MODELING PRODUCTION AND PROTECTION OF COTTON CROP IN MIDDLE EGYPT

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Abstract

A physiologically based model has been developed for use in addressing crop and pest management decisions in processing cotton (COTTAMIN Model). Field studies were conducted during the 2004-2006 cotton growing season in Fayum Governorate, to detect the adult population of the pink bollworm, *Pectinophora gossypiella*, cotton leaf worm, *Spodoptera littoralis,* cotton aphid*, Aphis gossypii,* sweetpotato whitefly*, Bemisia tabaci* and twospotted spider mite, *Tetranychus urticae*. Field generation numbers, life table parameters for the field, thermal requirements and heat unit accumulation were used. Cotton plant phenology was recorded as well as weather factors. The relationships in cotton complex were detected. The interaction of pest (5 pests), plant (phenology) and weather (four factors) were tested in COTTAMIN Model on two cotton varieties (Giza83 and Giza 90). A comparison was made between the expected and observed data. Most of the validations produced results that were in reasonable agreement with the observed data. The forecasts were more accurate when the phenology of the population peaks was compared than when actual population densities were compared. In general, no computer model can make perfect forecasts; however, we can use COTTAMIN Model successfully to help make pest management decisions in cotton fields.

Introduction

Modeling techniques applied to agriculture can be useful to define research priorities and understanding the basic interactions of the plant-climatic system. Using a model to estimate the importance and the effect of certain parameters, a researcher can notice which factors can be most useful.

Beginning in the mid-1960 through the present, a considerable effort has been directed at development of computer models of agricultural systems. These physiologically based strategic type models have proven particularly useful for defining what we do not know about a system, in the process providing a degree of focus not normally obtained in other research programs. More recently, systems biologists have focused on the development of tactical crop and pest management models, in some cases reemphasizing the physiological aspects and choosing a more empirical approach to addressing this problem.

In Egypt, cotton is subjected to yield and quality losses by insect pests. The pink bollworm (PBW), *Pectinophora gossypiella* and cotton leafworm, (CLW), *Spodoptera littoralis* are the most destructive pests causing significant losses to yield. Larval feeding within bolls is the basis for most economic losses caused by these pests. Since the larvae penetrate the bolls soon after hatching, efficient control by insecticides is hard to achieve. In addition, application of toxic insecticides may result in increased pest resistance to insecticides, interference with the activity of beneficial insects, environmental pollution, and hazards to public health. The reduction of insecticide applications in cotton is, therefore, of great benefit. Cotton bollworm has a number of difficult problems regarding sampling techniques, i. e. a)- larvae feeding inside green bolls causes special difficulty in estimating their population density; b)- PBW and CLW are multi-generational. Amin et al. (1994) found that PBW had four generations and CLW was found to have seven overlapping generations (Bishara 1926, Abdel-Badie 1977, Dahi 1997). The indiscriminate use of insecticides has caused a number of problems to various ecological niches around the world including Egypt. Hence there is a growing necessity and interest in the use of ecological approaches for management of these pests.

The rates of development in insects under natural conditions are largely driven by temperature. In most microenvironments, temperature is characterized by daily and seasonal cyclic variations with superimposed irregular fluctuations. However, studies of insect development rate most often involve experiments performed under constant temperatures (Howe 1967). In the development and application of development-rate models, it is always assumed that development rate at a given temperature is independent of thermal regime, whether the model is linear or nonlinear in relation to temperature. This assumption is also inherent in efforts to derive development-rate models from data obtained under varying temperatures, such as the work by Dallwitz and Higgins (1978). According to this assumption, development rate follows a definite function with respect to temperature, when other factors are equal, and the amount of development can be calculated by accumulating the fraction of development per unit time; i.e., rate summation (Kaufmann 1932). The formula may be expressed as:

