ECONOMICS OF THE COTTON BOLL WEEVIL CONTROL IN THE TEXAS HIGH PLAINS

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Abstract

This study analyzes the economics of the cotton boll weevil control in the Texas High Plains. It suggests that the specific economic threshold used for deciding when to control of boll weevil infestations can substantially impact farm-level profitability. The preliminary economic threshold recommendations advanced in this study are significantly different from current practice, which points to the need for further analyses. The results of the ET analyses are also used to evaluate the recently approved boll weevil eradication programs, concluding that farmers likely made an economically sound decision in approving these programs.

Introduction

In spite of eradication programs in progress in some areas and the knowledge that has been accumulated over the years concerning its control, the boll weevil (*Anthonomus grandis* Boh.) continues to cause millions of dollars in losses to the Texas cotton industry. During 1998, the reduction of yields due to this insect across the state was estimated at 7% (Williams). Beginning in 1992, boll weevils have spread dramatically through the cotton growing areas of the Texas High Plains (Texas High Plains Boll Weevil Task Force). From 1995 to 1998, more than $86 million have been spent in this region to control the weevil, and damage losses have exceeded $260 million (Leser and Haldenby).

Many efforts have been made over the years to reduce the use of insecticides to control this pest, but chemical control is still a critical component in the management of the cotton boll weevil. An efficient use of insecticides is essential to reduce the economic damage caused by the weevils and maintain the profitability of cotton production. Economic injury levels and economic thresholds are important tools that in the last half of the 20th century have improved the practice of pest management and provided for a more efficient use of pesticides (Ramírez and Saunders).

The main objective of this research is to determine economic thresholds for the chemical control of mid-to-late season boll weevil infestations in the Texas High Plains, and to compare them with current recommendations. A secondary objective is to economically evaluate the boll weevil eradication programs recently approved by farmers in the Texas High Plains.

Economic Injury Levels and Economic Thresholds: Basic Concepts

The concepts of economic injury levels (EIL) and economic thresholds (ET) were introduced by Stern et al. in the entomological literature in 1959. The EIL was defined as the lowest population density that would cause economic damage, economic damage being the amount of injury that justifies the cost of treatment. The ET was defined as the pest population density at which control measures should be taken to prevent the pest from reaching the EIL (Stern et al.). EIL and ET models have been developed with two different approaches: the entomological and the economic approach (Mumford and Norton). These approaches are summarized in the next two sections.

The Entomological Approach

Under the entomological approach, the EIL is defined as the pest population density where the benefit of treatment just exceeds its cost (Mumford and Norton). Southwood and Norton mathematically described the concept of EIL as occurring when:

$$C \leq \{Y(0)xP\} - \{Y(d)xP\},$$

where C is the cost of making a pesticide application, Y(d) is the yield obtained in a field tolerating a maximum pest population density d, and P is price per unit of product. In the entomological approach, the benefit of the control at a given pest population density (d) is defined as the difference between the gross revenues in a fully protected field {Y(0)*x*P} and the gross revenues in a field tolerating a maximum pest population density d {Y(d)*x*P} (Figure 1a).

Graphically the EIL is located at the "break-even" point where the benefit of the control is equal to the cost of the control (Figure 1b). By definition, the ET is localized at a lower pest density than the EIL. The calculation of the ET requires an exact understanding of the population dynamics in order to determine the highest pest density at which a control action can be implemented to prevent the pest density from reaching the EIL (Pedigo et. al). The following model, which is one of the most commonly used by entomologists, was originally developed to determine the ET for the control *Globodera* spp. in potato crops (Norton):

$$(2)\quad PxDxKx\Theta = C,$$

where P is the price per unit of product, D is the loss in yield per unit of the pest (per unit of sampling), K is the % reduction in pest population density after a pesticide application, Θ is the pest population density (per unit of sampling), and C is the cost of one pesticide application. Thus, $PxDxKx\Theta$ is meant to calculate the benefit of the control, as defined before, and C is the cost of the control. The economic threshold (Θ*), then, is:

$$(3)\quad \Theta^* = C / \{PxDxK\}.$$

Even though some of these variables have been defined somewhat differently in other studies (Pedigo et. al; Mi et. al; Hruska and Rosset), the entomological approach to determining ET's is still based on the general principles laid out by Norton.

