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FOREWORD

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TABLE OF CONTENTS

LIST OF APPENDIX TABLES

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Introduction

Partial evaluation of the Optimum Pest Management (OPM) trial in Mississippi and Boll Weevil Eradication in North Carolina will require estimation of cotton yield responses to changes in various production inputs, populations of selected insects, and weather variables; and the resultant effects on production costs and returns. In order to accomplish the estimating effort, a cotton production model should be developed and then the developed model be estimated. There are at least two approaches to estimation of the hypothesized cotton production model: (1) by use of econometric techniques, or (2) by simulation.

In this study, a cotton production model was developed and estimated by regression analysis. Included in this analysis were the responses of the population of the bollworm complex (*Heliothis Virescens* and *Heliothis zea*) to its natural enemies, insecticide applications, and a time variable; the degree of plant damage with respect to the pest population and time variable; and the relationship between the cotton lint yield and several selected variables and production inputs.

Objectives

The general objective of this study was to hypothesize a cotton production model and estimate the hypothesized model.

The specific objectives were:

(1) To determine and analyze the effectiveness of important beneficial insects and insecticide application in suppressing the *Heliothis* complex in the cotton field.

(2) To estimate and evaluate the influence of bollworms and boll weevils on the level of plant damage during the 1977 and 1978 cotton growing seasons.

(3) To investigate how plant damage caused by bollworms and boll weevils contributed to yield loss in cotton lint during the study period.

(4) To study the effect of rainfall, soil conditions, nitrogen application, and the other beneficial insects and pests on cotton lint yield.

Data Sources

Insect population, rainfall, and cotton plant damage data by field were obtained from surveys conducted by USDA-AR, OPM Research team in Panola and Pontotoc counties, Mississippi, in 1977 and 1978. This information was gathered to develop data which would make possible evaluation of the biological and economic impacts of both Boll Weevil Eradication and Optimum Pest Management programs if they are utilized across the Cotton Belt. Cotton yield, insecticide application, and fertilizer application data were obtained from surveys conducted by the Department of Agricultural Economics, Mississippi State University. Information regarding soil conditions by field was derived from surveys made by the OPM Research team and county soil surveys (Soil Conservation Service, USDA and Mississippi State University).

Procedure

The population of pests in a cotton field was assumed to be affected by weather variables, beneficial insects in the field, and the amount of insecticide applied. Pests may cause a loss in cotton yield through increases in plant damage. There appears to be a chain interaction in the biological processes of the insects in the cotton field. This chain interaction, combining weather variables, environmental variables, and production inputs, has important effect on cotton yield. Therefore, a simple recursive model seemed to be appropriate for the analyses. Ordinary least squares was applied to fit each equation in the developed recursive model. Details in the development of the model and the use of the estimating procedures are presented below.

Theoretical Model

Pest populations in cotton fields were viewed as functions of the quantity of insecticides applied, population of their natural enemies, time, and weather conditions. The level of various kinds of plant damage was considered to be related to the population of cotton pests and their age. Cotton yield was viewed as a function of the physical conditions of the cotton field, weather conditions during the growing season, cultural practices, fertilization programs, and the effects of the insect interaction. The theoretical cotton yield model for each field can be shown in functional form as follows:

$$Y_{ijt} = f(X_{Ben_{ijkt}}, X_{int_{it}}, W_{it}, t, U_{ijt}) \text{ ---- (1a)}$$

$$D_{int} \equiv h(Y_{ijt}, A_{ijt}, V_{int}) \text{ ------ (1b)}$$

$$Din = \sum_{t=1}^{T} D_{int} \text{ ----------------- (1c)}$$

$$Y_i \equiv g(W_i, P_i, M_i, D_i, E_i) \text{ -----(1d)}$$

$i = 1, 2, ..., I$

$j \equiv 1, 2, ..., J$

$k = 1, 2, ..., K$

$t = 1, 2, ..., T$

$n \equiv 1, 2, ..., N$

where:

Y_{ijt} = the observed population of the j-th pest in the i-th field at time t.

$X_{Ben_{ijkt}}$ = The observed population of the k-th beneficial insect in the i-th field at time t which was the natural enemy of the j-th pest.

$X_{int_{it}}$ = the amount of insecticides applied in the i-th field at time t.

t = time variable.

W_{it} = the set of all weather variables affecting the population of the pest concerned in the i-th field at time t.

U_{ijt} = the disturbance term representing the portion of population of the j-th pest in the i-th field at time t which could not be explained by the arguments of $X_{Ben_{ijkt}}$, $X_{int_{it}}$, W_{it}, and t.

D_{int} = the observed amount of the n-th damage in the i-th field at time t.

A_{ijt} ≡ the average age of the j-th pest in the i-th field at time t.

V_{int} = the disturbance term standing for the portion of the n-th plant damage in the i-th field at time t which was not explained by the arguements of all the explanatory variables.

D_{in} = the total amount of the n-th plant damage caused by the pests in the i-th field during the cotton growing season.

Y_i = the total cotton yield in the i-th field during the harvesting season.

W_i = the set of all weather variables affecting the cotton yield in the i-th field.

P_i = the set of variables representing the physical characteristics of the i-th field and the plants in the field that influence the cotton yield.