$$D = f\ r\,[T\,(t)]\ DT$$

Where development (D) is a function of temperature (T), which in turn is a function of time (t) and development rate (r) adjusted instantaneously to temperature. The above assumption is fundamental to the formulation of development-rate functions for phenological models. Life table studies are fundamental to not only demography but also to general biology. In such studies, development times and survival rates of each stage, longevity of adults, and the daily fecundity of females are recorded for every individual. Using elementary statistics, means and standard deviations can be calculated. In traditional life-table analysis, these means are used to calculate age-specific survival rates and age-specific fecundity using either the Leslie matrix (Leslie 1945) or Birch's method (Birch 1948). These procedures have been widely used by researchers in many different fields (Shib et al. 1976, Cave and Gutierrez 1983, Vargas et al. 1984, Carey and Vargas 1985). However, variation in development rate is well known, even when a population is kept under constant laboratory conditions. The range of variation depends on many factors (for example, temperature and food). To assume that all individuals have the same development rate is biologically unrealistic and may be misleading. Therefore, ignorance of such variation when using either the Leslie matrix or Birch's method should be carefully considered. The method of incorporating this variation is the use of distributed delay theory in modeling (Gutierrez et al. 1984, Plant and Wilson 1986). On the other hand, Chi & Liu (1985) developed an age-stage life table theory for both sexes, incorporating variable developmental rates among individuals. In comparison with the distributed delay models, Chi & Liu's model is different in that both sexes were included, and variation in development rates was integrated sequentially for all stages and expressed in the form of a stage distribution. The stage structure of a population can also be calculated in Chi & Liu's model. Furthermore, most life-table analyses have been concerned only with the "female" population. Most lepidopteran, coleopteran, and orthopteran pests are not parthenogenetic, however, and both males and females are economically important. Moreover, the development rate may differ between the sexes. Susceptibility to either chemical or biological control agents may be quite variable among stages and sexes. These and many other differences among stages and sexes explicitly point out the inadequacy of the female age-specific life table. In addition, whether to calculate the intrinsic rate of increase of a "female" population or of the population as a whole is a central question in ecology. In the theoretical model of Chi & Liu (1985), the population parameters are calculated with respect to both sexes and incorporate variable developmental rates among individuals. However, the major obstacle in taking the variable developmental rates and the male population into account is the difficult and tedious work of applying the age-stage, two-sex life table theory to the raw data analysis.

The number of days between observable events, such as cotton seedling emergence and first squares, and the duration of insect generations are necessary to characterize the growth and development of plants and insects. The number of days between events, however, may be misleading because growth rates vary with temperatures. The measurement of events can be improved by expressing development units in terms of temperature and time. The deviation between events is then based on accumulated degrees per unit time above a lower temperature representing a threshold of growth.

The goal of this study is to test the accuracy of the "Model COTTAMIN" in measuring the interaction of pest-plant-weather components on two cotton varieties to forecast the occurrence and timing of plant phenomena and pest infestation peaks as well as pest population density.

Materials and Methods

COTTAMIN models an organism's growth based on cumulative heat units above the lower growth threshold**.** (Wilson and Barnett 1983). Unlike simple phenomena models, however, biological rates are not strictly linearly proportional to heat above the lower threshold; factors such as solar intensity, water deficit stress, etc., regulate these temperature dependent rates. The linear approximation to physiological time, however, serves as a useful parameter for estimating potential rates of structural production (numbers) and biomass accumulation, which is in turn modified by the feedback mechanisms incorporated into the model.

COTTAMIN consists of two modules: one for plant phenomena and the second for the pest population. The crop module predicts the four main plant organs; seedlings, leaves, flowers, and bolls. Each component has its own life table measurements such as birth rates, death rates, and growth rates. The pest module also has the same features for the five tested pests.

The COTTAMIN software starts with a series of screens enabling the user to modify any of the default data at the beginning of simulation. Key data for the crop's module include cotton varieties, planting dates, and field geographical location for simulation. Key data for the five insect pests include observation date, and the numbers of individuals in samples.

Simulations.

Microsoft's Visual C11 compiler version 6.0 was used for programming the model. Running the simulation requires specifying the Julian day of planting, as well as the initial number of insects. The model requires the daily weather data, constant percentage hatch, and the mean density-dependent larval survival model for predicting insect adults and oviposition.

Stochastic versions of the model use random weather, hatch, and larval survival in various combinations and begin with an initial adult population of 1,000/m2. A common problem with stochastic population models is that there is some probability that the population will be zero. As a result, extinction eventually occurs if enough simulations are conducted, and the population can never recover without modeling re-colonization. Extinctions occurred for this model, and because dispersal is not modeled, no mechanism exists in the model for population recovery. As a result, simulations were conducted in 500-yr blocks and annual output from a block was retained only if the population did not become extinct. Experimentation indicated that 10,000 simulated years of output were sufficient for the mean and the standard deviation to stabilize.

COTTAMIN validation data were collected from Fayum Governorate (90 km south of Cairo) cotton fields in Middle Egypt. Data were collected throughout three successive cotton-growing seasons (2004-2006). Giza 83 was the cotton variety cultivated in 2004 and Giza 90 was cultivated in 2005 and 2006. Data collected were pest numbers, injured plant numbers, cotton boll numbers, predator numbers, and weather data.

Six PBW and CLW pheromone delta traps were installed and monitored from February 15th to the end of October. The gossyplure baits were replaced every 2 weeks or less depending on the weather. Adult males from each pheromone trap were checked twice per week. Yellow sticky traps were used to monitor aphids and whiteflies. Visual examination for spider mite was made on all plants found in randomly selected 25 m quadrats.

Twenty-five meters of cotton canopy were examined weekly and the number of squares (pinhead to matchhead, matchhead to 1/4 inch, and 1/4 inch to > 1/4 in diameter were recorded. Also, the number of bolls (<3/4 inch , >3/4 inch in diameter), and open bolls were recorded. Plant counts (plants in each m^2 multiplied by 4.047) were converted to obtain the absolute number per acre. Plant height/m was also recorded. For crop injury, samples of 100 bolls were collected weekly. Small, medium and large bolls were taken randomly from each field and the infestation percentages were estimated in the lab.

