ENTER YOUR DECISION CODE
```

Fig. 1—Sample crop and insect status scouting report from COTGAME (cases 3 & 4).

respectively; 21,000, 39,500, and 157,400 boll/budworm larvae of the third generation (with medium predators)/ha, respectively; 48,900, 83,000, and 150,500 adult boll weevils/ha, respectively.

After the set of conditions under which the crop will be grown is established, the management phase begins. On each decision date scheduled by the user, a scouting report of crop status, insect populations, and rainfall is printed as shown in Fig. 1. Based on this information the user has the option to schedule the following: (a) next decision date, (b) insecticide application, (c) irrigation, (d) fertilization, or (e) harvest. The user enters the desired value for the parameter as requested by the COTGAME. If the user schedules an insecticide application, the type of insecticide must also be selected. Upon the completion of a decision making process on a given decision date, the game then proceeds with the simulation of the cotton ecosystem until the next decision date.

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                        INPUT SUMMARY REPORT

WEATHER DATA USED:          -       STONEVILLE 1972
DATE OF CROP EMERGENCE:     -       5/5/1972
PLANT POPULATION:           -       98840 PLANTS/HA   (35000 PLANTS/AC)
TYPE OF SOIL USED:          -       GRENADA SILT LOAM
MAXIMUM ROOTING DEPTH:      -       89.9 CM  (35.4 IN)
RESIDUAL NITROGEN:          -       100.9 KG/HA  (90 POUNDS/AC)
NITROGEN FERTILIZAITON:             DATE           AMOUNT (KG/HA)
                                    5/5               100.9
                                    TOTAL             100.9

IRRIGATION:                         DATE           AMOUNT (CM)
                                    (8/31)               5
                                    TOTAL                5

TOTAL RAINFALL:             -       42.7 CM (16.8 IN)

COST OF FERTILIZATION $/APPLIC.  FIXED: 13.91    VARIABLE: .36

COTTON LINT VALUE:   $1.43/KG  ($0.65/LB)

INSECTICIDE COSTS:

  SCOUTING COST/SEASON    -       $ 9.88/HA        ($4.00/AC)
  EPN-METHYL              -       $13.59/HA        ($5.50/AC)
  CHLORDIMEFRM            -       $ 3.76/HA        ($1.52/AC)
  EPN-METHYL  +  OVICIDE  -       $16.11/HA        ($6.52/AC)

INSECT POPULATIONS:  HEAVY HELIOTHIS, LIGHT PREDATORS AND MEDIUM BOLL WEEVILS

INSECTICIDE APPLICATIONS:

         DATE        INSECTICIDE           COST $/HA          COST $/AC
         7/18         EPN-METHYL + OVC       16.11               6.52
         7/23         EPN-METHYL + OVC       16.11               6.52
         8/ 4         EPN-METHYL             13.59               5.50
         8/17         EPN-METHYL             13.59               5.50
         8/26         EPN-METHYL             13.59               5.50
         9/ 1         EPN-METHYL             13.59               5.50
         9/ 6         EPN-METHYL             13.59               5.50
         9/11         EPN-METHYL             13.59               5.50
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Fig. 2—Sample input summary report from COTGAME (case 4).

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                    ECONOMIC ANALYSIS REPORT (10/27/1972)
GROSS CROP VALUE
TOTAL YIELD         -  771.2  KG/HA  (687.95 LB/AC)
GROSS LINT VALUE AT 1.43/KG  ($0.65/LB)  $1104.96/HA    ($447.17/AC)
GROSS SEED VALUE at 0.13/KG  (0.06/LB)   $ 158.09/HA    ($ 63.98/AC)
          TOTAL GROSS CROP VALUE         $1263.05/HA    ($511.15/AC)

TOTAL COST OF FERTILIZATION              $  45.05/HA    ($ 18.23/AC)

INSECT CONTROL COSTS
NUMBER OF INSECTICIDE APPLICATIONS -          8
TOTAL COST OF INSECTICIDE APPLICATIONS   $ 113.76/HA    ($ 46.04/AC)

TOTAL NUMBER OF SCOUTING REPORTS   -          9
TOTAL COST OF SCOUTING PER SEASON        $   9.88/HA    ($  4.00/AC)
          TOTAL INSECT CONTROL COSTS     $ 123.65/HA    ($ 50.04/AC)

NET RETURNS ABOVE FERTILIZER, INSECTICIDE AND SCOUTING COSTS
LINT VALUE ($/KG)        1.25      1.32      1.43      1.54       1.65
RETURN     ($/HA)      924.35   1009.35   1094.33   1179.33    1264.33

NOW THE GAME IS OVER. . . IF YOU WOULD LIKE TO PLAY ANOTHER GAME PLEASE
TYPE: @ADD COTGAME.PLAY
```