M_i = the set of all cultural, nutritional, and technological variables affecting cotton yield in the i-th field.

D_i = the set of plant damage variables that cause loss of cotton yield in the i-th field.

E_i = error term accounting for the portion of the cotton yield not explained by the arguments of all the explanatory variables.

I = the number of fields

J = the number of species of pests

K = the number of species of beneficial insects.

T = the total number of points in time.

N = the number of types of plant damage.

W_i includes all the weather variables in the i-th field such as air temperature, rainfall, relative humidity, and solar radiation. P_i represents such variables as variety of cotton planted, planting pattern, density of cotton plants, and type, fertility, depth, and slope of soil. M_i includes variables such as fertilizer and insecticide application, irrigation, various production inputs such as fungicide and herbicide application, and other management practices such as scouting and reproduction-diapause boll weevil control.

Empirical Model

It would be impossible to obtain all the necessary knowledge for specifying a set of exact functions for each field. Even if it were possible, the resultant complexity of the specified equations would be as intractable as the real world. In order to abstract from the detail, the effects of all variables on cotton yield were classified into direct and indirect effects. Direct effects include those of soil characteristics, rainfall, fertilizer application, other pests and beneficial insects. Indirect effects include those of important beneficial insects, pests (*Heliothis* species and boll weevil), and insecticide applications. Insecticide applications and important beneficial insects were considered to contribute to the increase in cotton yield through the reduction in important pests, consequently decreasing plant damage.

The boll weevil is very mobile and lacks natural enemies to effectively suppress its population expansion. It is also difficult to control the boll weevil in an individual cotton field by means of any single practice. Because the boll weevil was not the target pest of insecticide applications during the 1977 and 1978 growing seasons, the boll weevil population was viewed as an exogenous variable in the cotton yield model. Important beneficial insects include spotted lady beetles, convergent lady beetles, big eyed bugs, assassin bugs, flower bugs, common green lacewings, brown lacewings, lynx spiders,[1/] wolf spiders,[1/] other spiders[1/] and *Scymnus* sp. They are the key natural enemies of the *Heliothis* complex. For simplicity, their total population was viewed as the important beneficial insect variable in the analysis.

[1/] Spiders, although not insects, were treated as insects in this report for ease of data treatment.

The type, depth, fertility, moisture, and slope of soil were combined and represented as an expected yield variable, where the data for the expected yield variable were obtained from the soil surveys for the two counties. Variations in air temperature, soil temperature, solar radiation, and pan evaporation among fields in a particular area at any given time are very small and difficult to measure by field. Therefore, it was assumed that the influence of the variations in these factors among the cotton fields were very small and insignificant. Since there are lags in the responses of bollworm population to the beneficial insect and insecticide application variables, the regression equations to analyze the population of Heliothis complex included lagged independent variables as regressors. The development of Heliothis life cycle was dependent upon temperature, and temperature fluctuates cyclically through time. Therefore, in addition to the beneficial insect and insecticide application variables, a time variable was also included in the regression equations as a proxy variable for temperature to analyze the population of the Heliothis complex.

Plant damage considered included feeding punctures made by boll weevils on tender foliage and square and boll damage caused by Heliothis complex (Hereafter the damage on the tender foliage caused by boll weevils' feeding will be called feeding puncture). The degree of plant damage made by each pest depends on its population and physical development and the development is dependent upon temperature, therefore, a time variable was also included in the regression equations to account for the variation in the level of plant damage. The preference of larvae of Heliothis spp. for various fruiting structures on cotton plants for food varies with the age of the insect and plant phenology.

Young bollworms prefer squares to bolls, and this preference reduces their dependence on bolls. Thus, estimates of square damage, when considered in addition to the population of Heliothis larvae in the field and time variable, serve as a partial explanation of variation in boll damage. Therefore, square damage by Heliothis complex has been included as an explanatory variable in the region equation of the level of boll damage in the cotton field.

Abstracting from the actual situations and based upon the available data, the theoretical model was redeveloped as follows:

$$Y_{h_{it}} = g(X_{Ben_{i(t-1)}}, X_{int_{i(t-1)}}, t, U^*_{it}) \text{ --------------------(2a)}$$

$$D_{int} = f(X_{pest_{int}}, t, X_{rd_{int}}, V_{int}) \text{ --------------------------(2b)}$$

$$D_{in} = \sum_{t=1}^{T} D_{int} \text{ --(2c)}$$

$$Y_{cotton_i} = h(D_i, X_{o.p._i}, X_{nit_i}, X_{w_i}, X_{e.p._i}, X_{o.b._i}, U_i) \text{ ----(2d)}$$

Where:

$Y_{h_{it}}$ = the observed population per acre of the Heliothis complex in the i-th field at time t.

$X_{Ben_{i(t-1)}}$ = the total population per acre of the beneficial insects in the i-th field at the time (t-1).

$X_{int_{i(t-1)}}$ = the level of the insecticide application variable in the i-th field at the time (t-1).

t = time variable = Julian days -151.

U^*_{it} = the error term representing the portion of the Heliothis population per acre in the i-th field at time t which was not explained by the arguments of $X_{Ben_{i(t-1)}}$, $X_{int_{i(t-1)}}$, and t.

