A PRACTICAL PLANT-BASED ECONOMIC INJURY LEVEL FOR EARLY-SEASON COTTON INSECT MANAGEMENT

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Abstract

Early-season cotton insect management faces the challenge to balance the advantages of earliness with the desire to rely more on cotton's compensatory capability and to maintain natural enemies. Balancing management options is further complicated by such factors as costs of damage, induced delays, aggregate effect of multiple pest species at sub-threshold densities, price of insecticides and crop value. Conventional economic injury level (EIL) fails to capture the insect population dynamics and the compensatory nature of cotton. Farmers who use economic threshold (ET) to initiate insect control decisions find it hard and impractical to relate ET with EIL. In this paper, a plant-based EIL is developed to calculate a break-even injury level (square shed frequency) up to first flower to validate an ET. It incorporates control costs, crop value, dynamic plant-monitoring results and cotton's compensation capacity into the calculation. Producers can compare the actual shed rate at any time prior to first flower with the calculated EIL to determine the effectiveness of an ET, and whether an adjustment on current insect control tactics is needed. The EIL model has been incorporated into the COTMAN computer program to facilitate implementation by users.

Introduction

It has long been observed that the cotton plant has the potential for tolerance and/or compensation for early fruit loss, depending upon the subsequent management and environmental growing conditions. Previous studies showed that early-season square loss under certain levels rarely had a negative effect on cotton yields due to the plant's compensation ability (Kletter & Wallach, 1982; Terry, 1992; Montez & Goodell, 1994; Holman, 1996), and thus less intensive insect control for injury under these levels could be recommended. However, square loss could cause maturity delay, exposing the growers to a higher probability of adverse weather occurring before harvest completion and a higher cost for managing late-season insect infestations (Eaton, 1931; Munro, 1971; Bagwell & Tugwell, 1992; Cochran, et al. 1994; Sadras, 1994). Therefore, to balance the benefits and costs of a pest control decision becomes even more complicated in cotton production.

Two basic components of decision rules in pest management are the economic injury level (EIL) and the economic threshold (ET). The EIL is defined as the lowest population density that will cause economic damage. Economic damage is the amount of injury which will justify the cost of artificial control measures. The ET is defined as the density at which control measures should be initiated to prevent an increasing pest population from reaching the EIL (Stern et al., 1959). Cotton growers often use ETs to initiate control actions. Most of the ETs are based on insect populations, farmer and applicator schedules, weather, equipment, farm size, intuition and any number of such specific factors that the EIL model usually does not reflect. Originally designed to be used in conjunction, the ET and the EIL are not well associated with each other in practical terms.

For example, a grower who knows about compensation and natural enemies is willing to withhold one or two applications of insecticide and let natural processes control the situation. This tactic represents the application of integrated pest management (IPM) practices. Yet the farmer suffers from the lack of assurance from the EIL rules that this delay in use of insecticide did not cause economic damage. Another example is in the case of transgenic cottons from which we usually anticipate better insect control. It is known that newly hatched larvae must consume some Bt plant material before mortality can occur. Therefore, conventional ET criteria such as the egg counts are more difficult to follow. There is an increased need for constant reassurance that pests are not causing economic damage. The same need exists with other IPM tactics which kill well, but slowly. The mere presence of live pests in a field that has been treated, even when the insects are sick and non-feeding, is enough to require some kind of reassurance of the effectiveness of the tactics. Again, the dilemma is apparent: the ET lacks economic guidance and assurance from an EIL.

A practical plant-based EIL is developed to facilitate the use of an EIL to judge the success of an ET. Based on the same economics of the conventional EIL model, the new EIL improves the practicality of the mechanisms by allowing dynamic evaluation of plant responses to multiple pest situations and multiple stresses. The model derives the break-even injury level by utilizing real-time data on cotton growth status, i.e., actual nodal development and shed rates at different growth stages. Other information such as projected crop values and costs are provided by growers and are incorporated into the model as well. The break-even injury level is used to derive a shed rate limit against which the growers can compare the actual shed rate. Injury level above the limit indicates that the ET was inadequate to prevent an increasing infestation from causing economic damage and vice versa.