Fig. 3—Sample economic analysis report from COTGAME (case 4).

If no decision is scheduled on a given decision date, the management phase of the game terminates and the simulation model runs to the harvest date. A summary of initialization conditions and management actions taken (Fig. 2) as well as an economical analysis (Fig. 3) are then printed to allow an evaluation of the user's management decisions. The user's success in the game is measured by economic return above costs of fertilizer, insecticide, and scouting. Fixed costs of field machinery and land and other variable costs were not included in calculating returns.

CASE STUDY

To demonstrate how COTGAME has been used to improve the decision making skills of the user, several case studies were conducted. In each case the model was initialized with the following conditions: 1972 Stoneville, MS weather data; May 5 crop emergence; cotton lint value, $1.43/kg; and 100.9 kg/ha nitrogen fertilization on the date of crop emergence. The following case studies were typical of several sessions in which farmers and extension personnel used COTGAME.

Case 1

In case 1, COTGAME was initialized with no insects present in the field. Therefore, the crop damage due to insects was completely eliminated. This case resulted in a cotton lint yield of 875 kg/ha with a return of $1384/ha above the fertilizer and insect control costs at a cotton lint value of $1.43/kg. This represented an idealized situation of no losses due to insect damage.

Case 2

In case 2, COTGAME was initialized with "medium" level boll weevil population, "high" level boll/budworm population, and "medium" level beneficial insect population. This combination of insect populations is common in the cotton growing region of Mississippi. No insect control action was taken in this case and the simulated yield was 539 kg/ha with a return of $835/ha.

Case 3

In case 3, COTGAME was initialized with the same insect populations levels used in Case 2. The user followed a rigid strategy of scouting the field every four days starting with the first floral bud (square) and

TABLE 2. RESULTS OF THE CASE STUDIES USING COTGAME

Case	Number of insecticide applications	Lint yield, kg/ha	Economic return,* $/ha
1. No insects	–	875	1384
2. Insects present, no insecticide	–	539	835
3. Insects present, rigid insect control strategy	9	692	944
4. Insects present, user selected control strategy	8	771	1094

*Return = [Gross value of cotton lint and seed] – [costs of fertilizer and insect control],
fixed costs of machinery and land were not considered, cotton lint value = $1.43/kg, and seed value = $0.13/kg

applying an insecticide whenever percent square damage exceeded 5%. This strategy resulted in 9 insecticide applications. The yield and return were 692 kg/ha and $944/ha, respectively. Therefore, the user's strategy resulted in net savings of $109/ha as compared with case 2.

Case 4

Case 4 was the same as case 3 except the user did not follow a rigid strategy. The user made decisions based on field experience and intuition. The information provided in the scouting reports was used to decide the type and timing of the insecticide applications. The user made 8 insecticide applications which resulted in a yield of 771 kg/ha and a return of $1094/ha. Therefore, compared with case 3, there was one less insecticide application, but the return was improved by approximately 16%. The results of these case studies are summarized in Table 2.