D_{int} = the amount of the n-th plant damage per acre caused by the pest in the i-th field observed at time t.

$X_{pest_{int}}$ = the population per acre of the pest that caused the n-th plant damage in the i-th field at time t, (when the pest concerned is Heliothis complex, $Xpest_{int} = \hat{Y}_{h_{it}}$).

$X_{rd_{int}}$ = the estimated amount per acre of plant damage related = to the n-th damage in the i-th field at time t.

V_{int} = the disturbance term representing the portion of the n-th plant damage in the i-th field at time t which was not explained by the arguments of $X_{pest_{int}}$, t, and $X_{rd_{int}}$.

D_{in} = the estimated total amount of the n-th plant damage per acre in the i-th field during the cotton growing season.

Y_{cotton_i} = the observed cotton yield per acre in the i-th field during the harvesting period or periods.

D_i = the set of plant damage variables in the i-th field during the growing seasons.

$X_{o.p._i}$ = the average total population per acre of the other pests in the i-th field during the growing seasons.

X_{nit_i} = the total amount of nitrogen applied per acre in the i-th field during the cotton growing seasons.

X_{w_i} = the set of rainfall variables in the i-th field for July, = August, and September.

$X_{e.p._i}$ = the expected yield variable in the i-th field representing the contributions made by soil conditions to the cotton yield.

$X_{o.b._i}$ = the average total population per acre of the other beneficial insects in the i-th field during the growing seasons.

U_i = the disturbance term representing the portion of the cotton yield in the i-th field not explained by the arguments of all the explanatory variables.

An important difference between the theoretical and empirical models is that time lags in the responses of the Heliothis complex population to the insecticide application variable and to the total population of its natural enemies were included in the empirical model but not in the theoretical model. Also, in equations (2a) and (2b), "t" is defined while it was included in the theoretical model only as a trend. Irrigation, management practices, relative humidity, solar radiation, plant variety, planting pattern, plant density, and temperature were not included in the empirical model due to either a lack of data or difficulty in data treatment. It is also important to note that the oviposition punctures made by the boll weevil on fruiting forms and the bloom damage by the Heliothis complex were not taken into account due to a lack of data. There were different kinds and amounts of insecticides applied for bollworm control among the cotton fields and between 1977 and 1978 growing seasons; therefore, an insecticide application index was designed to represent the amount of insecticides applied. Mathematically this index is:

$$I_{it} = \sum_{n=1}^{N} \frac{R_{a_{int}}}{R_{r_n}} \text{ ------------------------------------(3)}$$

where:

I_{it} = the insecticide application index for the i-th field at time t.

$R_{a_{int}}$ = the actual amount of the n-th insecticide applied per acre in the i-th field at time t.

R_{r_n} = the recommended application rate of the n-th insecticide per acre.

Statistical Method

The cotton model was developed as a simple recursive system. Thus, ordinary least squares is applicable in accordance with econometric theory (the estimation of the model followed the sequence of equations (2a), (2b), (2c), and (2d)). Relationships to be estimated were not considered to be linear. Various functional forms were tried for each regression equation in the empirical model. Then, based upon coefficients of determination, standard errors of estimation, the consistency of results for 1977 and 1978 data, and the number of statistically significant regression coefficients, the regression equations best approximating actual situations were selected.

Results

Three sets of regression equations were estimated and evaluated: the first set was based upon the information collected in 1977, the second set was based upon 1978 data, and the third set was based on combined 1977 and 1978 data. Results of the analyses are shown in Appendix Tables 2, 3, 4, 5, 6, and 7.

I. Population of Heliothis Complex

The results shown in Table 2 reveal that approximately 40, 49, and 60 percent of variations in the population of the bollworm complex were explained by the three equations. The time variable in these three equations show that there were four extremes in the population of the bollworm complex in 1977 and 1978 with respect to time, there having been two maxima and two minima. Elasticities of the bollworm population with respect to the lagged insecticide application and beneficial insect variables were as follows:

1977

$$\frac{\partial Y_{bollworm}/Y_{bollworm}}{\partial X_{int_{-1}}/X_{int_{-1}}} = -0.00106\ X_{int_{-1}} \text{----------------------} (4a)$$

$$\frac{\partial Y_{bollworm}/Y_{bollworm}}{\partial X_{Ben_{-1}}/X_{Ben_{-1}}} = -0.00005\ X_{Ben_{-1}} \text{---------------------} (4b)$$

1978

$$\frac{\partial Y_{bollworm}/Y_{bollworm}}{\partial X_{int_{-1}}/X_{int_{-1}}} = -0.00118\ X_{int_{-1}} \text{ --------------------(4c)}$$

$$\frac{\partial Y_{bollworm}/Y_{bollworm}}{\partial X_{Ben_{-1}}/X_{Ben_{-1}}} = -0.00004X_{Ben_{-1}} \text{ ---------------------(4d)}$$

and 1977 and 1978 combined

$$\frac{\partial Y_{bollworm}/Y_{bollworm}}{\partial X_{int_{-1}}/X_{int_{-1}}} = -0.00101922\ X_{int_{-1}} \text{ ----------------(4e)}$$

$$\frac{\partial Y_{bollworm}/Y_{bollworm}}{\partial X_{Ben_{-1}}/X_{Ben_{-1}}} = -0.00001094\ X_{Ben_{-1}} \text{ ---------------(4f)}$$