The Economic Approach

The economic approach uses the principle of marginality to find the ET that would maximize the net benefits (i.e. the profits) resulting from the pest control action(s) (Mumford and Norton; Ramírez and Saunders). The principle of marginality states that the maximum profits occur when marginal revenue equals marginal cost. In the case of pest management, the maximum profits occur when the additional cost of control required to lower the threshold (i.e. the maximum pest density or level of damage tolerated before making a pesticide application) by one unit equals the extra revenue generated by selling the product saved (Ramírez and Saunders). The last contribution to the ET literature using the economic approach is by Ramirez and Saunders. Their proposed model includes the determination of two basic equations:

$$(4)\quad Y = F(ET),$$
$$(5)\quad X = J(ET),$$

where Y is yield, F(ET) is a function relating yield to the maximum pest density tolerated before making a pesticide application (ET), X is the number of pesticide applications, and J(ET) is a function relating the number of pesticide applications required to the maximum pest density tolerated (ET). F(ET) and J(ET) are usually estimated from experimental data about the yields and number of applications required in field plots that

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have been subject to different ET's throughout the relevant segment of the cropping season, i.e. the segment during which the crop is susceptible to the pest damage.

Even though pesticide application is the only control tactic considered by Ramirez and Saunders, the same method can be used to determine ET's for other pest control tactics. Following Ramirez and Saunders, the optimal economic threshold ET* is found by maximizing the following profit function with respect to ET:

$$(6)\quad \pi(ET) = RGR - CSC = [\{P x Y\} - FOVC] - [\{C x X\} + SC] = [\{P x F(ET)\} - FOVC] - [\{C x J(ET)\} + SC],$$

where RGR stands for residual gross revenues, CSC for costs of sampling and control, P is the price per unit of product, FOVC represents the fixed cost of production and other variable costs not related to boll weevil control, C is the cost per pesticide application, and SC is the sampling costs. Thus π(ET) is a function estimating the profits that would be likely obtained when using different ET's. The model permits the use of different functional forms for F(ET) and J(ET), and considers the costs and benefits of the control throughout the relevant segment of the cropping season (Figure 2).

Economic Thresholds for Boll Weevil Control

Even though the ET concept was not formally proposed in the entomological literature until the late 1950's, the use of thresholds for boll weevil control dates back to the 1920's (Bottrell and Adkinson). In 1920, Coad and Cassidy explained that "the majority of the poisoning operations in the past have been planned so as to start when about 15 to 20 percent of the squares were punctured and then to repeat often enough to prevent the infestation from getting above 25 percent." It is clear that these percentages referred to what were later defined as economic thresholds. From 1920 to 1940, the recommendation of using a percentage of damage squares, specifically between 10 and 15 percent, to decide when to start the application of insecticides against the weevil is widely cited in the literature (Isely and Boerg; Robinson; Sanborn; Robinson and Arant; Young, 1934; Young, 1935; Young and Smith).

The effect of different insecticide schedules for boll weevil control was of special interest from the 40s to the 60s. Trials were conducted over a period of 2 or more years with treatments including early season applications to control overwintered weevils, and late season applications for later generations (Young, Garrison and Gaines; Gaines and Wipprech, 1948; Gaines and Wipprech, 1950; Gaines, Owen and Wiprecht; Parencia and Ewing; Hanna and Gaines; Hanna and Mistric, Watson and Sconyers).

The objective of these experiments was to determine the minimum number of applications required to hold the insect population at a level that would not reduce yields, without considering the costs of reaching that goal. Although in some experiments damaged squares between 40% and 60% did not significantly reduced yields (Gaines, Owen and Wiprecht; Lincoln and Leigh; Mistric and Covington), maximum yields were generally achieved by tolerating no more than 25% of damaged squares (Young, Garrison and Gaines; Hanna and Mistric; Lincoln and Leigh; Watson and Sconyers).

During the same period, the effect of boll weevil damage on yield was also investigated using artificial methods of infestation (Lloyd, Merkl and Crowe) and the manual removal of squares (Hamner; Mistric and Covington). These experiments resulted in a better understanding of the mechanisms of compensation to loss squares, but the data were not used to identify the relationship between the different levels of damage and final cotton yield. Instead, researchers focused on determining the maximum % of loss squares that would not have a negative effect on yields.

During the 70s and 80s, two different economic thresholds began to be cited in the literature: one for the overwintered boll weevil populations, and another for the mid to late weevil infestations. A trap system was developed to predict the need to apply insecticides for overwintered weevils (Texas High Plains Boll Weevil Task Force, Benedict et al.). The same ET's of between 10% to 30% continued being recommended to control mid to late season boll weevil infestations.