Results and Discussion

I - Prediction of cotton growth parameters

In 2004, data were collected for three different planting dates of Giza 83 in Fayum Governorate.. The three planting dates were: 26/3/2004, 3/3/2004 and 10/3/2004. In 2005, Giza 90 planting dates were: 15/2/2005, 1/3/2005 and 15/3/2005. Giza 90 planting dates in 2006 were: 20/2/2006, 7/3/2006 and 16/3/2006.

Table 1 shows planting date, seedling emergence, cotyledon stage, first true leaf, the first fruiting branch, the first bud, the first flower, the first boll and boll maturation for the nine planting dates. The table indicates the deviation between the observed data collected from the fields and the predicted values generated by the COTTAMIN model. Examination of the data reveal that the general average of deviation of DD's for the nine cultivation dates for the eight plant stages tested ranged from –34.278(first flower) to 5.611(first bud) DD's .

Data in Table 2 demonstrate the deviation of means between observed and predicted cotton growth in days, with averages ranging from – 4.11 (boll maturation) to –0.333 (seedling emergence) days. The growth development curves observed actually did not differ significantly than those obtained by the COTTAMIN model as all observed curves demonstrated a similar growth rate curve prior to the COTTAMIN model.

II – Prediction of key cotton pests

Cotton in Egypt is subjected to yield and quality losses by insect pests with PBW and CLW being the most destructive due to larval feeding on bolls. Early season sucking pests such as aphids, whiteflies, and spider mites also play an important role in reducing yield quality and quantity. Figures 1-5 demonstrate the observed and predicted populations of cotton aphid, spider mite, whitefly, CLW, and PBW during three successive cotton growing seasons (2004-2006) at Fayum Governorate, Middle Egypt. Simulated and observed cotton insect pest densities are shown in Table 3. COTTAMIN explained only 72 % of the variability for the field data for cotton aphid, 83.4 % for spidermite, 85.4 % for whitefly, 78.9 % for CLW, and 78.7 % for PBW. The predicted trend of population peaks is closed to the actual population peaks, with the general average for the pest component as a whole was 79.7 %. However, the COTTAMIN model could be successfully used for cotton insect pests predictions in Fayum, Middle Egypt.

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Table 1. Deviation between observed and predicted cotton phenology by COTTAMIN model by average of heat units (2004-2006), Fayum, Middle Egypt

Planting Dates	Seedling emergence	Cotyledon stage	First true leaf	First fruiting branch	First bud	First flower	First boll	Bolls maturation
26/02/2004	25.1	9.1	0	0	0	0	0	14
03/03/2004	0	1.82	7.5	22.4	23.7	11.1	10.1	0
10/03/2004	-3.78	0	3.2	0	30.2	0	0.8	13
15/02/2005	-3.3	6.6	1.4	-1.1	-3.6	-101.1	-18.5	-3.4
01/03/2005	-0.7	2.1	1.4	2.4	1.4	-117.6	5.6	1.7
15/03/2005	4.1	0	-1.6	0.1	3.8	-108.9	-3.1	-4
20/02/2006	-3	-5	1	-1	-6	4	0	1
07/03/2006	0	2	-3	-3	-1	2	-6	7
16/03/2006	5	3	1	-7	2	2	-8	1
General average	2.602	2.180	1.211	1.422	5.611	-34.278	-2.122	3.367
± S. D	8.983	4.021	2.974	8.288	12.554	56.439	8.256	6.562
99 % Confidence limits	7.713	3.452	2.554	7.116	10.779	48.459	7.089	5.634
95 % Confidence limits	5.869	2.627	1.943	5.415	8.201	36.873	5.394	4.287

Table 2. Deviation between observed and predicted cotton growth by COTTAMIN model by means of days (2004-2006), Fayum, Middle Egypt

Planting Dates	Seedling emergence	Catyledons stage	First true leaf	First fruiting branch	First bud	First flower	First boll	Bolls maturation
26/02/2004	-1	-1	0	0	-1	0	0	1
03/03/2004	0	1	-1	3	2	1	-1	0
10/03/2004	0	0	1	0	-2	0	1	-1
15/02/2005	6	5	-4	-3	-1	-3	-6	-2
01/03/2005	-2	-2	0	-1	0	-13	-2	-1
15/03/2005	2	1	-5	1	-1	-13	-2	-1
20/02/2006	-1	0	8	1	-2	1	-1	-9
07/03/2006	-4	-4	-5	-5	-5	-3	-5	-12
16/03/2006	-3	-5	-2	-5	-3	-3	-5	-12
General average	-0.333	-0.556	-0.889	-1.000	-1.444	-3.667	-2.333	-4.111
± S. D	2.958	2.963	4.014	2.784	1.944	5.545	2.449	5.302
99 % Confidence limits	2.540	2.544	3.446	2.390	1.669	4.761	2.103	4.552
95 % Confidence limits	1.933	1.936	2.622	1.819	1.270	3.623	1.600	3.464

