ECONOMIC ANALYSIS OF INSECT MANAGEMENT STRATEGIES FOR TRANSGENIC *Bt* COTTON PRODUCTION IN SOUTH CAROLINA

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Abstract

An economic evaluation of *Bt* cotton technology was undertaken using data from two on-farm experiments in South Carolina. Spraying for tobacco budworm (*Heliothis virescens*) and cotton bollworm (*Helicoverpa zea*) were not required in *Bt* cotton as the thresholds were not exceeded, but methyl parathion was applied at least once to control for stinkbugs. In both sites, cost savings from reduced insecticide application were evident. Actual experimental yield for *Bt* cotton was higher than non-*Bt* cotton in the Barnwell county site, while *Bt* yield was lower than non-*Bt* yield in the Lee county site. These results made *Bt* cotton very profitable in Barnwell county but unprofitable in Lee County. Further statistical analysis revealed that there was no significant difference between the yields of *Bt* and non-*Bt* cotton in both sites. Economic analysis that assumes constant yield levels showed that *Bt* cotton was profitable in both sites. Using *Bt* cotton technology was also found to be more efficient than non-*Bt* cotton. However, *Bt* cotton was riskier than non-*Bt* cotton in both sites. Although it seems advisable to adopt *Bt* cotton over non-*Bt* cotton based on the exprimental results for one year, the risk factor plus several implicit factors must also be considered before a definitive decision on the *Bt* cotton technology is made.

Background, Significance, and Objectives

The development of *Bt* cotton represents a technical change in cotton production. *Bt* cotton is a genetically engineered plant which contains the common soil bacterium *Bacillus thurigiensis (Bt)*. This technological breakthrough has the potential to expand the production frontier of cotton and improve producer welfare. A macro-level study by Eddleman et al. (1995) indicated that this technical change will increase producer surplus in the U.S. by $18 million annually, assuming that there is a yield increase from *Bt* cotton and chemical costs are constant. However, they also predicted that producer surplus will decrease by $19 million annually if there is only a reduction in chemical costs without any increase in yields. An economic analysis of on-farm experiments provides a micro-level perspective on the potential impact of this new technology.

Preliminary studies indicate that *Bt* cotton will practically eliminate the use of insecticides previously directed at the tobacco budworm, *Heliothis virescens*, and cotton bollworm, *Helicoverpa zea* (Benedict et al. 1993, Luttrell 1994, Jenkins et al 1993). South Carolina as a study area is relevant because these two pests have produced the most economic damage in the state (NAPIAP, 1993). Moreover, the boll weevil *(Anthonomous grandis)*, an important pest in other states, has been eliminated as a major pest in South Carolina due to the boll weevil eradication program implemented in the state. This study, therefore, can be used as a basis of comparison between the economic effects of *Bt* cotton technology in weevil-free and weevil-infested regions.

Other lepidopteran pests such as soybean looper *(Pseudoplusia includens)*, beet armyworm *(Spodoptera exigua)*, and fall armyworm *(S. frugiperda)* are apparently not directly controlled by *Bt* cotton (Bradley 1996), but biological control of these pests will be enhanced by conservation of natural enemies (beneficials) when "hard" insecticides are not applied to cotton (Green et al., Graham et al 1995). However, other pests like the tarnished plant bug *(Lygus lineolaris)* and several species of stinkbugs *(Nezara viridula, Acrosetum hilare, and Euschistus servus)* are not directly controlled by *Bt* and may require more insecticide applications because they were previously indirectly suppressed by the traditional insecticides targeted for tobacco budworm and cotton bollworm.