The improvement in the yield and the reduction in the number of insecticide applications when comparing case 4 with case 3 can be explained by the better timing of the first application and also the type (or combination) of insecticides used. Table 3 summarizes the date and the type of insecticide application which resulted from cases 3 and 4. Until the first insecticide application in case 4 on July 18, cases 3 and 4 were identical. The scouting report shown in Fig. 1 depicts the situation on July 17 for these cases. Even though large counts of boll/budworm eggs and larae were present on that day, the percent square damage was only 1%. Because this

TABLE 3. SUMMARY OF THE INSECTICIDE APPLICATIONS FOR CASES 3 AND 4

Application no.	Case 3		Case 4	
	Date	Type of application*	Date	Type of application*
1	7/24	A	7/18	C
2	7/29	A	7/23	C
3	8/15	C	8/4	A
4	8/20	C	8/17	A
5	8/25	A	8/26	A
6	8/30	C	9/1	A
7	9/8	C	9/6	A
8	9/13	A	9/11	A
9	9/18	A	–	–

*A: EPN-methyl-parathion only
B: Chlordimeform (ovicide)
C: EPN-methyl-parathion and chlordimeform combination

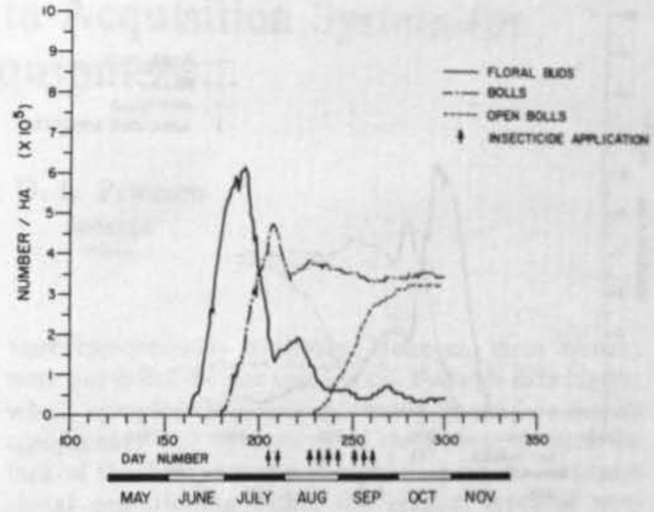

Fig. 4—Seasonal cotton plant status using predetermined insecticide strategy (case 3).

damage was much less than the user's rigid threshold of 5%, no application was made in case 3. However, the user in case 4 scheduled an application with ovicide on the next day mainly due to large numbers of eggs and larvae present in the field. The subsequent actions taken by the users in cases 3 and 4 are given in Table 3. The user in case 4 was more successful than the user in case 3. Figs. 2 and 3 are the input summary report and economical analysis report, respectively, for case 4.

These results are applicable only for this one year of weather data and the initialization conditions of these case studies. Other conditions would have to be considered with COTGAME to gain confidence in alternate strategies. At this point in a typical training session, the user might try the same initial insect conditions with a different year of weather data. Otherwise the user could select the same weather and vary the initial insect populations.

At the completion of the season, COTGAME also provides the user with daily results of the simulation in graphical form. In Fig. 4, the status of the cotton plant is shown in terms of floral buds, bolls, and open bolls (lint available for harvest) for case 3. Fig. 5 gives the

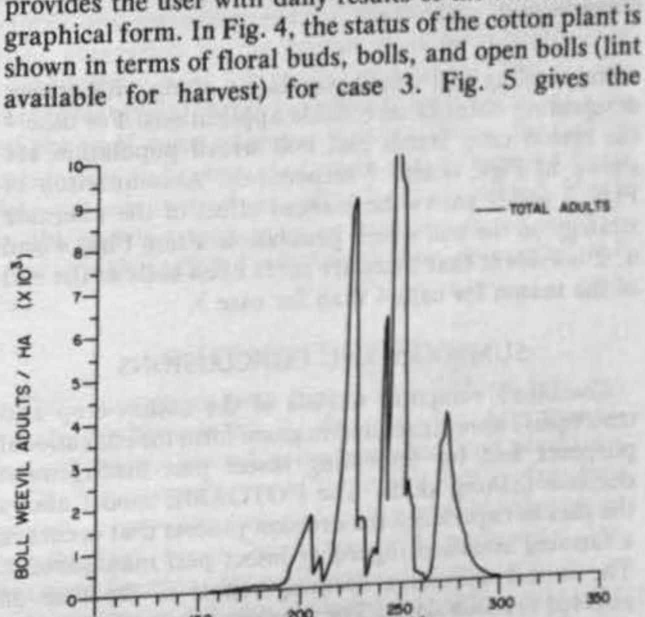

Fig. 5—Boll weevil adult population using predetermined insecticide strategy (case 3).