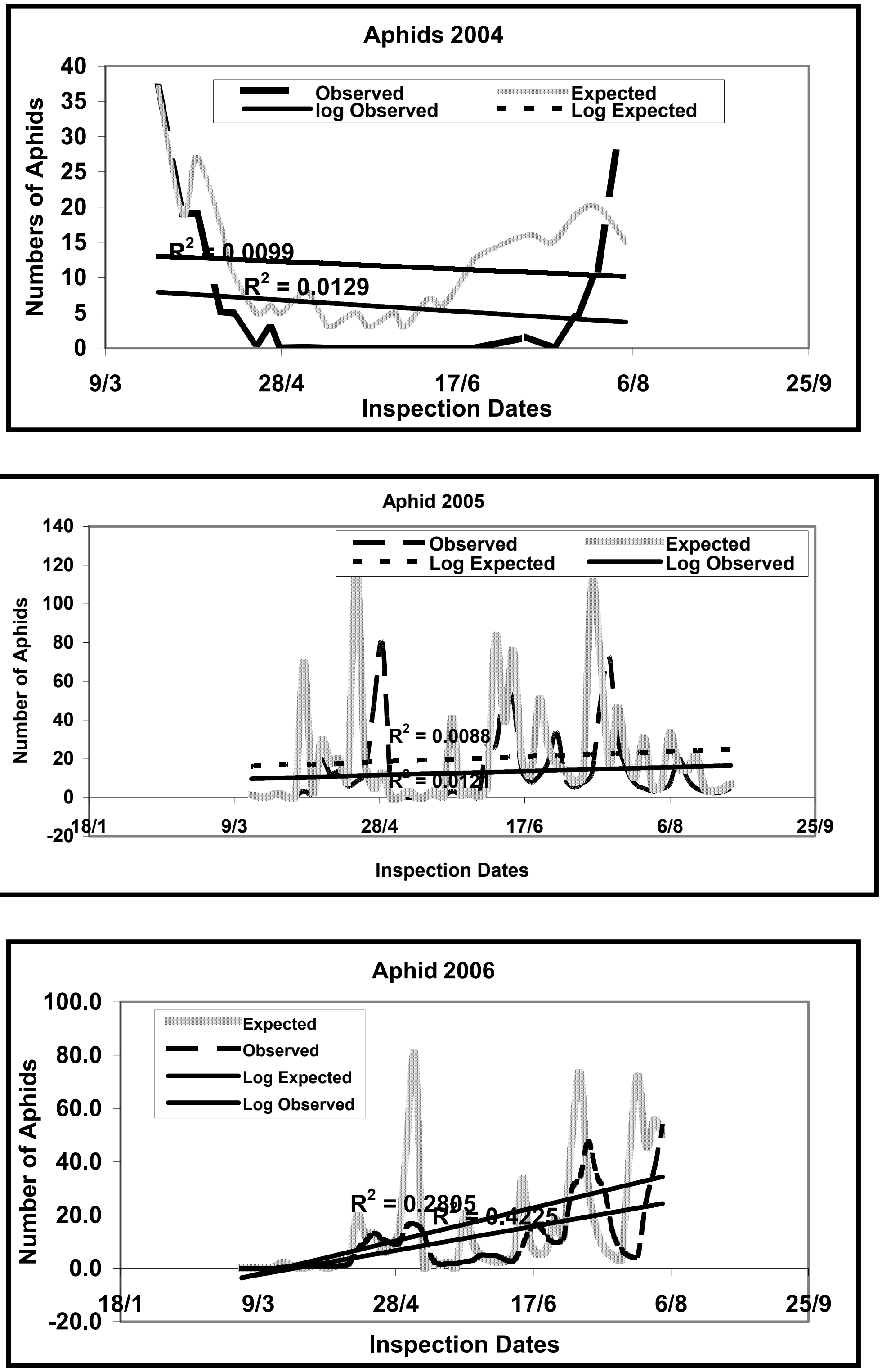


Figure 1. Observed and predicted population of cotton aphids during three successive cotton growing seasons (2004-2006) at Fayum Governorate, Middle Egypt