At the average levels for bollworm population and insecticide application, the elasticities were -0.082334 in 1977, -0.0361936 in 1978, and -0.0514956 for 1977 and 1978 combined. Elasticities at average bollworm and beneficial insect population were -0.24569 in 1977, -0.1753896 in 1978, and -0.0578423 for 1977 and 1978 combined. The elasticity of the Heliothis population with respect to the beneficial insect variable was greater than the elasticity with respect to the insecticide application index in both of these two years. The elasticities of bollworm population with respect to both the insecticide application and beneficial insect variables were not constant. Equations for the Heliothis population in 1977 and 1978 implied that, in order for the control power of insecticide to be greater than that of beneficial insects, the insecticide application rate should be raised to 231.78 and 148.64 percent of the recommended application rates, respectively.

II. Plant Damage

Feeding punctures made by boll weevils on tender foliage, and the damage caused by Heliothis spp. on squares and bolls were considered in this study. Results of the analysis are presented on Tables 3, 4, and 5. Over 80 percent of the variation in the level of the Heliothis damaged square during the 1977 and 1978 cotton growing seasons was explained by the regression equations chosen and all the regression coefficients were statistically significant at either the five or one percent level. The regression equations also show that maximum square damage by Heliothis spp. occurred around Julian days 192 and 202 in 1977 and 1978 cotton growing seasons, respectively, while minimum square damage by Heliothis complex happended on about Julian days 244 and 249, respectively. That is, the maximum and minimum square damage took place earlier in 1977 than in 1978. This may be due to the delayed planting of cotton in 1978.

Approximately 46 and 78 percent, respectively, of the variation in the level of boll damage during the 1977 and 1978 cotton growing seasons was explained by the fitted regression equations (Table 4). When the data for 1977 and 1978 were combined, about 81 percent of the variation in boll damage during these two growing seasons was explained by the selected regression equation. The regression equations also imply that the minimum boll damage by Heliothis complex occurred on about Julian days 204 and 190 in 1977 and 1978 while maximum damage happened on around Julian days 244 and 287, respectively. It was also shown that the level of square damage influenced the number of bolls damaged by the Heliothis complex.

Results of regression analyses show that about 58 and 56 percent, respectively, of the variation in the level of feeding punctures made by boll weevils during the two year cotton growing seasons was explained (Table 5). When data for the two years were combined, approximately 65 percent of the variation in the level of feeding punctures was explained. The results also show that maximum feeding punctures occurred on Julian days 211 and 206, in 1977 and 1978, respectively. The analysis indicates that the critical time periods for controlling *Heliothis* complex and boll weevils is around Julian days 190 and 280.

III. Cotton Lint Yield

Results of the analyses on cotton lint yield are shown on Tables 6 and 7. About 96 and 94 percent, respectively, of the variation in cotton lint yield in 1977 and 1978 was explained by the selected regression equations.

In addition to the regression analyses, marginal productivity and elasticity concepts were also utilized to analyze cotton lint yield. The marginal productivity of a production input is the increase or decrease in product due to a one unit increase in the input, *ceteris paribus*. For example, Table 7 shows that if the rainfall in August, 1977 were increased by one inch and all other factors held constant, cotton lint yield would have increased approximately 12.8 pounds per acre. An increase of one damaged square by *Heliothis* spp. per acre would bring about 0.00175 lb. loss in cotton lint yield. The elasticity of production with respect to an input is the percentage change in output due to a one percent change in production input under the condition that all the other factors are held constant. For example, Table 7 reveals that in 1977 a one percent increase in the nitrogen application would result in about 0.123 percent increase in cotton lint yield.

The regression equations imply that the marginal productivity of the explanatory variables was affected by their own levels. But the marginal productivity of the expected yield variable, in addition to its own level, was also influenced by the cotton lint yield. The elasticity of cotton lint yield with respect to any independent variable was very small in both 1977 and 1978, implying that all the factors concerned had their individual effects on cotton lint yield but any small change in a single factor could not substantially affect cotton lint yield. The positive elasticity of cotton production with respect to the other beneficial insect variable ($X_{o.b._i}$) was greater in absolute value than the negative elasticity with respect to the other pest variable ($X_{o.p._i}$). This implies that the other beneficial insects could offset the negative effect of the other pests in cotton lint yield.

Marginal losses in cotton lint yield due to square damage and feeding puncture variables also showed that the boll weevil was more destructive than the Heliothis complex. According to the regression equation for the 1977 and 1978 data combined, at the average, an increase in either 358 feeding punctures or 651 squares damaged per acre could bring about a one pound loss in cotton lint yield. The statistics on Table 7 also show that the damaged square by Heliothis complex was more detrimental to cotton lint yield than the other pests.