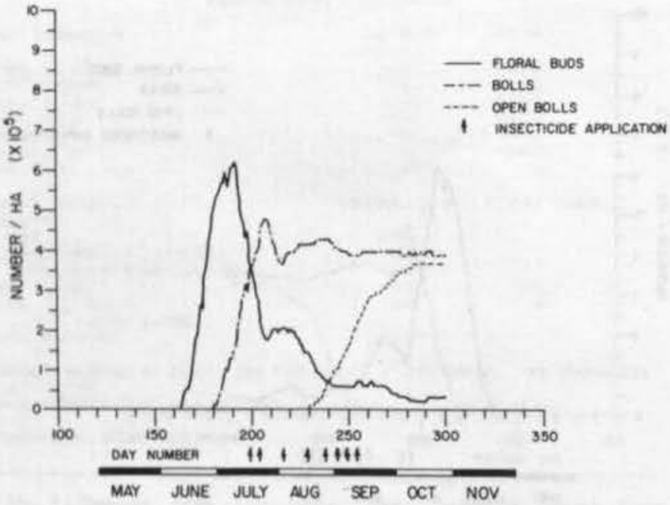

Fig. 6—Seasonal cotton plant status with user selected insecticide strategy (case 4).

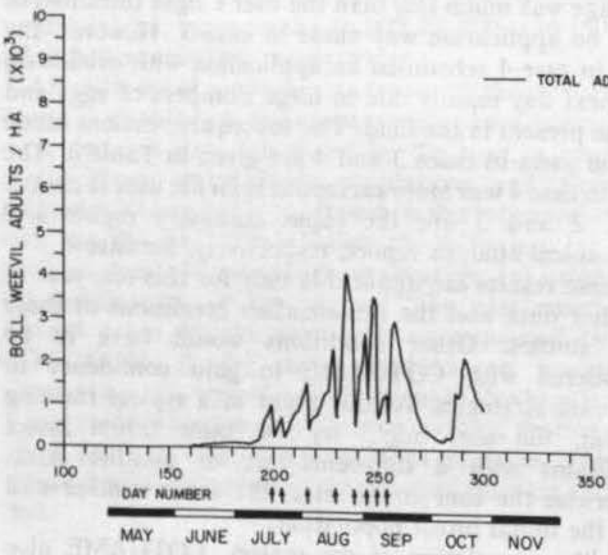

Fig. 7—Boll weevil adult population with user selected insecticide strategy (case 4).

corresponding boll weevil population along with arrows designating dates of insecticide applications. For case 4 the cotton crop status and boll weevil population are shown in Figs. 6 and 7 respectively. A comparison of Figs. 5 and 7 shows the marked effect of the alternate strategy on the boll weevil population. From Figs. 4 and 6, it is evident that there are more open bolls at the end of the season for case 4 than for case 3.

SUMMARY AND CONCLUSIONS

Combined computer models of the cotton crop and insect pests were structured in game form for educational purposes and for improving insect pest management decision making skills. The COTGAME model allows the user to experience the decision process that occurs in a farming situation regarding insect pest management. The model delivers a scouting report to the user on selected decision dates. The user can take action on that date or wait until a later date and re-evaluate the situation. The model allows the user to see the results of decisions immediately. It has been used as a training aid for consultants, extension personnel, students, and farmers. Although insect pest management with COTGAME was the topic of this paper, other decisions such as fertilization and irrigation could be considered. The management game format has increased its acceptance among people who are unfamiliar with computers and simulation models.

The COTGAME source code is written in FORTRAN 77 on a UNISYS 1174 and is available from the authors.