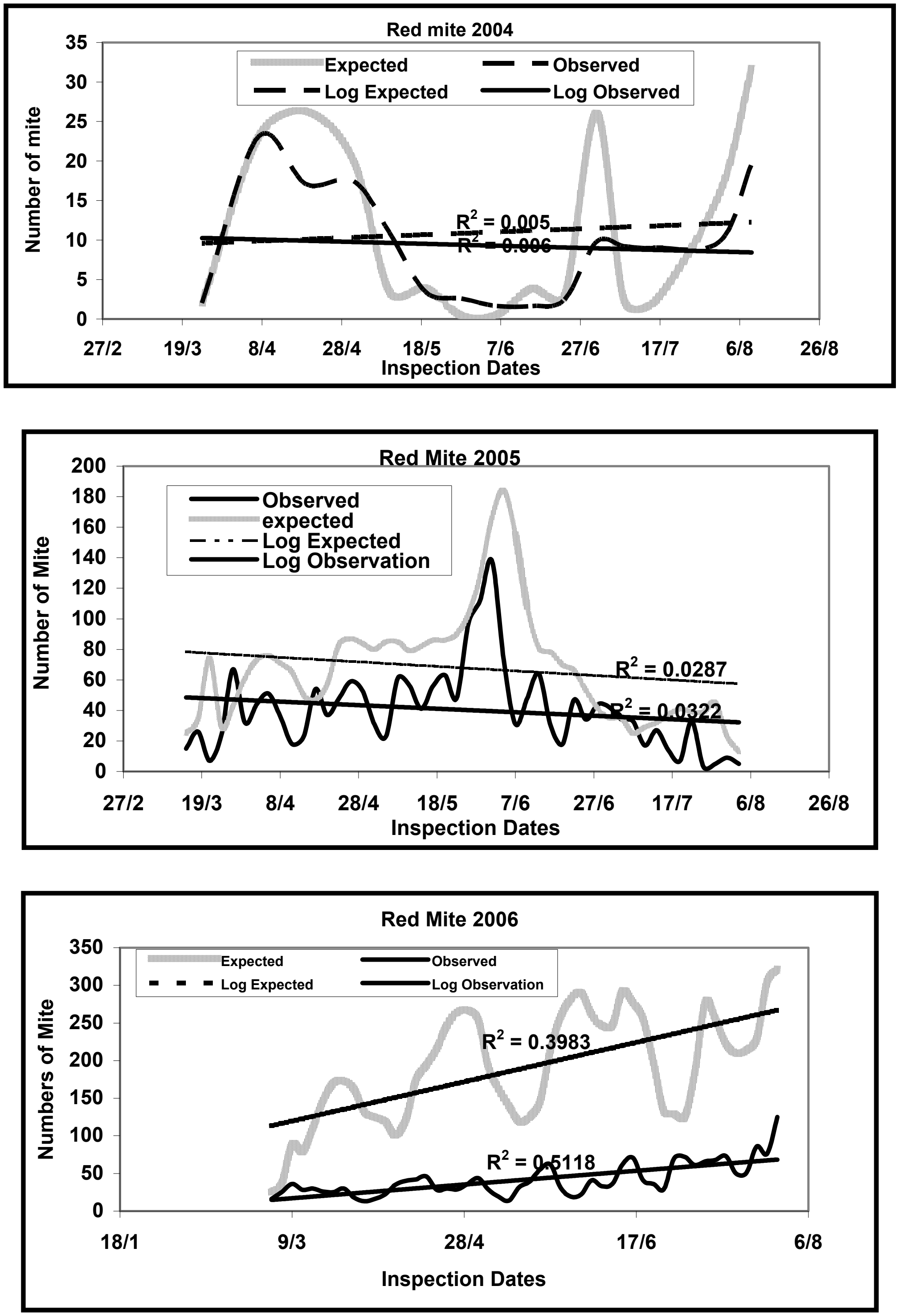
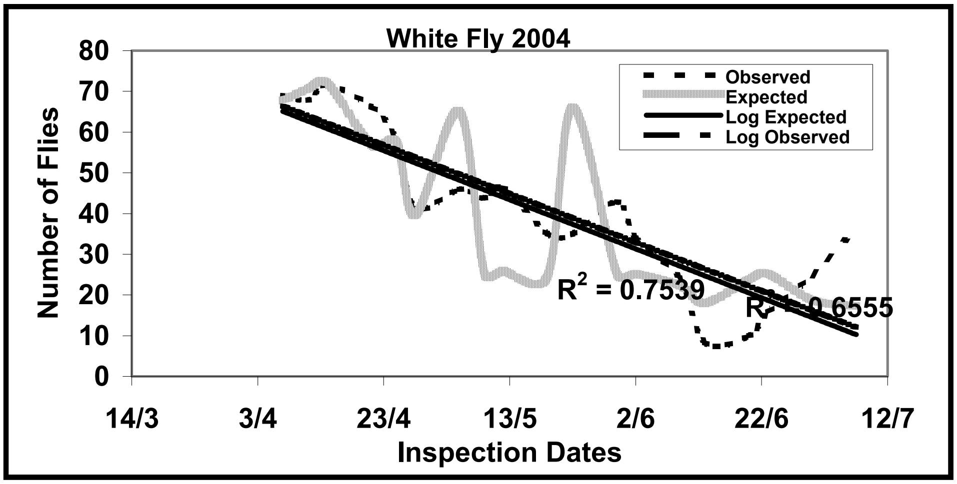
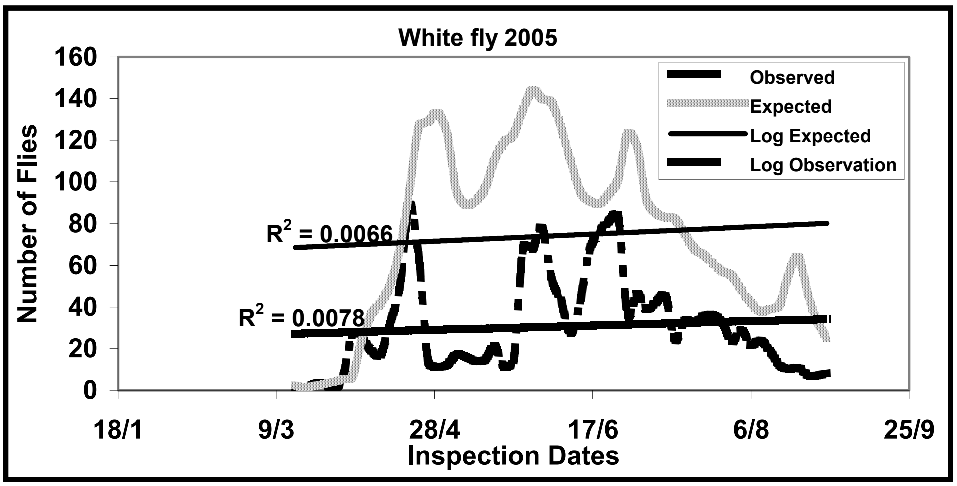