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The plant-based EIL calculation requires data collection and complicated calculations in order to achieve the goal of dynamic evaluation of ETs. Modern technology helps us expedite the calculation by including the model in a computer program. We have implemented the EIL model in the COTMAN (COTton MANagement) expert system computer software (Bourland et al., 1994; Zhang et al., 1994). In 1997, there were 170 registered users in nine states covering over 250,000 acres. Broader use is expected in 1998. COTMAN is comprised of two parts: the SQUAREMAN component is used from first square to first flower; and the BOLLMAN component is used after first flower. The COTMAN system uses plant monitoring to adjust crop management based upon plant response to pests and environment. Data collection involves monitoring plants in each field once or twice a week. Before first flower, 40-80 plants per field are mapped, with first-position squares recorded as retained or shed. These data are then used to calculate the number of squaring nodes and the square shed rates that are used in the model to capture the dynamics of pest activity. Producers are asked to input values for most of the other variables in the model, such as projected crop values and costs, etc. Combining all the information, COTMAN calculates the plant-based EIL and the results are presented in tables and graphs. A bar graph compares the actual shed rate for a field with the shed rate limit calculated from the model for the producer to promptly assess the effectiveness of a previous ET.

A Conventional Insect-Based EIL Model

Formal models have been developed to address the economic aspects of decision-making in pest management. They utilized the EIL concept in a mathematical framework, assessing the trade-off between economic benefits and costs of control actions. A commonly cited model was presented by Norton (1976). The model was developed to solve the decision problem concerning the control of potato cyst eelworm by the nematicide DD and was expressed as the following:

$$\underset{\text{(benefit of control)}}{PDK\theta} = \underset{\text{(cost of control)}}{C} \quad (1)$$

where: P = price of potatoes per tonne; D = the loss in potato yield (tonnes per hectare) associated with one egg per gram of soil; K = reduction in pest attack achieved by DD; θ = level of pest attack (eggs per gram of soil); and C = cost of applying DD per hectare.

The EIL (θ*) which is also the break-even pest density is then calculated as:

$$\theta^* = C / PDK \quad (2)$$

The mathematics involved in the model are simple and straightforward. Here we discuss the calculations to illustrate the break-even concept of the EIL. The following equations are two net revenue functions which calculate net revenues under options of treatment and no treatment, respectively:

$$Net\ Revenue\ (treatment) = Gross\ Revenue - C - PD\theta(1-K) \quad (3)$$

$$Net\ Revenue\ (no\ treatment) = Gross\ Revenue - PD\theta \quad (4)$$

Equation (3) shows that the decision of treatment incurs the cost of insecticide C. By treatment, pest density θ will be reduced by K percent, and at the end of the season there will be a pest density of $\theta(1\text{-}K)$ surviving in the fields which will then cause $D\theta(1\text{-}K)$ as the yield loss. Net revenue in this case is equal to gross revenue minus cost associated with treatment, C, and yield loss, $D\theta(1\text{-}K)$. In equation (4) the decision of no treatment will result in all pests surviving and cause $D\theta$ as the yield loss. Since at θ* (the break-even pest density) the net revenues of a decision to treat and not to treat are equal, we can equate (3) and (4) producing:

$$Gross\ Revenue - C - PD\theta(1-K) = Gross\ Revenue - PD\theta \quad (5)$$

Independent of the insect control decisions, gross revenue always refers to the value of an ideal yield potential. Yield loss is regarded as a cost ($PD\theta$) in addition to the control cost (C). The same concept is used in our plant-based EIL model. Therefore, equations (3) and (4) share the same gross revenue. It is only the cost factor that causes the two net revenues to differ. Equation (5) can then be transformed to equation (1) and the break-even pest density θ* can be calculated (equation 2). The EIL, represented by pest attack or pest density, is located at the break-even point where net revenues under the two alternative courses of action, treatment and no treatment, are equivalent. Pest population densities lower than this point lead to the economic decision of no treatment as higher net revenue is realized than with treatment. Conversely, it will be economical to treat at pest densities greater than the EIL level.