A revision of the 1998-2000 recommendations by Cooperative Extension Services throughout the U.S. shows that the ET's currently used are within this same range. Some of the Cooperative Extension Services (i.e. Texas and New Mexico) recommend different thresholds prior to peak bloom than after peak bloom. Our review of literature indicates that current EIL-ET recommendations are best estimates based on producer, research, and extension experience. However, these recommendations have not been determined utilizing the methods proposed by entomologists or economists.

Data, Methods and Procedures

The Experiment

The experiment focused on boll weevil control in the Texas High Plains during the nine weeks of the segment known as the "mid-to-late" cotton-growing season. This period starts with the appearance of one-third grown squares and ends at the early stages of boll maturation. The experiment, conducted in Lubbock County during 1999, consisted of twenty plots of eight rows (40" center wide and 50' long) randomly established in each of four blocks. One application of Vydate C-L (Oxamyl) at a rate of six oz/acre was made to the entire experiment to control overwintered weevils, as soon as trap counts exceeded two boll weevils per week (Texas High Plains Boll Weevil Task Force).

The treatments were three pre-established economic thresholds of 10%, 20%, and 30% of damaged squares, a minimum damage treatment with nine weekly applications, and a control without mid-to-late season insecticide applications. Boll weevil infestations were monitored by examining 50 one-third grown squares per plot and recording the percentage of squares injured by boll weevils each week. In the case of the three ET treatments, once a plot reached the pre-established ET, insecticide applications were made weekly until the end of the mid-to-late season.

Determination of the Optimal Economic Threshold

Equations (4) and (5), which predict the yields and the number of applications required under different possible economic thresholds, were estimated using the data from the experiment described above and suitable statistical procedures (Carpio et al., 2001). The profit function {equation (6)}, was then put together using the estimates of equations (4) and (5) and the required cotton price and production cost information.

The optimal economic threshold was determined by finding the ET value that maximized the profit function {equation (6)} under 1998-1999 cotton lint and seed prices, scouting and insecticide application costs, and other variable costs (Texas Agricultural Extension Service). Following standard practice, seed yields were assumed to be a fixed 176% of cotton lint yields (Texas Agricultural Extension Service). The average price paid for cotton lint in the Texas-Oklahoma marketing region during the 1999-2000 marketing year was 37.82 cents/lb (Nelson et al.). Therefore, the minimum loan deficiency payment program price of 50 cents/lb was used for the analysis.

The sensitivity of the optimal ET with respect to changes in prices and costs was evaluated. Sensitivity analyses with respect to model estimation uncertainty were also conducted using 90% confidence intervals for the predictions from the estimated yield and cost of control models (Carpio et al., 2001).

Results and Discussion

A linear model best describes the relationship between the ET utilized and the cotton yields obtained {equation (4)} (Carpio et al., 2001). This model includes an intercept (β_0), two intercept shifters (β_1 and β_2) accounting for differences in yields due to the replicates in the experiment, and a slope parameter (β_3). The slope parameter estimate suggests a yield loss of 5.13 units (e.g. pounds of lint per acre) for each one unit (e.g. 1%) increase in the pre-established ET. A specialized Tobit model best describes the relationship between the ET utilized and the number of applications required to maintain that ET {equation (5)} (Carpio et al., 2001).

The residual gross revenues (RGR) and the costs of sampling and control (CSC) relations implied by these two models are depicted in Figure 3. Because of the low cotton price of $0.50/lb used in the baseline analysis, the estimated residual gross revenues turned out to be considerable negative at all ET values. Thus, the fixed costs ($168.45/acre) were added back to the RGR depicted in Figure 3 to facilitate the discussion. This results in a parallel shift of the RGR function and, therefore, it does not affect the determination of the profit-maximizing ET. The profit function (RGR(ET)-CSC(ET)) in Figure 4, however, is to be interpreted as estimating the profits in excess of variable costs only.

Since the estimated relation between yields and the % of damaged squares (e.g. the ET's) is linear, the relation between the RGR and the ET's is also linear. The model predicts that one percent increase in the ET reduces the RGR by $ 3.06 per acre. As the ET increases, the CSC decreases at a decreasing rate, since less insecticide applications are needed under higher pre-established ET's.

The maximum profits clearly occur at the ET where the difference between the RGR and the CSC equations is greatest, e.g. at the ET where the profit function (Figure 4) reaches a maximum value. Figures 3 and 4 illustrate the biological and economic relations involved in the determination of the profit maximizing ET. At a 0% ET, the profits are the same ($29.2/acre) as at ET=16%. At a 0% ET, less-than-maximum profits are obtained because, even though most insect damage is avoided through the continuous application of insecticides, the costs of control are very high. At a 16% ET, a much greater level of insect damage is compensated by substantially lower costs of control.