Figure 2. Observed and predicted population of red mite during three successive cotton growing seasons (2004-2006) at Fayum Governorate, Middle Egypt





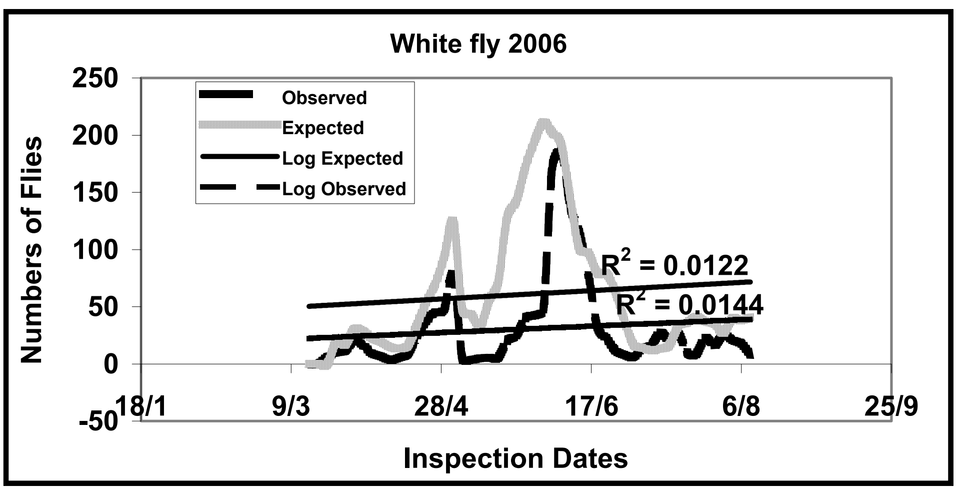
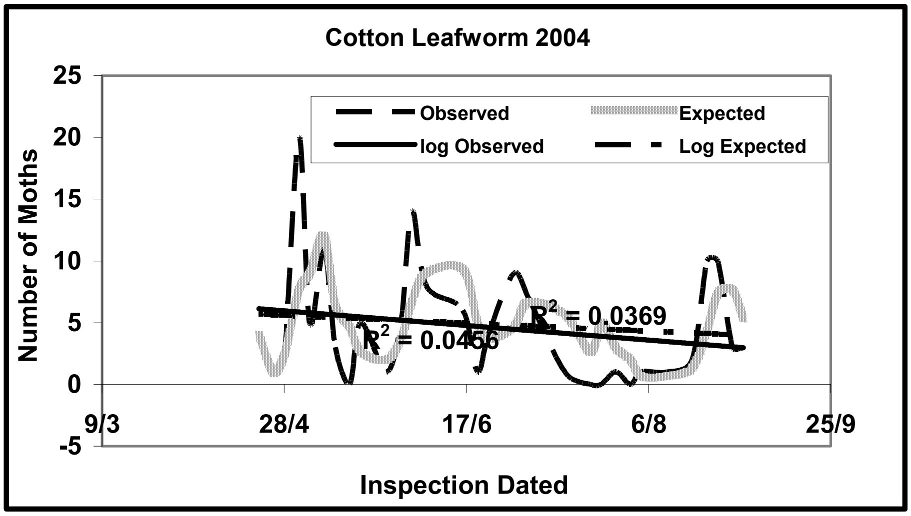
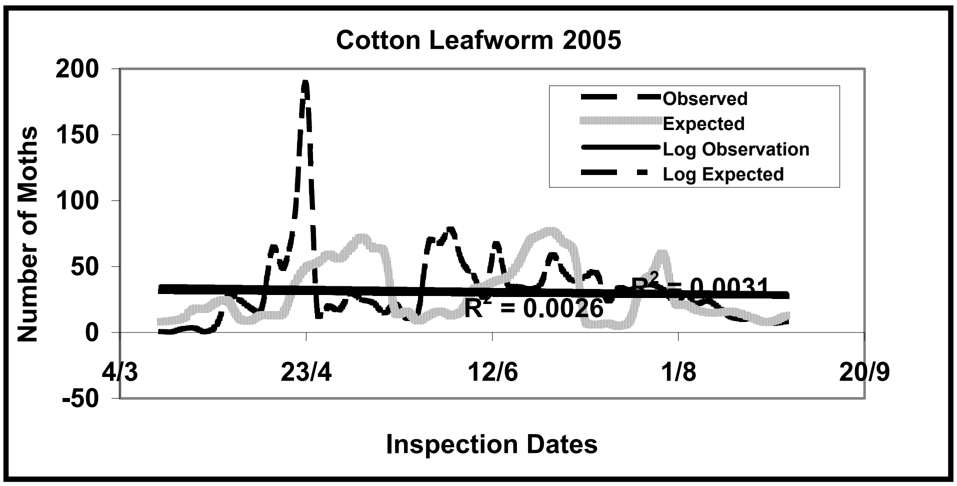


