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An Estimation of Producer Returns from Bt Cotton with Varying Refuge Sizes

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Abstract

The U.S. Environmental Protection Agency (EPA) has mandated an Insect Resistance Management (IRM) program that attempts to preserve the benefits and insect protection of *Bacillus thuringiensis* (Bt) cotton. According to that mandate, growers planting Bt cotton are required to follow the IRM practices designed to keep some lepidopteran populations from being exposed to the Bt protein. Thus, a refuge of non-Bt cotton must be planted. Currently, producers may select among different sprayed and unsprayed refuge percentages. Recently, EPA has been petitioned to remove all refuge requirements. In order to compare farm-level returns from various refuge requirements, returns for a cotton farm in the Mississippi Delta were calculated from observed and simulated yields. Results indicate higher mean returns above insecticide costs for Bt cotton than for non-Bt cotton (refuge). For any given non-Bt cotton (refuge) percentage, returns are higher without increased risk when insecticide sprays are applied.

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Introduction

Bt cotton is a genetically engineered variety of cotton named after a soil bacterium, *Bacillus thuringiensis* (Bt), whose genetically introduced toxins generally protect and provide high levels of suppression in cotton plants from certain lepidopteran insect pests including tobacco budworms, pink bollworms, cotton bollworms, armyworms, loopers, and other leaf- and fruit-feeding caterpillar pests in cotton. When larvae feed on a Bt cotton plant, the toxic proteins protect the plant by reducing larval survival and associated plant-foliage damage. In most cases, the requirement for remedial insecticide treatments for these pests is either reduced or eliminated. However, lepidopteran cotton pests have demonstrated an ability to develop resistance to many chemical insecticides.

The U.S. Environmental Protection Agency (EPA), in order to protect the social welfare benefit of Bt cotton, has mandated an Insect Resistance Management (IRM) program that attempts to preserve the benefits of insect protection of this technology. According to that mandate, growers planting Bt cotton are required to follow the IRM practices designed to assure some lepidopteran populations are not exposed to the Bt protein. This allows the reintroduction of susceptible pests into the selected populations, which delays development of pests' resistance to the Bt toxin. Thus, insects are provided a refuge food source that does not contain the Bt protein. This refuge is provided by simultaneously planting either a minimum of 5% unsprayed non-Bt cotton or a minimum of 20% non-Bt cotton that can be sprayed with insecticides. EPA has previously suggested that refuge percentages be increased (Muzzi, 2001). Recently, with the introduction of Bollgard II®, Monsanto™ has asked EPA to not require a non-Bt refuge (Robinson, 2006).

The primary objective of this analysis was to document and compare farm-level returns with various selected refuge requirements based on observed and simulated farm-level yields. Specifically, data from Mississippi Delta cotton farms were used as an example to see how partial net farm returns were affected by refuge size and the application of insecticide sprays.

Limited applied studies have addressed Bt and non-Bt net returns (Bryant et al., 2002; Cooke et al., 2001; Ward et al., 2002). These studies compared returns from Bt and non-Bt (conventional) cotton varieties. Bryant et al. and Cooke et al. both found that either system provided similar lint yields and net returns. While these studies addressed relevant issues at the farm level in terms of one cultivar type versus another, they were lacking in respect to number of observations, and the size of the areas studied, and more importantly, they did not address the issue of lost revenue from a refuge. Both Bt and non-Bt cotton in these studies were managed to maximize returns. However, if an unsprayed refuge system was selected, a non-Bt cotton cultivar could not be sprayed. Thus, net returns would be assumed to be reduced; otherwise, the "almost complete" adoption of Bt cotton (74% in 2004, USDA, 2006) would not have occurred. However, the cost (in terms of net revenue) of the refuge to a producer has not been evaluated or documented.

MATERIALS AND METHODS

Per-hectare partial returns for Bt and non-Bt cotton, respectively, were calculated as follows:

(1) $$\pi_b = p\ y_b - K_b$$

and

(2) $$\pi_c = p\ (1 - \lambda)\ y_c + [(p\ \lambda_s y_c - K_c]\ \tau\ ,$$

where π_b = per-hectare returns for Bt cotton, π_c = per-hectare returns for non-Bt cotton (refuge portion of the farm), p = price of cotton lint, y_b = per-hectare farm yield for Bt cotton lint, K_b = per-hectare insecticide cost of Bt cotton (i.e., the technology fee), λ = proportional yield loss per hectare due to uncontrolled pests, y_c = per-hectare farm yield for non-Bt cotton lint, K_c = per-hectare insecticide cost of non-Bt cotton yield, λ_s = proportion of non-Bt cotton lint yield per hectare saved by insecticide applications, and τ = indicator variable for insecticide application(s) (equals 1 when applied and 0 otherwise).

Marketing year average prices for 1996 through 2003 for Mississippi were obtained online from the National Agricultural Statistics Service (NASS) of the United States Department of Agriculture [9]. For each of those years, lint prices were calculated as the greater of the marketing year average price or the government loan price, the latter being given at \$0.236 per kilogram. The average of this price series, approximated at \$0.263 per kilogram, was used in the calculation of net returns.