At the profit maximizing ET of 7%, a moderate 4.4 insecticide applications (CSC=$35.4/acre) would be needed, on average, compared with 9 applications (CSC=$72.8/acre) at a 0% and 2.9 applications ($23.5/acre) at 16%; while a yield loss of 42.8 lbs/acre (equivalent to a $21.4/acre gross revenue loss) would be tolerated, on average, compared with a zero (baseline) yield loss at 0% and a 106.2 lbs/acre yield loss (equivalent to a $53.1/acre gross revenue loss) at 16%.

The confidence intervals for the estimated profit equation (Figure 4) take into account model estimation uncertainty, e.g. the uncertainty about the yields and costs of control that should be expected under different ET's. These confidence intervals support the conclusion that the profit maximizing ET is between 5 and 9%. When using an ET within this range, profits are predicted to average $45/acre, and to be between -$15 and $108/acre with a 95% level of certainty. Weekly pesticide applications, or a higher ET of 16%, are predicted to results in average profits of $29.5/acre ranging from -$29 to $89/acre.

At the currently recommended ET of 25% for the Texas High Plains, the models predict average profits of $8/acre, ranging from -$62 to $80/acre. This means that, at a price of $0.50/lb, farmers using the currently recommended ET would barely cover their variable costs of production, on average, and could incur substantial losses.

The differences in the profits expected under alternative ET's are substantial in comparison to the total costs of producing irrigated cotton in the Texas High Plains, which average $500/acre ($330/acre total variable and $170/acre total fixed costs). This attests to the importance of establishing and using the profit maximizing ET. Table 1 contains the profit maximizing ET's and the corresponding average profits and profit ranges predicted by the models given alternative cotton price and per-application cost scenarios, as well as the expected profits and profit margins under weekly insecticide applications and the currently recommended 25% ET.

Table 1 suggests that the profit-maximizing ET is not very sensitive to changes in cotton prices or per application costs. At the average cost of $8 per insecticide application, only at fairly high prices ($0.80/lb) does it become economically justified to use a lower ET of 1%, which implies an average of seven applications per season. On the other hand, even at the lowest cotton price of $0.40/lb and the highest per application cost of $10, the profit maximizing ET does not exceed 8%. The expected profits and profit ranges, however, are substantially affected by cotton price. At the average insecticide application cost and at a cotton price of $0.70/lb, for example, expected profits increase to $183.01/acre, which is enough to cover the $170/acre fixed costs that had been left out of the profit calculations. Under the currently recommended ET of 25%, however, expected profits would drop to $127.38/acre. Table 1 clearly shows that the choice of ET would make a substantial difference on the profitability of the farm operation in this case.

Finally, it is important to understand that the former ET recommendations are for the cotton-growing period considered in the experiment (mid-to-late season), and contingent on the efficacy of the insecticides used to control the boll weevil in this case. More importantly, they could change if the intensity of boll weevil attack were different from what was observed in Lubbock County during the 1999 season. A substantially different intensity of pest attack could alter the shape and location of the RGR and CSC curves and, thus, of the profit function, and affect the optimal ET recommendation.

Implications for the Boll Weevil Eradication Program

In November 2000 farmers in the Texas High Plains voted in a referendum in favor to carry out Boll Weevil Eradication Programs during the next five years, at an annual cost of $12 per acre of irrigated cotton and $6 per acre of dry-land cotton. Assuming that the 1999 population dynamics in Lubbock County are representative of the average severity of boll weevil attack in this region, and that the program will completely eliminate the weevil after five years, the estimated models indicate that acceptance of the program was an economically sound decision.

If, for example, a farmer borrows the money to pay for the program at a 10% interest rate, he would have to make a balloon payment of $61.05 to cover the principal and interest due on the loan by the end of the fifth year. The residual gross revenues predicted by the model at ET=0 are $102.0/acre-year, versus $80.6/acre-year at the profit maximizing ET of 7%, which costs $35.4/acre-year to maintain, on average. Thus, at current cotton prices and insecticide costs, the program is predicted to increase a typical farmer's net revenues by $102.0-($80.6-$35.4) = $56.8/acre-year once the bowl weevil has been completely eradicated.