Figure 3. Observed and predicted population of white fly during three successive cotton growing seasons (2004-2006) at Fayum Governorate, Middle Egypt


Cotton Leafworm 2004
Observed
Expected
log Observed
Log Expected
$R^2 = 0.0369$
$R^2 = 0.0456$
Number of Moths
25
20
15
10
5
0
-5
9/3
28/4
17/6
6/8
25/9
Inspection Dated


Cotton Leafworm 2005
Observed
Expected
Log Observation
Log Expected
$R^2 = 0.0031$
$R^2 = 0.0026$
Number of Moths
200
150
100
50
0
-50
4/3
23/4
12/6
1/8
20/9
Inspection Dates

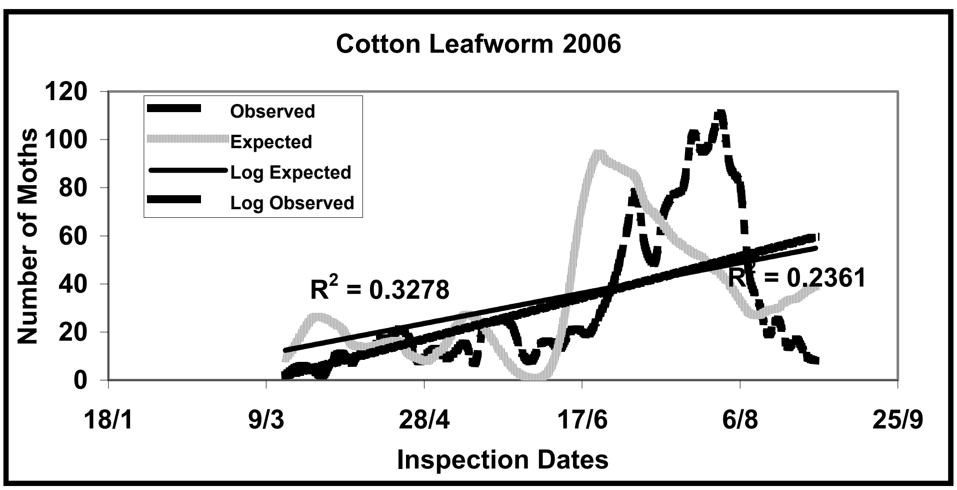
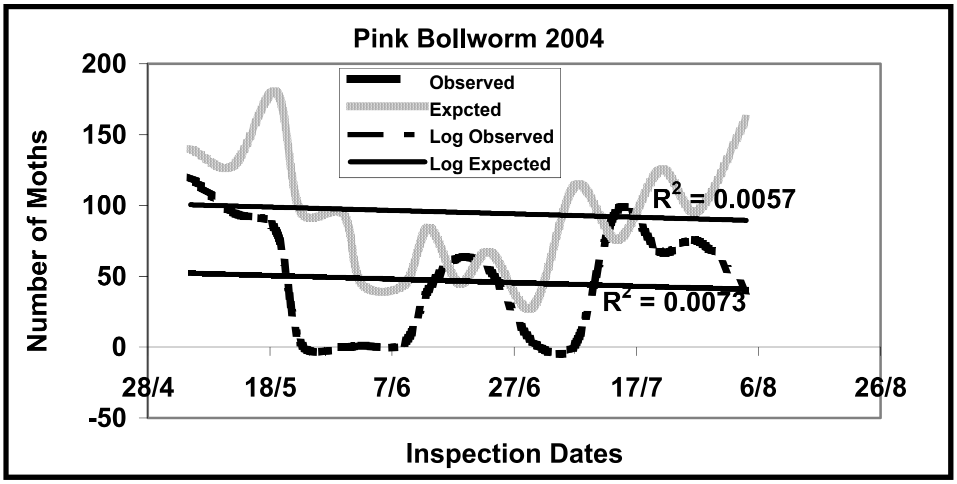
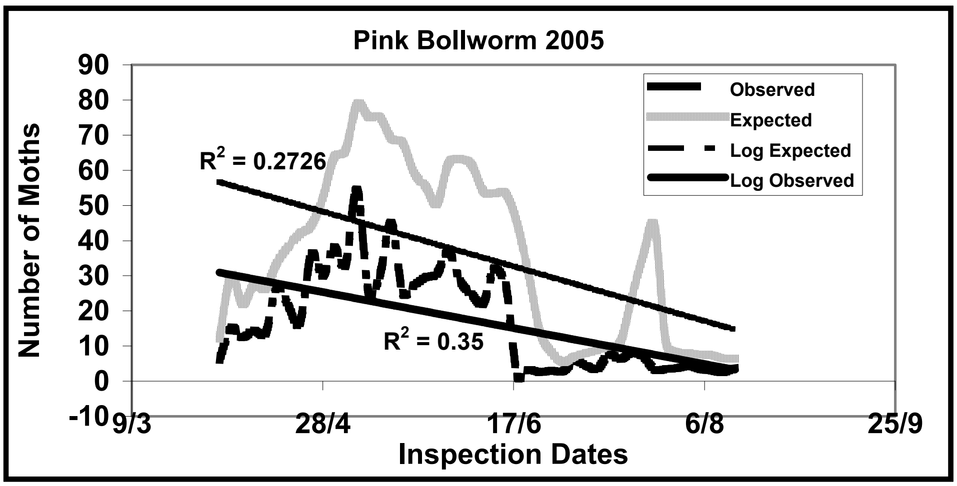