Introduction of a new technology will induce changes in management practices, and these changes will affect relative factor costs and returns. Transgenic *Bt* cotton would need adjustments in the integrated pest management (IPM) strategies currently being used so that it can be viable to farmers. Hence, to evaluate *Bt* technology, the costs due to changes in management practices must be weighed against the benefits the technology provides. Phillips (1995) and Benedict (1996) revealed that potential benefits from adoption of *Bt* cotton would be from improved lepidopteran pest control at a lower cost, increased yields, yield/cost stabilization, and more environmentally compatible management of important pests. The environmental benefits would also increase the sustainability of the system and may provide future benefits in terms of resource conservation. Costs may be direct through increased seed costs, technology charges, additional insecticide applications for pests not affected by *Bt* (i.e. emergent pests like stink bugs), application costs (if insecticides are sprayed separately from growth regulators or fertilizers), and increased scout and consultant effort to correctly use the new technology. Indirect costs of *Bt* cotton technology may include a more rapid development of resistance to *Bt* by lepidopteran pest species, which will add more pressure on the scientific community to continually develop alternative control strategies.

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The objective of this study is to determine the potential profitability and efficiency of *Bt* cotton production relative to conventional "best" practice cotton production. Economic analysis of *Bt* cotton production using data from on-farm experiments provides a more complete picture of the potential changes in costs and returns when this technology is adopted and subsequently aids in farm decision making. The results will also be able to guide researchers to further streamline management practices to fit farmers' needs.

Methods

There are three possible interpretations of the impact of technological innovations such as *Bt* cotton on producer welfare. First, *Bt* cotton fields will still contain some lepidopteran pests and so chemical insecticide use will not decrease from levels used for non-*Bt* cotton (Eddleman et al., 1995). As a result, control of pests will be more effective but lint yields will increase. The second interpretation is that *Bt* cotton will keep insect pest numbers down and so insecticide use will be reduced as compared to non-*Bt* cotton; however, lint yields will stay the same (Eddleman et al., 1995). The third interpretation is a mixture of the first two, that is, insecticide use will be reduced and lint yields will be increased but not by as much as the two "extreme" interpretations above. Insecticide use will decrease due to the effectiveness of *Bt* cotton to control lepidopteran pests, but emergent pests (i.e. stink bugs) may arise which forces the farmers to apply higher chemical control relative to the levels applied in the second interpretation. The latter interpretation is considered the most likely to occur (Bradley et al., 1995, Phillips 1995). But in all cases, the probability of improved economic efficiency with *Bt* cotton technology appears to be high.

Experimental Design and Data

The data used in this study were primarily drawn from the on-farm experiments conducted by Greene and Turnipseed (1996) at Clemson University's Edisto Research and Education Center in Blackville, SC. Two on-farm experimental sites were chosen for their study, site 1 in Barnwell County, SC (Sandifer farm) and site 2 in Lee County, SC (McDaniel farm). Large plots of 24 rows by 80 feet (0.14 acre) were used in a randomized block design with four replications. Both *Bt* and non-*Bt* cotton were grown on the two sites using recommended production practices, except for insect management.

Greene and Turnipseed (1996) controlled insect populations in *Bt* and non-*Bt* cotton plots based on different thresholds for stinkbugs and budworm/bollworm. We will utilize data from the *Bt* and non-*Bt* treatments where the threshold levels were at 1 bug per 6 feet of row for stinkbugs and 3 worms per 100 plants for budworm/bollworm. These are the "best" available thresholds for these pests. Weekly sampling of insects were undertaken to monitor the threshold levels in both sites. When the threshold level for stinkbugs was reached, methyl parathion (4EC) was applied at 0.50 lb (AI)/acre with a high clearance sprayer to control populations. When the budworm/bollworm threshold is reached, *lambda*-cyhalothrin (Karate® 1EC) was applied at 0.033 lb (AI)/acre. The data from these treatments were used in order to fairly compare the changes in insect management practices of *Bt* cotton and non-*Bt* cotton. Other data pertaining to the input costs, input prices, and yields for both *Bt* and conventional cotton were collected to develop the appropriate economic assessments (see below).