Conclusions

Beneficial insects had a greater effect on the control of the bollworm complex than did insecticide application according to equations (4a), (4b), (4c), (4d), (4e), and (4f). The maximum boll damage and the minimum square damage by Heliothis comples seemed to occur approximately at the same time in accordance with the time variable in the regression equations shown in Tables 3 and 4. It was shown that feeding punctures made by boll weevils had a greater negative effect on cotton lint yield than square damage (Table 7). The marginal loss in cotton lint yield due to a one unit increase in square damage was about 0.001537 lb. while the yield loss due to a unit increase in feeding puncture was approximately 0.00279465 lb. Approximately 358 feeding punctures or 651 damaged squares would bring about a one pound reduction in cotton lint yield according to the regression equation for the 1977 and 1978 data combined.

On the average, as total nitrogen application increased at a rate of one pound per acre, cotton lint yield would be raised about 0.8658 lb. The marginal productivity of both August and September rainfall variables was comparatively large even though the elasticity of cotton yield with respect to either of them was very small. This implies that an increase in rainfall during these two months would bring about substantial yield increases.

Implications

Some of the more important implications of this study concern insecticide application versus beneficial insect population, and the relative level and timing of crop damage made by the boll weevil versus the bollworm complex.

First, the suppressing power of beneficial insects on Heliothis population implies that there is a need to pay more attention to utilization of the beneficial insects for pest management. Second, the comparatively great marginal productivity of rainfall in August and September implies that some attention should be paid to crop irrigation during these two months.

Finally, even though the boll weevil population was very low in the study areas during these two years and they were not the targets of insecticide application at all, the results of analyses indicate that the feeding punctures were more detrimental to the cotton yield than square damage. Therefore, attention should still be paid to the population buildup of boll weevil in the cotton field. The results also show that square damage by Heliothis complex was more harmful to cotton lint yield than the other pests, implying that relatively more effort should be devoted to suppressing bollworm complex than the other pests during the growing season.

Limitations

The major limitation of this study lies in the narrow scope of the data utilized and the short study period. Data were collected in just two Mississippi counties--Panola and Pontotoc. The study period was only 1977 and 1978. There is also a lack of data concerning weather variables such as air temperature, solar radiation, and relative humidity and data regarding some plant damage in 1977 such as bloom damage caused by Heliothis complex and oviposition punctures made by boll weevils. Weather variables are very important to the growth of cotton plants and the development of insects, including both beneficial insects and pests. The oviposition punctures and bloom damage also affect the cotton yield. Therefore, more data need to be gathered and more research of this type needs to be conducted on a wider geographic scope over longer periods in order to make this kind of analyses applicable regionally or beltwide.

The deviation in observed rainfall by field in August 1977 and in September 1978 from the long run trend also presented a significant limitation on the validity of the results obtained from this study regarding the rainfall variables. The observed average frequencies of insecticide application were 5.7 and 3.6 in Panola and 1.9 and 1.0 in Pontotoc county, respectively, in 1977 and 1978. These observed average frequencies were substantially low. Thus, these facts greatly limit the application range of the analytical results concerning insecticide application and rainfall variables.

APPENDIX

Table 1. List of variables employed in the analyses.

Dependent variables:

$Y_{Bollworm}$	: Population of bollworm per acre.
$Y_{SQ.\ D.}$	: The number of squares damaged per acre between two survey times.
$Y_{Boll\ D.}$	: The number of bolls damaged per acre between two surveys.
$Y_{Feed.\ punct.}$	: The number of feeding punctures made per acre between two surveys.
Y_{cotton}	: Cotton lint production in pounds per acre.

Independent variables:

X_{Ben-1}	: Population of important beneficial insects per acre lagged one week.
X_{int-1}	: Index of insecticide application lagged one week.
t	: Julian days - 151 (time variable).
$X_{Bollworm}$	: The estimated population of bollworm per acre.
$X_{sq.D.}$	: The estimated number of squares damaged per acre between two survey times.
X_{weevil}	: The population of boll weevils per acre.
$X_{SQ.D.}$	: The estimated total number of squares damaged per acre during cotton growth season.
$X_{A.R.}$	: August rainfall in inches.
$X_{S.R.}$	: September rainfall in inches.
$X_{E.P.}$	: Expected yield per acre (pounds/acre).
$X_{F.P.}$	: The estimated total number of feeding punctures made per acre during growth season.
$X_{o.b.}$	: Average population of other beneficial insects per acre.
$X_{Nit.}$	: Total amount of Nitrogen applied per acre.
$X_{o.p.}$	: Average population of other pests per acre.

Table 2. Results of regression analyses of bollworm population, Panola and Pontotoc counties, Mississippi, 1977 and 1978.