The New Plant-Based EIL Model

The plant-based EIL model utilizes the same economic principles as the Norton (1976) model, but incorporates more information. The model uses control costs, crop value, dynamic plant-monitoring results and cotton's compensation capacity for early-season square loss to calculate a break-even injury level for first flower. The basics of the model are described in this paper. A more formal and technical presentation of the model is provided by Mi et al. (1998).

First, field monitoring data on nodal development and first-position square loss are used to calculate changes in square sheds relative to new nodal growth. These change rates are used to anticipate future loss in order to capture dynamics in plant injury related to multiple pests. We call this variable

A (insect activity, as represented by per node shed change). The formula for the calculation of *A* is as follows:

$$A = \frac{X2*Y2 - X1*Y1}{X2 - X1} \qquad (6)$$

where: *A* = square shed change per additional squaring node since the previous sampling date; *X2* = actual squaring node number on sampling date 2; *Y2* = first position square shed rate on sampling date 2; *X1* = actual squaring node number on sampling date 1; and *Y1* = first position square shed rate on sampling date 1.

The plant-monitoring variables *X1*, *X2*, *Y1* and *Y2* are regularly collected as part of the early-season COTMAN component, SQUAREMAN. Two examples are presented in Table 1 to illustrate the calculation of *A*, per node shed change. In example 1, *A* is reasonably small. It indicates an increase of only 0.10 square sheds per additional squaring node since the first data collection date. In example 2, the value for *A* is very high. It indicates that for each new squaring node since the first data collection date, 1.08 squares were shed. Therefore, the cotton crop is losing more squares than it is gaining squaring nodes.

One assumption the new EIL model makes about *A* is that immediate control action will be effective enough to prevent future square loss up to first flower. Another assumption is that the no control decision will result in continuation of the pest activity, causing future square loss at the same rate as the current one. In practical terms, the assumptions are that the injury will either be arrested at the current level or will continue to increase at the same rate during the short time-span from the current sampling date until the next data collection date. Therefore, in evaluating these assumptions, it is important to bear in mind the fact that this model is dynamic and a new trend of pest activity will always be assessed in the updated calculation of *A*. However, it is also important to consider any recent control actions in relation to the sampling dates used to calculate *A*. Whether *A* captures the last action triggered by an ET is important when making an interpretation of the recent changes in square injury. The two assumptions about *A* allow the derivation of two possible shed rates at first flower, one for the option of treatment (arrested pest activity) and one for the option of no treatment (continued pest activity). Those two shed rates are then used to assess net revenues under each treatment option and allow the calculation of a break-even shed rate or plant-based EIL. Therefore, the variable *A*, based on field-monitoring data, plays a large role in the model.

The new plant-based EIL model also considers other variables. The following is a brief introduction of each variable:

R represents the recovery or compensation capacity of the plant for square loss that does not affect yield. Holman (1996) estimated that square loss lower than 19% before first flower did not have an adverse effect on yield, while Johnson and Jones (1996) use 25% and Gutierrez et al. (1981) use 30% as compensation estimates. COTMAN users may provide the square loss compensation percent they are willing to accept.

T represents average total sympodial (squaring) nodes expected in the field at first flower. Total nodes at first flower is very important because it provides the end-point for projection of *A*. The lower the total nodes, *T*, the closer the observed nodes are to the total expected at first flower. Hence there exists a lower ability for plants to compensate for continued loss. The COTMAN target development curve defines 10.25 as the total sympodial nodes (9.25 nodes-above-first-square) expected at first flower (Bourland et al., 1992). Within COTMAN this value can be user supplied based on production history and/or current field observations.

M represents maturity delay in days/acre. While we recognize the plant's ability to compensate for square loss, we also realize that square loss can result in maturity delay which can put the crop at risk for late-season insect pressure. Holman (1996) estimated that for every 1% square loss, maturity was delayed by 0.1818 days/acre. This estimate is used in COTMAN.