References

1. Baker, D. N., J. R. Lambert, and J. M. McKinion. 1983. GOSSYM: A simulator of cotton crop growth and yield. South Carolina Agric. Experiment Sta. Tech. Bull. 1089. Clemson, SC.

2. Boehlje, M. D. and V. R. Eidman. 1978. Simulation and gaming models: Application in teaching and extension programs. American Journal of Agricultural Economics 60(5):987-992.

3. Brown, L. G., J. W. Jones, J. D. Hesketh, J. D. Hartsog, F. D. Whisler, and F. A. Harris. 1985. COTCROP: Computer simulation of cotton growth and yield. Information Bulletin 69. Miss. Agric. and Forestry Exp. Sta., Mississippi State, MS.

4. Brown, L. G., R. W. McClendon. and J. W. Jones. 1983. A cotton insect simulation model. In: Agricultural Handbook No. 589: Cotton Insect Management with Special Reference to the Boll Weevil. R. L. Ridgway, E. P. Lloyd, and W. H. Cross (eds.). United States Department of Agriculture 437-479.

5. Campbell, W. R., C. J. Counselman, H. W. Ray, and L. I. Terry. 1979. Evaluation of Chlordimeform (Galecron) for *Heliothis virescens* control of cotton. Proceedings of Beltwide Cotton Production Research Conferences. National Cotton Council of America, Memphis, TN. pp. 122-125.

6. Eilon, S. 1963. Management games. Operations Research Quarterly 14:137-149.

7. Feldman, R. H. and G. L. Curry. 1982. Operations research for agricultural pest management. Operations Research 30:601-618.

8. Graham, R. G., and C. F. Gray. 1969. Business games handbook. American Management Association, Inc.

9. Harris, F. A. 1972. Resistance to methyl parathion and toxaphene-DDT in bollworm and tobacco budworm from cotton in Mississippi. Journal of Economic Entomology 65:1193-1194.

10. Hartstack, A. W., Jr., J. A. Witz, J. P. Hollingsworth, R. L. Ridgway, and J. D. Lopez. 1976. MOTHZV-2: A computer simulation of *Heliothis zea* and *Heliothis virescens* population dynamics. Users manual. U.S. Department of Agriculture, ARS-S-127, 55 p.

11. James, R. J. 1959. Learning from experience in business games. California Management Review 1:92-107.

12. Jones, J. W., H. D. Bowen, R. E. Stinner, J. R. Bradley, Jr., J. S. Bacheler. 1977. Simulation of boll weevil population as influenced by weather, crop status, and management practices. TRANSACTIONS of the ASAE 20:121-125, 131.

13. Jones, J. W., L. G. Brown, and J. D. Hesketh. 1980. COTCROP: A computer simulation model for cotton growth and yield. In: Predicting Photosynthesis for Ecosystem Models, p. 209-241. CRC Press, Boca Raton, FL.

14. Kalman, J. C., and E. Thenman. 1961. The role of management games in education and research. Management Science 7:131-166.

15. King, E. G., J. R. Phillips, and R. B. Head. 1987. 40th annual conference report on cotton insect research and control. 1987 Proceedings of Beltwide Cotton Production Research Conferences, National Cotton Council of America, Memphis, TN.

16. Lemmon, H. E. 1986. COMAX: An expert system for cotton crop management. Science 233:29-33.

17. McClendon, R. W. and L. G. Brown. 1983. Using the CIM model to evaluate and improve cotton insect control strategies in Mississippi, task force -79 and -81. Technical Bulletin 117, Miss. Agric. and Forestry Exp. Sta., Mississippi State, MS.

18. McClendon, R. W., L. G. Brown, J. W. Jones, J. D. Hesketh, J. D. Hartsog. F. A. Harris and D. W. Parvin. 1977. Modeling crop-insect pest ecosystems for studying conflicting alternatives caused by species interactions. Proceedings of the Symposium on Bio-and Ecosystems, International Federation for Automatic Control 5:121-130.

19. McDaniel, S. G. 1976. Rate, temperature, *Heliothis* spp. and developmental stage effect on methyl parathion efficacy in cotton. M.S.