	Regression equations	R^2	Calculated F-values	Critical values for t-test[a] 10% level	5% level	1% level	Standard errors of estimation	d. f. for t- test
1977	$\ln Y_{bollworm} = -12.26296 - 0.00005\ X_{Ben-1} - 0.00106 X_{int-1}$ (-3.863056)*** (-2.031748)** $+1.94315\ t - 0.06976\ t^2 + 0.00116\ t^3 - 0.000009\ t^4$ (3.791200)*** (-3.558188)*** (3.414630)*** (-3.286366)*** $+0.000000026\ t^5$ (3.145362)***	0.4028	13.491	1.658	1.98	2.617	0.5817	140
1978	$\ln Y_{bollworm} = -56.62519 - 0.00004\ X_{Ben-1} - 0.00118\ X_{int-1}$ (-4.503943)*** (-1.874033)* $+5.67564\ t - 0.19280\ t^2 + 0.00313\ t^3 - 0.00002432\ t^4$ (3.295907)*** (-3.535081)*** (3.745170)*** (-3.9217598)*** $+0.00000007\ t^5$ (4.063496)***	0.4865	9.88	1.671	2.00	2.66	0.2907	81
1977 & 1978	$\ln Y_{bollworm} = -5.39426 - 0.00001094\ X_{Ben-1} - 0.00101922\ X_{int-1}$ (-2.810747)*** (-5.469516)*** $+1.02564209\ t - 0.03175887\ t^2 + 0.00046973\ t^3$ (4.734892)*** (-3.781851)*** (3.167444)*** $-0.00000328\ t^4 + 0.00000001\ t^5$ (-2.685666)*** (2.247665)**	0.6882	72.191	1.645	1.96	2.576	0.2687	229

Note: The numbers in parentheses are calculated t-values.

[a] The critical values for t-test are approximate values.

*The coefficients are significant at 10% level.

**The coefficients are significant at 5% level.

***The coefficients are significant at 1% level.

Table 3. Results of regression analyses of square damage , Panola and Pontotoc counties, Mississippi, 1977 and 1978.

	Regression equations	R^2	Calculated F-values	Critical values for t-test[a] 10% level	5% level	1% level	Standard errors of estimation	d.f. for t-test
1977	$Y_{SQ.D.} \equiv -3834.56274 + 1.40233\, X_{bollworm} + 316.46999\, t$ (21.803476)*** (3.990263)*** $-5.47428\, t^2 + 0.0263\, t^3$ (-4.243324)*** (3.987668)***	0.8064	162.484	1.658	1.98	2.617	922.1661	163
1978	$Y_{SQ.D.} \equiv -45353.426 + 1.12011\, X_{bollworm} + 2460.13245\, t$ (16.191973)*** (15.878038)*** $-37.42512\, t^2 + 0.17313\, t^3$ (-15.805512)*** (15.205663)***	0.8287	229.832	1.645	1.96	2.326	1186.1263	190
1977 & 1978	$Y_{SQ.D.} \equiv -24272.100 + 1.19823\, X_{bollworm} + 1413.38785\, t$ (26.563018)** (15.163545)*** $-21.95959\, t^2 + 0.10194\, t^3$ (-15.413105)*** (14.790757)***	0.8339	424.26	1.645	1.96	2.326	1062.9442	358

Note: The numbers in parentheses are calculated t-values.

[a] The critical values for t-test are approximate values.

** The coefficients are significant at 5% level.

*** The coefficients are significant at 1% level.

Table 4. Results of regression analyses of boll damage, Panola and Pontotoc counties, Mississippi, 1977 and 1978.

	Regression equations	R^2	Calculated F-values	Critical values for t-test[a] 10% level	5% level	1% level	Standard errors of estimation	d.f. for t-test
1977	$Y_{boll\ D.} = 23315.43506 + 0.46118\ X_{bollworm} - 0.10382\ X_{sq.D.}$ (6.216792)*** (-2.692296)*** $-1055.09569\ t + 15.47739\ t^2 - 0.07028\ t^3$ (-2.598057)** (2.851754)*** (-2.98327)***	0.4642	22.875	1.658	1.98	2.617	1106.8473	109
1978	$Y_{boll\ D.} = 5081.15576 + 0.07954\ X_{bollworm} - 0.02594\ X_{sq.D.}$ (3.773248)*** (-1.991130)** $-285.16739\ t + 4.77549\ t^2 - 0.01817\ t^3$ (-5.019363)*** (4.045887)*** (-2.519841)**	0.7794	77.016	1.658	1.98	2.617	745.8239	132
1977 & 1978	$Y_{boll\ D.} = 22896 + 0.11689\ X_{bollworm} - 0.03372\ X_{sq.D.}$ (7.044807)*** (-3.703971)*** $-1032.85947\ t + 15.12267\ t^2 - 0.06705\ t^3$ (-5.395619)*** (5.844891)*** (-5.900025)***	0.8104	135.937	1.645	1.96	2.576	532.2416	247

Note: The numbers in parentheses are calculated t-values

[a]The critical values for t-test are approximate values.

**The coefficients are significant at 5% level.

***The coefficients are significant at 1% level.

Table 5. Results of regression analyses of feeding punctures, Panola and Pontotoc counties, Mississippi, 1977 and 1978.