P represents late-season insect protection cost ($/acre/day). When the crop is delayed due to plant injury, the late-season protection cost will likely be increased. *P* is the cost for insect control necessary to protect a delayed crop from late-season insect pressure. Estimates in Arkansas were $0.63/acre/day in the northeast region, $1.15/acre/day in the east-central region, and $2.00/acre/day in the southeast region (King et al., 1996). COTMAN users can provide a value based either on one of the above estimates or on production records.

D represents the damage or percent loss of yield that can occur if square loss exceeds the plant's compensation capacity, *R*. When shed rate at first flower is estimated to be above *R*, yield loss to sheds above *R* is considered as a cost. Holman (1996) provided data that allowed us to compute a 0.97% yield loss for each percent shed above *R*. This estimate is used in COTMAN.

Y represents total yield potential (lb./acre) of the field. The field history as well as current observations should allow the COTMAN user to provide a realistic target value. The amount of yield loss associated with plant injury above compensation capacity, and therefore the value of yield loss, is naturally related to the total yield potential.

V represents value of lint yield ($/acre). The price of cotton is used to calculate the cost of yield loss associated with square shed above compensation capacity, R. Current market information should be used to provide this value.

C represents insect control cost ($/acre) for an anticipated application. This information allows the evaluation of cost of control versus possible costs of crop delay and yield loss without control. Values supplied to COTMAN should include cost of application.

Shed rate at first flower under the option of treatment is calculated as:

$$\textit{Shed Rate at First Flower (treatment)} = \frac{X2 * Y2}{T} * 100 = \theta \qquad (7)$$

This shed rate gives the potential net revenue under the option of treatment as:

$$\textit{Net Revenue (treatment)} = \textit{Gross Revenue} - C - \theta * M * P \qquad (8)$$

where: C = cost of insect control ($/acre); θ = range of square shed rates at first flower; M = maturity delay (days) caused by 1% square shed at first flower; and P = average delay cost per acre per day ($).

Shed rate at first flower under the option of no treatment is calculated as:

$$\text{Shed Rate at First Flower (no treatment)} = \frac{A * (T - X2) + (X2 * Y2)}{T} * 100 = \frac{A * (T - X2) * 100}{T} + \theta \qquad (9)$$

This shed rate gives the potential net revenue under the option of no treatment as:

$$\text{Net Revenue (no treatment)} = \text{Gross Revenue} - \left(\frac{A * (T - X2) * 100}{T} + \theta\right) * M * P - \left(\frac{A * (T - X2) * 100}{T} + \theta - R\right) * V * D * Y \qquad (10)$$

where: A = square shed change per additional squaring node since previous sampling date; T = total squaring nodes at first flower; $X2$ = current observed number of squaring nodes; θ = range of square shed rates at first flower; M = maturity delay (days) caused by 1% square shed at first flower; P = average delay cost per acre per day ($); R = recovery or compensation capacity (%): first-position square shed at first flower above which yield is reduced; V = price of cotton lint ($/1b.); D = percent yield loss caused by 1% increase in shed rate at first flower above R; Y = lint yield potential (1b./acre).

Following the same economics of the Norton (1976) model, at the break-even shed rate, the two net revenues equate to each other:

$$\text{Gross Revenue} - C - \theta * M * P = \text{Gross Revenue} - \left(\frac{A * (T - X2) * 100}{T} + \theta\right) * M * P - \left(\frac{A * (T - X2) * 100}{T} + \theta - R\right) * V * D * Y \qquad (11)$$

Solving for the break-even shed rate θ^* gives the formula:

$$\theta^* = \frac{C}{V * Y * D} + R - \frac{100 * A * (T - X2) * M * P}{T * V * Y * D} - \frac{100 * A * (T - X2)}{T} \qquad (12)$$

Figure 1 shows a COTMAN-generated net revenue graph for a range of square sheds and identifies the location of the break-even shed rate at first flower, θ^*. Net revenue is shown on the vertical axis and shed rate at first flower is shown on the horizontal axis. Net revenue under the option of treatment is shown with a dashed line, and net revenue under the option of no treatment is shown with a solid line. As can be seen from the graph, the break-even shed rate is the point where net revenue for treatment is equal to the one for no treatment. Shed rate at first flower lower than the break-even point is associated with higher net revenue under the option of no treatment while shed rate above the break-even is associated with higher net revenue under treatment.