Thus, the per-acre cost of the program would be nearly recovered just one year after completion. An added economic benefit on the program not considered above, is that it would gradually reduce bowl weevil populations from the start, lowering control costs and increasing yields before throughout its five-year duration. Also, the economic benefits of the program with respect to the currently recommended ET of 25% would be even larger.

Conclusions and Recommendations

In regards to the control of the cotton boll weevil, we conclude that current EIL-ET recommendations by Cooperative Extension Services throughout the U.S. are best estimates based on producer, research and extension experience, not on the more formal methods proposed by entomologist or economists. Using recently proposed methods, we conclude that the profit maximizing ET for the control of the boll weevil in irrigated cotton production in the Texas High Plains is 7% of damaged squares, which is below the 20-30% currently recommended (Texas High Plains Boll Weevil Task Force).

The difference in the expected profits and profit ranges under the profit maximizing and the currently recommended ET's is substantial. This highlights the potential importance of establishing and using profit maximizing ET's for controlling the boll weevil in the Texas High Plains and other cotton producing areas of the U.S. The study also shows that, under the boll weevil population/damage dynamics observed in Lubbock County during the 1999 season, the profit-maximizing ET is not very sensitive to changes in cotton prices or insecticide application costs. The profit maximizing ET, however, could be quite sensitive to differences in the population/damage dynamics, e.g. in the severity of pest attack. Since the severity of boll weevil infestations varies from year to year, we recommend repeating this experiment during various cotton growing seasons to gain a better understanding of the variation in the profit maximizing ET due to changes in the population/damage dynamics.

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References

Benedict, J.H., K.M. El-Zik, L.r. Oliver, P.A. Roberts, and L.T. Wilson. Economic Injury Levels and Thresholds for Pests of Cotton. Integrated Pest Management Systems and Cotton Production. Raymond E. Frisbie,

Kamal M. El-Zik, and L. Ted Wilson, ed., pp. 121-153. New York: Wiley-Interscience Publication, 1989.

Bottrell, D.G., and P.L. Adkisson. Cotton Insect Pest Management. Ann. Rev. Entomol. 22 (1977): 451-481.

Breen, R. Regression Models: Censored, Sample Selected, or Truncated Data. Sage University Paper series on Quantitative Applications in the Social Sciences, series no. 07-111. Thousand Oaks, CA: Sage, 1996.

Brown, J.E., and D.E. Ethridge. Functional Form Model Specification: An Application to Hedonic Pricing. Ag. and Res. Econ. Review, Oct.,1995.

Carpio, C.E.,O.A. Ramirez and S. Armstrong. Profit Maximizing Economic Thresholds for the Cotton Boll Weevil in the Texas High Plains. Paper presented in the annual meetings of the Southern Agricultural Economics Association, Fort Worth, Texas, January 28-31 2001.

Coad, B.R., and T.P. Cassidy. Cotton Boll Weevil Control by the Use of Poison. Washington DC: U.S. Department of Agriculture, Bull. No. 875, July 1920.

Gaines, J.C., W.L. Owen, and R. Wipprecht. Effect of Dusting Schedules on the yield of Cotton. J. Econ. Entomol. 40(1947):113-115.

Gaines, J.C., and R. Wipprecht. Effect of Dusting Schedules on the yield of Cotton During 1947. J. Econ. Entomol. 41(1948): 410-412.

Gaines, J.C., and R. Wipprecht. Evaluation of Dusting and Spraying Schedules for Cotton Insect Control. J. Econ. Entomol. 43(1950): 286-288.

Hamner, A.L. The Effect of Boll Weevil Infestation at Different Levels on Cotton Yield. Mississippi State College Agr. Exp. Sta. Bull. No. 389, June 1943.

Hanna, R.L., and W.J. Mistric. Effect of Different Treatment Schedules for Control of Cotton Insects. J. Econ. Entomol. 46(1953): 641-644.

Hanna, R.L., and J.C. Gaines. Evaluation of Dusting Schedules for Control of Cotton Insects. J. Econ. Entomol. 45(1952): 549-550.

Hruska, A.J., and P.M. Rosset. Estimación de los Niveles de Daño Económico para Plagas Insectiles. Manejo Integrado de Plagas. 5(1987): 30-44.

Isely, D., and W.J. Baerg. The Boll Weevil Problem in Arkansas. University of Arkansas. Agr. Exp. Sta. Bull. No. 190, January 1924.

King, G. Unifying Political Methodology: The Likelihood Theory of Statistical Inference. New York: Cambridge University Press, 1989.