Economic Analysis

Farmers consider two basic factors when deciding to adopt a new technology: the benefits and costs of the new technology, and the risk involved in adopting the new technology. Economic analysis of *Bt* cotton technology must then be evaluated with these criteria in mind. Partial budgets and enterprise budgets for both *Bt* cotton technology and the conventional technology were constructed based on the data collected from the "on-farm" experiments. These budgets were used to assess the benefits and costs associated with the *Bt* technology as compared to the conventional cotton technology. Construction of these budgets was based on the methods and guidelines developed by the Clemson Agricultural Extension Service (Jordan et al., 1995).

Risk is an important element in a farmer's decision to adopt a technology and must somehow be considered in the analysis. Farmers in general are risk averse. That is, if expected returns of two different strategies are the same, they would choose to adopt the strategy that exhibits a lower degree of return variability. Since we will assume constant prices in the analysis, yield variability will be the main source of risk in production. Therefore, standard deviation of the yield will be used as an indicator of risk.

Economic efficiency of farm operations under *Bt* and non-*Bt* technology will also be evaluated. Economic efficiency is a term which has many different meanings and must always be clarified. In this study, net returns per unit cost will be used as a measure of economic efficiency. The technology with the higher returns per unit cost is deemed a "more efficient" technology.

Results and Discussion

Experimental Results

Experimental results relevant to the economic analysis of *Bt* cotton production show that in site 1, lint and seed yields of *Bt* cotton are higher than the non-*Bt* cotton. In contrast, site 2 non-*Bt* cotton had a higher lint and seed yield than the *Bt* cotton. Although there were numerical differences in yield for *Bt* and non-*Bt* cotton, further statistical analysis using Duncan's Multiple Range test revealed that non-*Bt* cotton yields were not significantly different from *Bt* cotton yields in both sites (Greene and Turnipseed, 1996).

Bt cotton provided excellent control for the budworm/bollworm complex as the treatment thresholds were not exceeded, thus avoiding the use of pyrethroids for *Bt* cotton in both sites. However, stinkbug thresholds were exceeded twice in site 1 and once in site 2. Hence, methyl parathion was applied twice in site 1 and once in site 2 to control stinkbug damage.

The conventional cotton in both sites did not effectively control the budworm/bollworm complex as the thresholds were exceeded eight times in site 1 and four times in site 2. Thus, the pyrethroid Karate® was applied eight times in site 1 and four times in site 2. Stinkbug thresholds were not exceeded in both sites, hence no methyl parathion applications were necessary. This may be attributed to the indirect effect of pyrethroids on the stinkbugs.

<u>Economic Analysis: The Marginal Approach</u>

The marginal approach to economic analysis of on-farm experiments involves the use of partial budgets. Partial budgets are designed to show the marginal loss or benefit of a new technology as compared to a baseline technology. In our case, we are trying to ascertain the marginal effect of *Bt* cotton production relative to conventional cotton production. The first part of this section discusses the partial budgets using the actual numerical yields from the two sites. The second part of this section discusses the partial budgets where it is assumed that there are no yield differences between *Bt* and non-*Bt* cotton.

Partial budgets for the two sites were constructed considering the actual yield differences and differences in insecticide applications. The lint and seed price used were based on the prices in the 1996 Clemson University Extension budgets for cotton. The cost of pyrethroid application was calculated by multiplying the rate of application (0.033 gal/acre) by the price per gallon ($255.00). Similarly, cost of stinkbug control was based on the rate of methyl parathion application (0.125 gal/acre) multiplied by the its per gallon cost ($25.70). Cost of labor per application was computed by multiplying the labor hours required for each application (0.35) times the cost per hour ($5.00/hr.). Machinery cost, which includes the variable costs associated with machinery use of a hiboy (i.e. repair cost and depreciation), was lifted from the estimates in the Clemson Extension budgets. The *Bt* seed cost ($1.00/lb) was set 10 cents higher than the non-*Bt* seed ($0.90/lb). Assuming the rate of planting is 10 lbs/acre in both *Bt* and non-*Bt* plots, the *Bt* seed costs $1.00 more per acre. The technology charge is assumed to be $35.00 per acre. All other input costs and practices that are not in the partial budgets are assumed to be the same for both conventional and *Bt* cotton.