As the plant-based EIL is dynamic, once the break-even shed rate at first flower is found, the shed rate limit for the current number of squaring nodes, $X2$, can be calculated as:

$$\theta_{X2} = \frac{\theta^* * T}{X2} \qquad (13)$$

where: θ_{X2} = shed rate limit at currently observed number of squaring nodes, $X2$; θ^* = break-even shed rate at T; T = squaring nodes at first flower; and $X2$ = currently observed number of squaring nodes.

Figure 2 shows a graph generated by COTMAN which displays the shed rate limit for the currently observed total number of squaring nodes, θ_{X2}, that was derived from the break-even shed rate at first flower. Bar A is the actual shed rate, $Y1$, for the first date when the number of squaring nodes, $X1$, was 3.3. Bar B is the actual shed rate, $Y2$, for the second date when squaring nodes, *X2*, increased to 6.4. The black bar beside Bar B is the shed rate limit bar. As shown by Figure 2, the actual shed rate is below the limit for the current date. By comparing the currently observed square shed percentage, *Y2*, with the shed rate limit, θ_{X2}, the effectiveness of a previous ET can be assessed. If *Y2* is higher than θ_{X2}, i.e., the shed injury is above the limit, economic loss may result if no adjustment in the ET for a given tactic is not or has not been corrected. When *Y2* is lower than θ_{X2}, it indicates that the injury remains below the EIL, confirming the efficacy of the previous ET decisions.

Some situations, especially those with extremely low or extremely high shed increase per node between sampling dates, will result in an inability to solve for a break-even point. In those cases, one of the options, no treatment or treatment, always results in higher net revenue than the other, and the two net revenue lines illustrated in Figure 1 will never cross. It is possible to compare the net revenue for each option (equations 8 and 10) in those situations. A higher net revenue for no treatment indicates that the ET was likely effective, while a higher net revenue for treatment indicates that the ET was likely ineffective.

Results

Elasticity Analysis of the Model

Elasticity measures the proportional response of one variable relative to another. It can help identify the effects of a percent change of one variable on another. The numerical calculations of the elasticity values for variables in the model are presented in Table 2. It displays the impact a 1% change in the value of a specified variable will have on θ^*, the break-even shed rate at first flower. For example, a 1% increase in *R*, the compensation capacity, would result in a 1.88% increase in θ^*. This tells us that an increase in the compensation capacity would lead to an increase in the EIL and would suggest that more damage could be tolerated and insecticide would optimally be used less frequently. The sign on the elasticity indicates the relationship between θ^* and the variable under consideration. A negative sign indicates an inverse relationship, i.e. an increase in the value of the variable results in a lower EIL. The elasticity measures also reflect the relative importance of each variable in determining θ^*. The variables *T*, *R*, and *A* have the most influence while *M* and *P* have the least. In other words, θ^* is more responsive to changes in *T*, *R*, and *A* than to changes in the other variables. Note that we provided a default value for each variable in the elasticity calculations presented in Table 2.

Sensitivity Test Results

A few selected variables are considered here to illustrate the sensitivity of the EIL calculation to changing variables values. Default values used for all variables are listed in Table 2.

Assume a decision is made to depend more on the crop's compensation or recovery capacity and the value of the variable *R* is raised from 19% to 25%. Values of the other variables remain unchanged. Values of both the EIL and the shed rate limit for the current number of nodes change when the value of *R* is changed. Notice that the actual shed rate for date 2, *Y2*, is above the limit with the compensation capacity at 19%. This implies that the previous ET was not effective. However, as the compensation capacity goes up to 25%, *Y2* is well below the shed rate limit, representing a damage level below the EIL. Intuitively, it means that if we can rely on crop compensation, we do not have to control pest activity at an early stage. A higher EIL indicates that more pests can be tolerated and prompts the decision that pesticides should be used less frequently.