	Regression equations	R^2	Calculated F-values	Critical values for t-test 10% level	5% level	1% level	Standard errors of estimation	d. f. for t-test
1977	$Y_{Feed.\ Punct.} = -37870.364 + \underset{(7.863333)^{***}}{1.66138\ X_{weevil}} + \underset{(2.472913)^{**}}{1740.67784\ t} \underset{(-2.815369)^{***}}{-25.6255\ t^2} + \underset{(3.189561)^{***}}{0.1235\ t^3}$	0.5762	26.512	1.671	2.00	2.66	760.882	78
1978	$Y_{Feed.\ Punct.} = -8132.27087 + \underset{(9.510021)^{***}}{0.89507\ X_{weevil}} + \underset{(2.475702)^{**}}{420.50532\ t} \underset{(-2.297107)^{**}}{-6.17491\ t^2} + \underset{(2.094946)^{**}}{0.02838\ t^3}$	0.5598	24.798	1.671	2.00	2.66	751.575	78
1977 & 1978	$Y_{Feed.\ Punct.} = -16717.176 + \underset{(15.111986)^{***}}{1.53018\ X_{weevil}} + \underset{(6.185976)^{***}}{903.07993\ t} \underset{(-6.424951)^{***}}{-14.72543\ t^2} + \underset{(6.647782)^{***}}{0.07667\ t^3}$	0.6466	73.628	1.658	1.98	2.617	815.7386	161

Note: The numbers in parentheses are calculated t-values.

[a] The critical values for t-test are approximate values.

** The coefficients are significant at 5% level.

*** The coefficients are significant at 1% level.

Table 6. Results of regression analyses of cotton lint yield, Panola and Pontotoc counties, Mississippi, 1977 and 1978.

	Regression equations	R^2	Calculated F-values	Critical values for t-test[a/] 10% level	5% level	1% level	Standard errors of estimation	d.f. for t-test
1977	$\ln Y_{cotton} = 8.78451233 + 0.01996011\ X_{A.R} + 0.01588639\ X_{S.R.}$ (1.817966)* (4.967726)*** $+0.00113699\ X_{E.P.} - 0.00000273\ X_{SQ.D.} - 0.00000335\ X_{F.P.}$ (3.054538)*** (-4.393529)*** (-2.509482)** $-0.00000022\ X_{o.p.} + 0.00167061\ X_{Nit.} - 0.60449313 \ln X_{E.P.}$ (-2.574374)** (5.153824)*** (-2.523430)** $+0.07551709 \ln X_{o.b.}$ (3.325026)***	0.9605	54.077	1.725	2.086	2.845	0.0283576	20
1978	$\ln Y_{cotton} = 11.325 + 0.0213\ X_{A.R.} + 0.04175\ X_{S.R.} + 0.0021\ X_{E.P.}$ (2.639886)*** (2.009054)* (2.902516)*** $-0.00000187\ X_{SQ.D.} - 0.00001538\ X_{F.P.} - 0.00000066\ X_{o.p.}$ (-1.990251)* (-3.407727)*** (-2.649736)** $+0.00094564\ X_{Nit} - 1.17919 \ln X_{E.P.} + 0.14153485 \ln X_{o.b.}$ (2.031354)* (-2.563572)** (4.267927)***	0.9383	33.794	1.725	2.086	2.845	0.0564097	20
1977 & 1978	$\ln Y_{cotton} = 9.27044934 + 0.01538847\ X_{A.R.} + 0.01624341\ X_{S.R.}$ (2.530593)** (2.849456)*** $+0.00155853\ X_{E.P.} - 0.00000253\ X_{SQ.D.}$ (3.161487)*** (-4.278458)*** $-0.0000046\ X_{F.P.} - 0.00000041\ X_{o.p.} + 0.00142515\ X_{Nit.}$ (-2.337263)** (-3.394878)*** (3.976996)*** $-0.82988525 \ln X_{E.P.} + 0.14834502 \ln X_{o.b.}$ (-2.657348)** (6.321819)***	0.909	55.466	1.6775	2.0105	2.682	0.0550664	50

Note: The numbers in parentheses are calculated t-values.

a/The critical values for t-test at 50 degrees of freedom are approximate values.

*The coefficients are significant at 10% level.

**The coefficients are significant at 5% level.

***The coefficients are significant at 1% level.

Table 7. Elasticities of cotton lint yield with respect to selected independant variables and their marginal productivities, Panola and Pontotoc counties Mississippi, 1977 and 1978.

	August rainfall	September rainfall	Expected yield	Square damage	Feeding punctures	Other beneficial insect	Other pest	Nitrogen
1977 elasticities	0.0333266	0.0424749	0.17235529	-0.089198	-0.03503296	0.0755171	-0.0178039	0.1227046
Marginal productivities	12.766486	10.160935	0.161344225	-0.00174611	-0.00214266	0.0017038	-0.000140712	1.068522156
1978 elasticities	0.0553018	0.04872225	0.2815349	-0.0955256	-0.1703099	0.141535	-0.030198	0.0600796
Marginal productivities	12.25815	24.027125	0.23293163	-0.001076185	-0.00885119	0.0040458	-0.00037983	0.5442158
1977 & 1978 elasticities	0.0328236	0.0311927	0.244591297	-0.1059519	-0.0495214	0.148345	-0.02596978	0.09761077
Marginal productivities	9.349	9.8684	0.2155407	-0.00153706	-0.00279465	0.00371789	-0.000249088	0.865826

Note: Marginal productivities, nitrogen, and expected yield variables were measured in pounds per acre. Rainfall variables were measured in inches.