Krinsky, I., and A.L. Robb (1986). On approximating the statistical properties of elasticities. Rev. Econ. and Statist. 68(1986): 715-719.

Leser, J.F., and R.K. Haldenby. The Boll Weevil Problem on the High Plains of Texas and eastern New Mexico. Proceedings of the 1999 Beltwide Cotton Conferences. pp. 828-831, Orlando-FL, January 1999.

Lincoln, C., and T.F. Leigh. Timing Insecticide Applications for Cotton Insect Control. University of Arkansas, Ag. Exp. Sta. Bull. No. 588, May 1957.

Lloyd, E.P., M.E. Merkl, and G.B. Crowe. The Effect of Boll Weevil Infestations on Yield and Quality of Cotton. J. Econ. Entomol. 55(1962): 225-227.

Maddala, G.S. Limited Dependent and Qualitative Variables in Econometrics. New York: Cambridge University Press, 1983.

Mistric, W.J., and B.M. Covington. Effect of Square Removal on Cotton Production with Reference to Boll Weevil Damage. J. Econ. Entomol. 61(1968): 1060-1066.

Mi, S., D.M. Danforth, N.P. Tugwell, and M.J. Cohran. Plant-Based Injury Level for Assessing Economic Thresholds in Early Season Cotton. The Journal of Cotton Science. 2(1998): 35-52.

Mumford, J.D., and G.A. Norton. Economics of Decision Making in Pest Management." Ann. Rev. Entomol. 29(1984): 157-174.

Nelson J., K. Hoelscher, S. Misra , and D. Ethridge. Texas-Oklahoma Producer Cotton Market Summmary: 1999-2000. Dept. of Agr. and Appl. Econ., Texas Tech University, CER-00-16, September 2000.

Neter, J., M.H. Kutner, C.J. Nachtsheim,and W. Wasserman. Applied Linear Regression Models. Third edition. Irwin/McGraw-Hill, U.S.A., 1996.

Norton, G.A. Analysis of Decision Making in Crop Protection. Agroecosystems. 3(1976):27-44.

Parencia, C.R., and K.P. Ewing. Comparison of Early-Season, Late-Season, and a Combination of Early-Season Plus Late-Season Insecticide Applications for Cotton Insect Control. J. Econ. Entomol. 43(1950): 596-598.

Pedigo, L.P., S.H. Hutchins, and L.G. Higley. Economic Injury Levels in Theory and Practice. Ann. Rev. Entomol. 31(1986): 341-368.

Ramírez, O.A., and J.L. Saunders. Estimating Thresholds for Pest Control: an Alternative Procedure. J. Econ. Entomol. 92(1999): 391-401.

Ramírez, O.A., and S.D.Shultz. Poisson Count Models to Explain the Adoption of Agricultural and Natural Resource Management Technologies by Small Farmers in Central America Countries. J. of Agr. and Appl. Econ. 32(2000): 21-33.

Robinson, J.M. Dusting Cotton with Calcium Arsenate for Boll Weevil Control. Ala. P.I. Agr. Exp. Sta. Circ. No. 51, May 1926.

Robinson, J.M., and F. S. Arant. Eight Years of Experimental Work in Boll Weevil Control on Plots Receiving Different Rates of Fertilizer. J. Econ. Entomol. 25(1934):759-766.

Sanborn, C.E. Boll Weevil in Oklahoma. Oklahoma Agr. Expt. Sta. Bull. No. 157, February 1926.

Southwood, T.R.E., and Norton, G.A. Economic Aspects of Pest Management Strategies and Decisions. Insects: Studies in Population Management.

P.W. Geir, L.R. Clark, D.J. Anderson, H.A. Nix, ed., pp168-184. Camberra: Ecol. Soc. Aust. 1973.

Stern, V.M., Smith, R.F., van den Bosch, R.,Hagen,K.S. The Integrated Control Concept. Hilgardia 29(1959):81-101.

Texas High Plains Boll Weevil Task Force. Boll Weevil Management in TheTexas High Plains, Entomology Fact Sheet. April 1998.

Watson, T.F., and M.C. Sconyers. Comparison of Insecticide Application Schedules for Control of Cotton Insects.. J. Econ. Entomol. 58(1965):1124-1127.

Williams, R.M. Cotton Insect Losses 1998. Proceedings of the 1999 Beltwide Cotton Conferences. pp. 785-806, Orlando-FL, January 1999.

Young, M.T., G.L. Garrison, and R.C. Gaines. Experiments on Time to Begin Dusting with Calcium Arsenate and Number of Applications for Boll Weevil Control. J. Econ. Entomol. 35(1942):484-486.