The variable *C* represents cost of an insect control action. Assume that keeping other variables the same, the user finds there are two types of insecticide available but with different costs. Calculation of the EILs by using different values for the cost of control gives different EILs (Table 4). When the cost of control is $15/acre, the EIL is rather low and the actual shed rate *Y2* is above the shed rate limit, which indicates that the previous ET was not effective and economic damage can be incurred if no additional control is implemented. However, with the cost of control going up to $35/acre, the EIL goes up as well and the actual shed rate is below the shed rate limit. This indicates that if the cost of an insecticide treatment is very high, it is economical to tolerate more injury and apply insecticide at a higher level of damage. A higher EIL suggests a higher tolerance for pest activity.

The variable *T* represents the total sympodia expected by the producer at first flower in each field. Table 5 shows that a higher value for *T* results in a lower EIL. A high value for *T* usually suggests a high expectation on square numbers, which can indicate a high potential yield. With the higher yield potential associated with a higher *T*, the cost of control can be justified at a lower pest level.

The above examples are cases in which the value of one variable is changed and other variables remain the same. Changes involving more than one variable become more complicated and less predictable because of the high interaction between variables. For example, the grower anticipates a higher compensation capacity and changes the value of *R* from 19% to 25%. Heavy late-season insect pressure is expected and late-season crop protection cost, *P*, is raised from $0.63 to $1.15/acre/day. Table 6 shows the calculated EIL under the two scenarios. Although the rise in delay costs should result in a lower EIL so as to avoid higher delay cost at the end of the season, the increase in the compensation capacity is too overwhelming and plays the dominant role in this case. It allows a higher tolerance for pest infestation.

Conclusion

The concept of EIL has persisted in models of pest management decision-making. However, lack of dynamics and practicality has prevented this concept from providing essential guidance and assurance to cotton growers who use an economic threshold (ET) as their operational tool. As cotton production faces multiple insect pests, multiple stresses and new developments such as transgenic cottons, a traditional EIL based on insect populations becomes even less practical. Growers follow their intuition and use other kinds of information to assist their ET decisions, such as weather, farm size, equipment, and farmer and applicator schedules. Yet the need for continuous assessment of ETs by a practical EIL is eminent and urgent.

A plant-based EIL model is proposed in this paper. Based on plant injury (square shed frequency), the plant-based EIL not only considers conventional factors such as control costs and crop value, but also incorporates new variables including dynamic plant-monitoring results and cotton's compensation capacity for early-season square loss. It calculates a break-even injury level for first flower. The break-even level is then transformed into a shed rate limit for specific stages of plant development, against which producers can compare the actual shed rate at any time prior to first flower. A shed rate below the limit indicates that initiated control prevented pests from causing economic injury, while a shed rate above the limit indicates that economic loss is on the course if a previous ET is not or has not been adjusted.

The new plant-based EIL is calculated as a part of the COTMAN software and a graph compares the shed rate limit to the actual shed rate observed in a field. Field-monitoring data on nodal development and square sheds provide the information necessary to calculate a dynamic EIL based on current plant-injury trends. Values of many other variables in the break-even analysis can be changed by COTMAN users. This allows a quick evaluation of the impact that different cost and production factors can have on decisions regarding the cost-effectiveness of insect control. As shown by the elasticity analysis and sensitivity test results, the variables T (total squaring nodes at first flower), R (recovery or compensation capacity), and A (square shed change per additional squaring node since previous sampling date) have the most influence on the calculation of EIL. Since these variables reflect the kind of information that is often farm and field specific, we believe that the plant-based EIL provides an opportunity for each decision-maker to take advantage of his/her situation and to maximize the utility of his/her experience.

Pedigo et al. (1986) suggested that the best method for developing a comprehensive ET through an EIL is by examining the host physiology and physiological response to injury. The challenge is to incorporate more host and pest dynamics into the EIL. We feel that the plant-based EIL presented in the paper can provide the key to solve this problem. It is intended to verify insect management decisions and to help recognize more efficient ETs.