REFERENCES

[1] Bacheler, J. S., J. W. Jones, J. R. Bradley, Jr., and H. D. Bowen, "The Effect of Temperature on Development and Mortality of Boll Weevil Immature Stages." Environmental Entomology, Vol. 4, No. 5, pp. 808-810, October, 1975.

[2] Brown, L. G., J. W. Jones, J. D. Heskety, J. D. Hartsog, F. D. Whisler, R. W. McClendon, F. A. Harris, D. W. Parvin, Jr., and H. N. Pitre, "The Use of Simulation to Predict Cotton Yield Losses Due to Insect Damage." Proceedings of Beltwide Cotton Production Research 1975, pp. 1-11.

[3] Carlson, Gerald A., "Long-Run Productivity of Insecticides." American Journal of Agricultural Economics. Vol. 59, No. 3, pp. 543-548, August, 1977.

[4] Grube, Arthur H. and Gerald A. Carlson, "Analysis of Field Scouting and Insecticide Use, "Annual Meeting of American Agricultural Economics Association, August, 1978, Blacksburg, Virginia.

[5] Hamill, James G., David W. Parvin, Jr., Fred T. Cooke, Jr., and Dan Seale, "Estimated Costs and Returns, Row Crops, Northern Brown Loam Area of Mississippi, 1978, "Information Bulletin 3, MAFES in cooperation with Commodity Economics Division; Economics Statistics and Cooperatives Service; USDA, March, 1978.

[6] Headley, J. C., "Estimating the Productivity of Agricultural Pesticides. "American Journal of Agricultural Economics, Vol. 50, pp. 13-25, February, 1968.

[7] Hueth, D. L. and L. Regev, "Optimal Agricultural Pest Management with Increasing Resistance. "American Journal of Agricultural Economics Vol. 56, No. 3, pp. 543-552, August, 1974.

[8] Jones, James W., H. D. Bowen, R. E. Stinner, J. R. Bradley, Jr., R. S. Sowell, and J. S. Bacheler, "Female Boll Weevil Oviposition and Feeding Processes: A Simulation Model." Environmental Entomology, Vo. 4, No. 5, pp. 815-821, October, 1975.

[9] Koretsch, Jack L., "Moisture Uncertainties and Fertility Response Studies." Journal of Farm Economics, Vol. 41, pp. 70-76, February, 1959.

[10] Koutsoyiannis, A., <u>Theory of Econometrics</u>, 2nd Edition, Harper & Row Publishers, Inc., 1978.

[11] Oury, Bernard, "Allowing for Weather in Crop Production Model Building." Journal of Farm Economics, Vol, 47, pp. 270-283, May, 1965.

[12] Parencia, C. R., W. P. Scott, J. W. Smith, and T. C. Lockley, Development of Base Line Data in panola and Pontotoc Counties, Mississippi in 1977 for the Optimal Pest Management Trial-A Special Report, Insect Population Management Research Unit, AR, SEA, USDA, Stoneville, Mississippi.

[13] Parencia, C. R., W. P. Scott, J. W. Smith, and T. C. Lockley, A Report of Biological Data Developed in 1978 for the Optimal Pest Mangement Trial, Panola and Pontotoc Counties, Mississippi, Insect Populations Management Research Unit, Bioenvironmental Insect Control Laboratory, AR, SEA, USDA, Stoneville, Mississippi, In cooperation with the Delta Branch of the MAFES, Stoneville, Mississippi.

[14] Parvin, David W. Jr., "A New Technique for Estimating the Economic Potential for Irrigation of Peanuts, Corn, and Soybeans in the Georgia Coastal Plain, " Research Bulletin 127, Department of Agricultural Economics, Georgia Experiment Station, University of Georgia, May, 1973.

[15] Parvin, D. W., Jr. and Fred H. Tyner, "A Procedural Outline for Developing a Complete Simulation Model of a Cotton Production System" Staff Paper No. 10, Department of Agricultural Economics, Mississippi State University.

[16] Parvin, D. W., Jr., and Fred H. Tyner, "Crop Growth Models, Crop Production Models and Farm Management Models," Staff Paper No. 13, Department of Agricultural Economics, Mississippi State University.

[17] Parvin, D. W., "Evaluating the Boll Weevil Trials with Emphasis on Beneficial Insects." Staff Paper No. 32, Department of Agricultural Economics, Mississippi State University.

[18] Parvin, D. W., Jr., F. A. Harris, and M. L. Laster, "Cotton Insect Control in Mississippi: An Overview," Staff Paper, Department of Agricultural Economics, Mississippi State University.

[19] Soil Survey Panola County, Mississippi, United States Department of Agriculture and Mississippi Agricultural and Forestry Experiment Station, Series 1960, No. 10, December 1963.

[20] Soil Survey Pontotoc County, Mississippi, United States Department of Agriculture and Mississippi Agricultural and Forestry Experiment Station, 1977.

[21] The Boll Weevil: Management Strategies, Southern Cooperative Series, Bulletin No. 228, June, 1978.

[22] Stallings, James L., "A Measure of the Influence of Weather on Crop Production," Journal of Farm Economics, Vol. 43, pp. 1153-1160, December, 1961.

[23] Theil, Henri, Principles of Econometrics, John Willey & Sons, Inc. New York, 1971.