Bt cotton production earned an additional $104.92 per acre relative to the conventional cotton production in site 1. This indicates that the additional returns from the yield boost and the savings from reduced pyrethroid application ($147.34) more than outweighed the additional costs of the *Bt* seed, the stinkbug control, and the fixed technology charge ($42.42). In site 2, *Bt* cotton production earned $81.68 less than conventional cotton production. The substantial differences in yields in both sites resulted to the contrasting result. The substantially higher yield of *Bt* cotton in site one enabled it to gain a large amount, while the lower yield in site two made it lose.

Another measure relevant to the analysis of *Bt* cotton relative to conventional cotton is the marginal rate of return (MRR). This measure is computed by dividing the marginal net benefits of adopting the *Bt* technology over its marginal costs. Site 1 has an MRR of 2.47; which means that for every dollar invested in *Bt* cotton, a farmer will gain $1.00 and obtain an additional $1.47. In site 2 the MRR was -0.59, which means that for every dollar invested, a farmer only gets $0.41 in return, which does not cover his initial $1.00 investment. Again, this implies that site 1 gained from the adoption of *Bt* cotton while site 2 did not.

The measures presented above indicate that it is highly profitable to adopt *Bt* cotton given the conditions in site 1. This can be attributed mainly to the yield boost plus the high amount of pyrethroid applications required in conventional cotton. However, in site 2, it is not profitable to adopt the *Bt* technology since the yield decline in *Bt* more than outweighed the savings in pyrethroid applications.

Partial budgets which assumes no yield differences were also constructed because, as mentioned earlier, the yields of *Bt* cotton and non-*Bt* cotton were not statistically different. This follows the theory that *Bt* cotton technology shifts out the production frontier by reducing insecticide use yet still having the same yield as conventional cotton (Eddleman et al., 1995). In sites 1 and 2, respectively, *Bt* cotton production earned $68.44 and $17.12 per acre more than the conventional cotton production. The savings in insecticide applications more than outweighed the increased seed cost and technology charge. Both MRRs for the no yield difference case were positive. Sites 1 and 2 had MRR's of 1.61 and 0.45, respectively. This means that for each dollar invested in the new technology, a farmer in both sites will recover the $1.00 investment, plus an additional $1.61 in site 1 and an additional $0.45 in site 2. Therefore, in both these sites, *Bt* cotton production is profitable assuming that there is no difference in yields.

<u>Economic Analysis: The Total Approach</u>

The total approach to the economic analysis of on-farm experiments involves the use of full enterprise budgets. This method shows the gross or total effect of a technology on the entire farm operation. It does not directly compare two technologies as in the partial budgets. This section presents enterprise budgets for *Bt* cotton and non-*Bt* cotton at both experimental sites. However, the budgets presented here only considered the case where there are no yield differences. A 900 lb. lint yield and 1600 lb seed yield were assumed in both sites for each treatment.

Assuming standard production practices, site 1 *Bt* cotton production earned $223.65 above variable costs per acre and a total net return of $32.62 per acre. The variable costs ($470.35) accounted for roughly 71 percent of the total costs ($661.38). The non-*Bt* cotton, on the other hand, earned $155.30 above variable costs per acre while incurring a total net loss of $41.20 per acre. This loss was due to the high number of pyrethroid applications required to control for the budworm/bollworm complex. The variable costs for the non-*Bt* cotton ($538.70) accounted for 73 percent of total costs ($735.20). In site 2, *Bt* cotton and non-*Bt* cotton earned, respectively, $234.16 and $155.30 above variable costs per acre. Both treatments had a positive total net returns of $43.97 and $26.48 for *Bt* and non-*Bt* cotton, respectively. Variable costs for both treatments roughly accounted for 70 percent of total costs. Except for non-*Bt* cotton in site 1, all treatments were profitable in a "whole-farm" sense. This means that if the treatment parameters were included in a "typical" farm operation, the farm will earn a positive net return.