References

Bagwell, R.D., and N.P. Tugwell. 1992. Defining the period of boll susceptibility to insect damage in heat units from flower. p. 767-768 *In* Proc. Beltwide Cotton Conf., Nashville, TN. 6-10 Jan. 1992. National Cotton Council, Memphis, TN.

Bourland, F.M., D.M. Oosterhuis, and N.P. Tugwell. 1992. Concept for monitoring the growth and development of cotton plants using the main-stem node counts. J. Prod. Agric. 5:532-538.

Bourland, F.M., N.P. Tugwell, and D.M. Oosterhuis. 1994. Cotton planting monitoring: The Arkansas system (an overview). p. 1280-1281 *In* Proc. Beltwide Cotton Conf., San Diego, CA. 4-8 Jan. 1994. National Cotton Council, Memphis, TN.

Cochran, M.J., N.P. Tugwell, D.M. Danforth, C.D. Klein, and J.P. Zhang. 1994. The economic potential of plant monitoring to guide the termination of late-season insect control in Arkansas. p. 914-915 *In* Proc. Beltwide Cotton Conf., San Diego, CA. 4-8 Jan. 1994. National Cotton Council, Memphis, TN.

Eaton, F.M. 1931. Early defloration as a method of increasing cotton yields, and the relation of fruitfulness to fiber and boll characters. J. Agric. Res. 42:447-462.

Gutierrez, A.P., R. Daxl, G.L. Quant, and L.A. Falcon. 1981. Estimating economic thresholds for bollworm, *Heliothis zea* Boddie, and boll weevil, *Anthonomus grandis* Boh., damage in Nicaraguan cotton, *Gossypium hirsutum* L. Environ. Entomol. 10:872-879.

Holman, E.M. 1996. Effect of early-season square loss on cotton (Gossypium hirsutum L.) plant development. Ph.D. diss. University of Arkansas, Fayetteville.

Johnson, D.R., and B.F. Jones. 1996. 1996 insecticide recommendations for Arkansas. U. of Arkansas Coop. Ext. Serv., Little Rock, AR.

King, W.H. Jr., M.J. Cochran, and N.P. Tugwell. 1996. Frequency of insecticide applications in Arkansas fields approaching cutout as defined by COTMAN. p. 732-733 *In* Proc. Beltwide Cotton Conf, Nashville, TN. 9-12 Jan. 1996. National Cotton Council, Memphis, TN.

Kletter, E., and D. Wallach. 1982. Effects of fruiting form removal on cotton reproductive development. Field Crops Res. 5:69-84.

Mi, S., D.M. Danforth, N.P. Tugwell, and M.J. Cochran. 1998. Plant-based economic injury level for assessing economic thresholds in early-season cotton. J. Cotton Sci. In press.

Montez, G.H., and P.B. Goodell. 1994. Yield compensation in cotton with early season square loss. p. 916-919 *In* Proc. Beltwide Cotton Conf., San Diego, CA. 4-8 Jan. 1994. National Cotton Council, Memphis, TN.

Munro, J.M. 1971. An analysis of earliness in cotton. Cotton Grow. Rev. 48:28-41.

Norton, G.A. 1976. Analysis of decision making in crop protection. Agro-Ecosystems. 3:27-44.

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

Sadras, V.O. 1994. Compensatory growth in cotton after loss of reproductive organs. Fields Crops Res. 40:1-18.

Stern, V.M., R.F. Smith, R. van den Bosch, and K.S. Hagen. 1959. The integrated control concept. Hilgardia. 29:81-101.

Terry, L.I. 1992. Effect of early season insecticide use and square removal on fruiting patterns and fiber quality of cotton. J. Econ. Entomol. 85:1402-1412.

Zhang, J.P., N.P. Tugwell, M.J. Cochran, F.M. Bourland, D.M. Oosterhuis, and C.D. Klein. 1994. COTMAN: a computer-aided cotton management system for late-season practices. p. 1286-1287. *In* proc. Beltwide Cotton Conf., San Diego, CA. 4-8 Jan. 1994. National Cotton Council, Memphis, TN.