Cotton Leafworm 2006
Observed
Expected
Log Expected
Log Observed
$R^2 = 0.3278$
$R^2 = 0.2361$
Number of Moths
120
100
80
60
40
20
0
18/1
9/3
28/4
17/6
6/8
25/9
Inspection Dates

Figure 4. Observed and predicted population of cotton leafworm during three successive cotton growing seasons (2004-2006) at Fayum Governorate, Middle Egypt





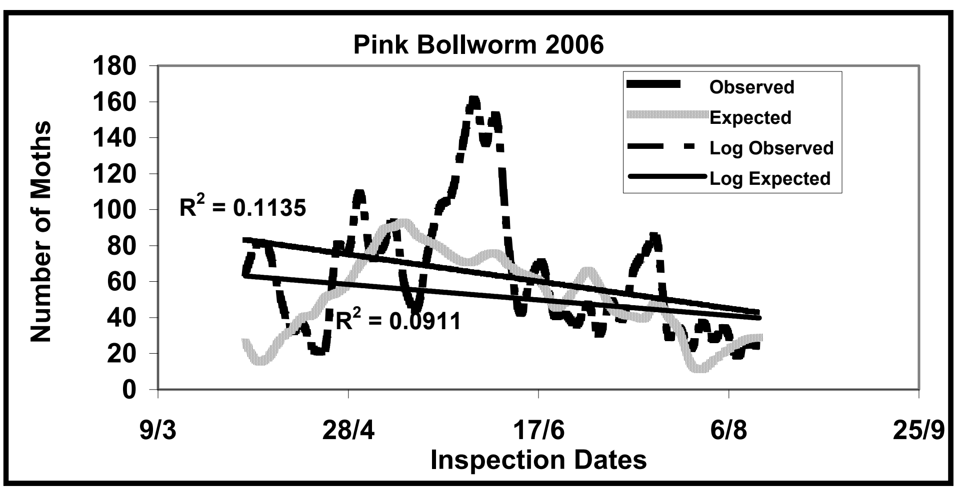


Figure 5. Observed and predicted population of pink bollworm during three successive cotton growing seasons (2004-2006) at Fayum Governorate, Middle Egypt

Table 3. Simple correlation of log observation and prediction curves of some cotton insect pests during three successive cotton growing seasons (2004-2006) at Fayum Governorate, Middle Egypt

Pest	**R^2**		**% Accuracy**
	Observed	**Expected**	
Aphid 2004	0.0129	0.0099	76.7
Aphid 2005	0.0121	0.0088	72.7
Aphid 2006	0.4225	0.2805	66.4
Average			**72.0**
Red Mite 2004	0.006	0.005	83.3
Red Mite 2005	0.0322	0.0287	89.1
Red Mite 2006	0.5118	0.3983	77.8
Average			**83.4**
White Fly 2004	0.7539	0.6555	86.9
White Fly 2005	0.0078	0.0066	84.6
White Fly 2006	0.0144	0.0122	84.7
Average			**85**.4
Cotton Leafworm 2004	0.0456	0.0369	80.9
Cotton Leafworm 2005	0.0031	0.0026	83.9
Cotton Leafworm 2006	0.3278	0.2361	72.0
Average			**78.9**
Pink Bollworm 2004	0.0073	0.0057	78.1
Pink Bollworm 2005	0.35	0.2726	77.9
Pink Bollworm 2006	0.1135	0.0911	80.3
Average			**78.7**
General Average			**79.7**