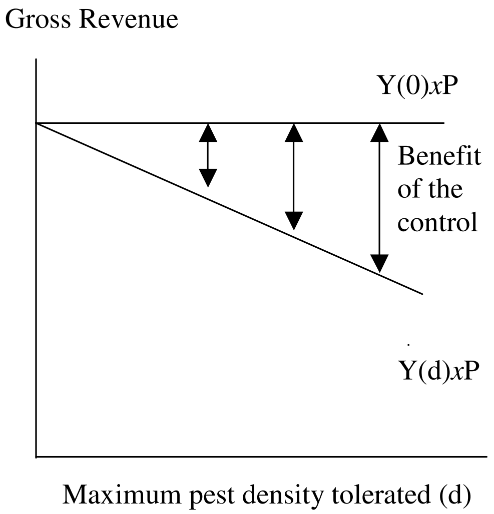
Young, M.T., and G.L. Smith. Field-plot and Cage Tests for Boll Weevil Control. J. Econ. Entomol. 29(1936):105-111.

Young, M.T. Field-plot Tests for Boll Weevil Control at Tallulah, Lousiana, during 1933. J. Econ. Entomol. 27(1934):749-756.

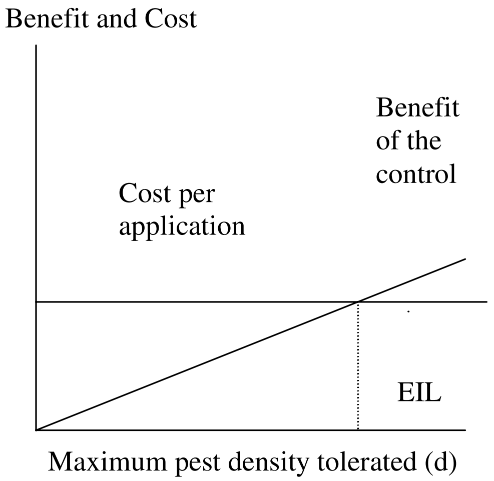
Young, M.T. Boll Weevil Control with Calcium Arsenate on Field Plots in Madison, Parish, Louisiana from 1920 to 1934. Washington DC: U.S. Department of Agriculture, Tech. Bull. No. 487, October 1935.

Table 1. Expected, maximum and minimum profits predicted by the models under the profit-maximizing (Pmax) ET and alternatives ET's of zero and 25% and several cotton price–application cost scenarios.

		0%	**Pmax ET**	**25%**
Cotton Lint Prices($/lb)		**Per Application Costs of $6/acre**		
0.40	Expected Profit	-24.87	-14.95 (7%)	-47.14
	Maximum Profit	23.13	33.54	11.24
	Minimum Profit	-72.88	-64.40	-105.46
0.50	Expected Profit	47.56	54.12 (6%)	12.46
	Maximum Profit	105.23	112.96	82.39
	Minimum Profit	-10.11	-6.82	-57.41
0.60	Expected Profit	119.99	123.48 (6%)	72.06
	Maximum Profit	187.32	191.46	153.54
	Minimum Profit	52.65	53.38	-9.36
0.70	Expected Profit	192.42	197.37 (1%)	131.66
	Maximum Profit	269.42	274.66	224.69
	Minimum Profit	115.42	120.25	38.70
0.80	Expected Profit	264.85	269.28 (1%)	191.26
	Maximum Profit	351.52	356.12	295.84
	Minimum Profit	178.18	182.63	86.75
		Per Application Costs of $8/acre		
0.40	Expected Profit	-43.01	-23.82 (7%)	-51.43
	Maximum Profit	4.94	25.74	7.29
	Minimum Profit	-91.07	-74.66	-110.07
0.50	Expected Profit	29.37	45.02 (7%)	8.17
	Maximum Profit	87.03	103.70	78.45
	Minimum Profit	-28.30	-14.95	-62.02
0.60	Expected Profit	101.8	113.86 (7%)	67.78
	Maximum Profit	169.13	181.66	149.60
	Minimum Profit	34.46	44.77	-13.97
0.70	Expected Profit	174.25	183.01 (6%)	127.38
	Maximum Profit	251.22	261.57	220.75
	Minimum Profit	97.22	101.62	34.09
0.80	Expected Profit	246.66	254.12 (1%)	186.98
	Maximum Profit	333.33	341.40	291.90
	Minimum Profit	159.99	167.09	82.14
		Per Application Costs of $10/acre		
0.40	Expected Profit	-61.26	-32.22 (8%)	-55.71
	Maximum Profit	-13.25	17.58	3.35
	Minimum Profit	-109.26	-82.82	-114.68
0.50	Expected Profit	11.18	36.15 (7%)	3.89
	Maximum Profit	68.84	95.90	74.50
	Minimum Profit	-46.49	-25.22	-66.63
0.60	Expected Profit	83.61	104.99 (7%)	63.49
	Maximum Profit	150.94	173.86	145.66
	Minimum Profit	16.27	34.50	-18.57
0.70	Expected Profit	156.04	173.82 (7%)	123.09
	Maximum Profit	233.04	251.82	216.81
	Minimum Profit	79.04	94.22	29.48
0.80	Expected Profit	228.47	242.66 (7%)	182.69
	Maximum Profit	315.13	329.78	287.96
	Minimum Profit	141.80	153.94	77.53