Table 1. Examples for the Calculation of *A*, Per Node Shed Change

	Date 1		Date 2		
Example	*X1*, nodes	*Y1*, % square shed	*X2*, nodes	*Y2*, % square shed	*A*, per node shed change
1	4.6	0.0	7.7	3.9	0.10
2	5.9	4.2	6.5	13.8	1.08

Table 2. Numerical Calculations of Elasticity Values

Variable	Default Value	Elasticity Value
A, Pest Activity (Per Node Shed Increase)	0.32	e_A = -1.098
R, Compensation Capacity (%)	19	e_R = 1.88
C, Cost of Insect Control ($/acre)	15	e_C = 0.22
Y, Yield Potential (1b./acre)	1000	e_Y = - 0.186
V, Price of Cotton ($/1b.)	0.7	e_V = - 0.186
D, % Yield Loss/% Shed > *R*	0.97	e_D = - 0.186
M, Days of Maturity Delay/Shed %	0.1818	e_M = - 0.033
P, Late-season Protection Cost ($/acre/day)	1.15	e_P = - 0.033
T, Number of Squaring Nodes at 1st Flower	10.25	e_T = - 2.16

Table 3. Change the Value of Compensation Capacity, *R*

	R (%)	EIL (%)	Shed Limit (%)	Shed Rate Above Limit?
Before	19	10.11	15.24	Yes
After	25	16.11	24.28	No

Table 4. Change the Value of Cost of Control, *C*

	C ($/acre)	EIL (%)	Shed Limit (%)	Shed Rate Above Limit?
Before	15	10.11	15.24	Yes
After	35	13.03	19.64	No

Table 5. Change the Value of Expected Number of Squaring Nodes at First Flower, *T*

	T (number of sympodia)	EIL (%)	Shed Limit (%)	Shed Rate Above Limit?
Before	11.00	8.62	13.90	Yes
After	8.25	15.40	18.70	No

Table 6. Change the Value of Compensation Capacity, *R*, and the Value of Delay Cost, *P*

	P ($/acre/day)	R (%)	EIL (%)	Shed Limit (%)	Shed Rate Above Limit?
Before	1.56	19	10.26	15.46	Yes
After	2.84	25	16.11	24.28	No

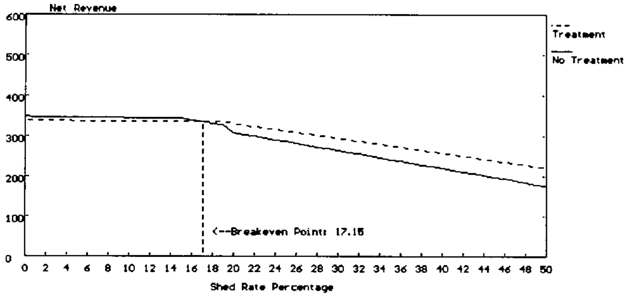
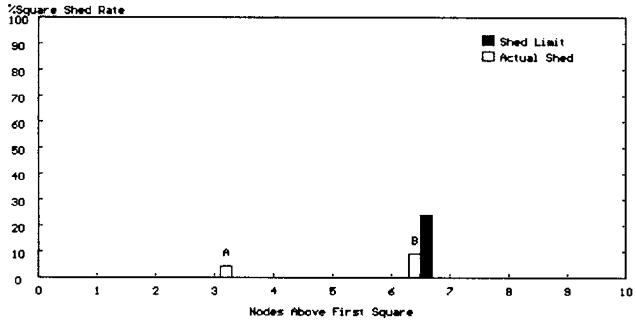


Figure 1. Net Revenue Graph



*** Shed Rate Limit vs. Actual Shed Rate ***

ID	Date	Nodes	%Actual Shed	%Shed Limit
A	6/11	3.3	4.6	----
B	6/19	6.4	9.4	24.8

Figure 2. Shed Rate Limit Graph