Risk and Efficiency

Efficiency of the farm was measured using the ratio of net returns over total costs (expressed in percentage terms). This measure was based on our enterprise budgets, hence our efficiency indicator assumes no difference in yields. In site 1, net returns per unit of cost were 4.9 percent and -5.6 percent for *Bt* and non-*Bt* cotton, respectively. For site 2, the efficiency measures were 6.8 percent and 3.9 percent for *Bt* and non-*Bt* cotton, respectively. This indicates that non-*Bt* cotton technology was less efficient than *Bt* cotton technology.

A slightly modified efficiency measure is the ratio of income above variable cost (IVC) over the total variable costs (TVC). This alternative measure is relevant because the *Bt* technology only affected the variable aspect of the costs. In site 1, IVC over TVC for *Bt* cotton was 47.5 percent, while for non-*Bt* cotton it was 28.8 percent. In site 2, the alternative efficiency measures were 50.9 percent and 45.7 percent for *Bt* and non-*Bt* cotton, respectively. These measures reveal that *Bt* cotton production provides an efficiency gain of roughly 39 percent in site 1 and 10 percent in site 2.

Standard deviation of the yield was our indicator of risk. This measure shows the degree of variability in yields for each plot in every treatment. The standard deviation for *Bt* and non-*Bt* yields were 254.79 lbs/acre and 196.24 lbs/acre, respectively, in site 1. On the other hand, site 2 had standard deviations of 455.55 lbs/acre and 153.09 lbs/acre for *Bt* and non-*Bt* cotton. In both sites, *Bt* cotton had a higher risk compared to non-*Bt* cotton. This may be due to the fact that *Bt* cotton is a new technology where the "best" practices are still currently evolving. Aside from insect management practices, all other practices used were based on the recommended "best" practices for conventional cotton which may not be the "best" for *Bt* cotton technology. This uncertainty in the production of *Bt* cotton may have caused the variablity in yields. However, in time, farmers and scientists will become more familiar with the *Bt* cotton and its responses to different management practices. This, in turn, may reduce the risk involved in planting *Bt* cotton in the future.

Economic Implications

Assuming no yield differences between *Bt* an non-*Bt* cotton, the partial budgets and enterprise budgets revealed that it is profitable for farmers to invest in *Bt* cotton technology. Farmers who are spraying more than four pyrethroid applications per season in conventional cotton should strongly consider this technology. However, certain factors must be considered in interpreting the results from our economic analysis and in using it as a decison-making tool; remember that implicit assumptions were made in the construction of the budgets. These assumptions and their corresponding implications are discussed in this section.

The partial budgets above assumed that all other practices remained constant. This implies that growth regulators (i.e. PIX) were applied the same way in both *Bt* and non-*Bt* cotton. But in reality, non-*Bt* farmers may mix PIX with their pyrethroid applications to save some trips to the field, especially during the first few applications of pyrethroids. This may mean that farmers who adopt *Bt* cotton technology may need to apply PIX separately as opposed to simply mixing it with pyrethroids. This may then reduce the savings in labor and machinery cost in our budgets. However, we may argue that it is sometimes not advisable to apply the growth regulators together with insecticides because cotton growth in the field may not be uniform. Spot application of PIX is sometimes needed. If this is the case, our assumption of separate applications for both *Bt* and non-*Bt* cotton is reasonable.

A factor that may affect our savings in insecticide applications is the effect of methyl parathion on beneficials. Timing of methyl parathion application is critical in the management of insect pests. If this chemical kills some beneficials and an emergent pest comes in (i.e. armyworms), additional insecticide applications may be needed. The recommended practice is for the methyl parathion to be applied towards the end of the season so as not to substantially disrupt the ecosystem. Hopefully, this practice will not induce the farmer to apply more insecticides for emergent pests.