(a) Gross Revenues



(b) Economic Injury Level

Figure 1. Graphic Illustrator of the EIL under the Entomological Approach.

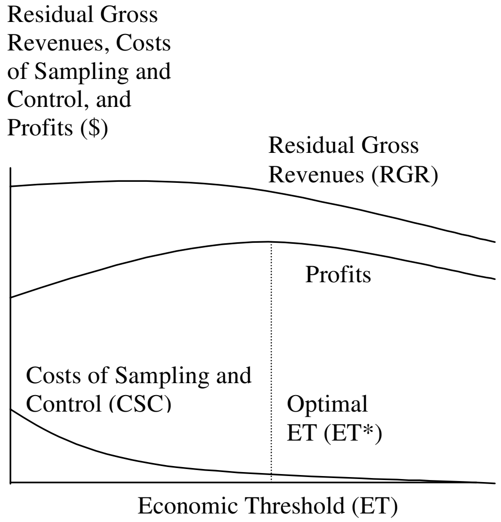


Figure 2. Graphic Illustration of the ET under the Economic Approach.

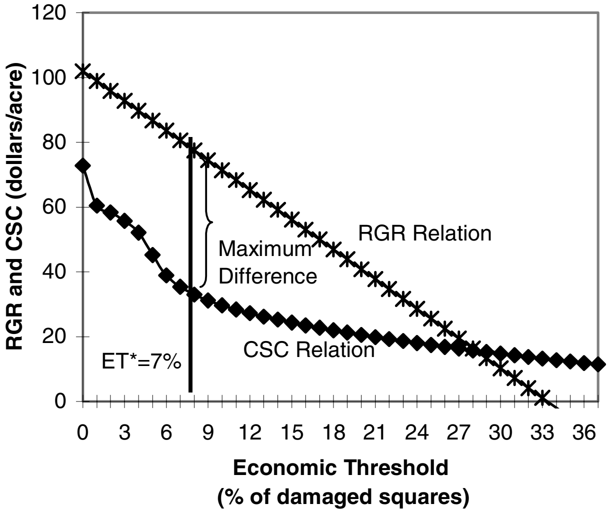


Figure 3. Estimated Residual Gross Revenue (RGR) and Costs of Sampling and Control (CSC) Relations.

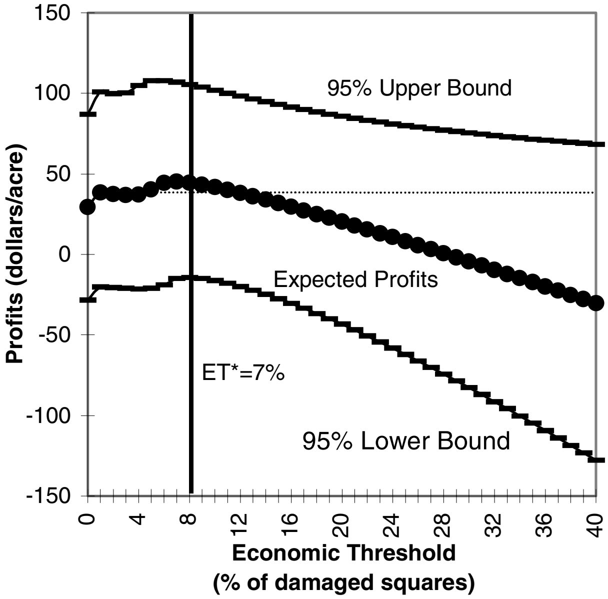


Figure 4. Estimated Profit Equation and its 95% Confidence Interval.