Another potential cost to consider is the higher insect selection pressure in *Bt* cotton plants which may result in faster resistance development in lepidopterans. Scientists have recommended the refuge concept to curb this potential problem (Benedict, 1996 and Lutrell and Capiro, 1996). This management practice was not included in our analysis. However, we can argue that as of this writing there are still substantial number of acres that are not planted to *Bt* cotton as well as other alternative hosts. These areas already serve as the refuge, hence, resistance management in our study was not included. This refuge option, however, must be included in future economic analysis.

The factors cited above affect the marginal costs in our budgets, but some implicit additional returns not covered by our budgets must also be considered. First, it is important to take note of the positive environmental and health externality of adopting *Bt* cotton. The reduced insecticide application due to the *Bt* technology may result in reduced environmental and resource degradation. This in turn may provide better future returns for the farmers as compared to the case of continued chemical insecticide application. Health benefits of the *Bt* cotton technology may be embodied in reduced medical expenses associated with reduced exposure to chemicals. These positive externalities must also be taken into consideration when deciding whether to adopt the *Bt* cotton technology.

A second factor that may affect our returns is the potential savings from "wet" weather losses by planting *Bt* cotton. Our budgets assumed "normal" weather, which did not consider the effect of untimely rain that may delay pyrethroid applications in conventional cotton. This may result in untimely control of lepidopterans in non-*Bt* cotton, which then can cause significant economic damage. With *Bt* cotton, wet weather losses are not a concern, since the *Bt* is inside the plant and cannot be washed away. This characteristic provides an additional "return" embodied in potential savings from wet weather loss and potential savings from not needing aerial application.

A third variable is the distance of the cotton fields from the farmers' shop. In our budgets we assumed the same price for machinery cost. But this may vary depending on the distance and terrain that the hiboy must traverse. Farmers with distant cotton fields would have an additional benefit in terms of this additional savings in machinery cost.

Farmers deciding to adopt *Bt* cotton must be aware of the implicit factors cited above and not completely rely on the hard dollar figures in the partial and enterprise budgets. Long run gains to farmers may be realized when a holistic and dynamic view of the technology is taken. Policy makers must also remember the factors above when evaluating the results of this study.

Summary and Conclusions

Based on the actual experimental yield results, *Bt* cotton production in site 1 was very profitable as compared to conventional cotton. This was attributed to the yield boost that *Bt* cotton has over conventional cotton in this site. In contrast, *Bt* cotton production in site 2 was not profitable relative to non-*Bt* cotton when we used the actual experimental yields. This was due to *Bt* cotton's lower yield relative to the non-*Bt* cotton in this site.

Further, statistical analysis of the plot data revealed that *Bt* cotton yields were not significantly different than non-*Bt* cotton yields. Economic analysis which assumes constant yield levels showed that *Bt* cotton was more profitable than non-*Bt* cotton in both sites. The cost savings from reduced pyrethroid applications more than outweighed the added investment in *Bt* cotton technology. The measures of efficiency, which were computed assuming that yields are the same, also showed that using *Bt* cotton technology in production was more efficient than non-*Bt* technology. Returns per unit of cost were higher in *Bt* cotton production as compared to non-*Bt* cotton production.

Preliminary economic results based on one year's data indicate that it is advisable to adopt *Bt* cotton. Potential yield increases and insecticide savings in *Bt* cotton can benefit farmers in South Carolina. Farmers who are now spraying insecticides four or more times in conventional cotton should especially consider *Bt* cotton because of the cost savings that can accrue to them. However, *Bt* cotton is not a "win-all" proposition since the it was found to be a riskier technology than non-*Bt* cotton in both sites, exhibiting higher yield variability in both locations.

Caution must be taken when using the results above because some implicit factors not covered by the analysis may adversely affect the net results. Factors such as timing and method of growth regulator applications, timing and effect of methyl parathion applications, resistance management, the "normal" weather assumption, cotton field distance, and the environmental/health benefits of the *Bt* cotton technology, should all be taken into consideration when interpreting the results from the economic analysis. Farmers and policy makers will benefit from the results of this study as long as they factor in the other implicit variables in their evaluation.

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