Variable input costs (denoted by K) used in the production of Bt and non-Bt cotton were obtained from the 2002 Mississippi State Cotton Planning Budgets [3]. Costs were assumed to be fixed at the 2002 level for both observed and simulated return calculations. All insecticide costs from the planning budgets were included because some overlap may occur in terms of target pests.

Entomological literature regarding pest loss is limited as most entomological studies focus on fruit retention and damaged bolls. Few studies actually include a "check" plot that allows yield comparisons of "uncontrolled" pests versus "completely controlled" pests. Townsend studied lepidopteran and other pests and yield loss in the Mississippi Delta in the early 1970s. Townsend's research indicated a 45% loss due to uncontrolled lepidopteran pests. Many advances in insecticides, not to mention boll weevil eradication and the introduction of Bt cotton, have occurred since the Townsend study. Gore et al. (2000) in northeastern Louisiana (an area similar to the Mississippi Delta) found that yield reductions in untreated non-Bt cotton were approximately 35% from 1997 to 1998. Additionally, Gore and Adamczyk (2004) found yield losses ranged from 25% to 50% from 2002 to 2003 in the Mississippi Delta. Thus, λ was set equal to 35% in the net revenue calculations.

Observed (on-farm) yields for 1997 through 2000 were obtained from the Cooke et al. study (2001) and used to calculate returns at the farm level. As mentioned, actual farm-level data that reports yields separately for Bt and non-Bt cotton are limited to small geographical areas. Thus, district-level yield data from 1983 through 2003 for Crop Reporting District 40 (D40, Lower Delta, Mississippi) — a district representative of Mississippi Delta cotton farming — were obtained online from NASS (2006). Using the Cooke et al. data as a proxy for a Mississippi cotton farm, returns at the farm level were calculated for selected refuge percentages using the actual Cooke et al. Bt and non-Bt yields as observed data. Simulated Bt and non-Bt yields were then calculated and estimated similar to Miller et al. (2003) from the NASS data in order to incorporate farm-level yield variability into a broader (district-level) geographical area. Following the Miller et al. study, the farm-level (observed) data were used to calculate farm-level yield variations (residuals) and combined with the NASS data to simulate farm-level yields (returns).

Further, equations (1) and (2) were used to aggregate returns to the farm level. Thus, total returns for a representative-sized farm that typically plants both Bt and non-Bt cotton were calculated as:

(3) $$\Pi = A\ [z\ \pi_c + (1 - z)\ \pi_b],$$

where A = average cotton farm size in hectares in the Mississippi Delta (293 hectares, USDA, 2006), z = proportion of non-Bt cotton (refuge) planted per hectare on average, π_b = per-hectare returns from Bt cotton, from equation (1), and π_c = per-hectare returns from non-Bt cotton, from equation (2).

Farm returns were calculated for the following refuge scenarios: (1) z = 0%, τ = 0; (2) z = 1%, τ = 0; (3) z = 5%, τ = 0; (4) z = 10%, τ = 0; (5) z = 20%, τ = 0; (6) z = 26%, τ = 0; (7) z = 0%, τ = 1; (8) z = 1%, τ = 1; (9) z = 5%, τ = 1; (10) z = 10%, τ = 1; (11) z = 20%, τ = 1; and (12) z = 26%, τ = 1.

Note that the sum of actual proportions (0.16 and 0.58, respectively) of insect-resistant (Bt) and stacked-gene varieties observed in 2003-2004 was 0.74 (USDA, 2004). Therefore, if the proportion of Bt cotton was 74%, then the proportion of non-Bt cotton would be 26%, thus explaining the inclusion of the z = 26% scenarios.

Results and Discussion

Each year (1997-2000) using observed data, per-hectare returns obtained from Bt cotton were found to be slightly higher than those obtained from non-Bt cotton with insecticide application(s), which in turn were found to be considerably higher than the returns from non-Bt cotton without insecticide application(s). This is in slight contrast to Cooke et al., who used actual observed whole-farm budgets, while this analysis was based on published state planning budgets and included only insecticide expenses. (Cooke et al. used whole-farm budgets and actual insecticide costs, but actual insecticide costs were not reported.) The mean per-hectare returns above insecticide costs for Bt cotton were $1,097; for non-Bt cotton with insecticide spray(s), $994; and for non-Bt cotton without insecticide spray(s), $454. The coefficients of variation (CVs) were smaller for Bt returns than for non-Bt returns with or without insecticide(s). CVs were calculated as standard deviation divided by the mean. These results are shown in Table 1.

Table 1. Per-hectare returns above insecticide costs from observed yields on Bt and non-Bt (conventional) cotton in the Mississippi Delta, 1997-2000.

Year	Bt returns	Non-Bt returns	
		with insecticide application(s)	without insecticide application(s)
1997	$1,225	$1,132	$530
1998	$1,139	$1,030	$474
1999	$998	$888	$396
2000	$1,027	$925	$416
Mean	$1,097	$994	$454
SD[1]	$104	$110	$61
CV[2]	0.095	0.111	0.134

[1]SD = Standard Deviation.
[2]CV = Coefficient of Variation = SD/Mean.

Using simulated yield data, returns above insecticide costs per hectare from Bt cotton were found to be generally higher than the returns per hectare from non-Bt cotton with insecticide spray(s), and they were considerably higher than those from non-Bt cotton without insecticide spray(s). For example, as shown in Table 2, mean per-hectare returns over the period 1983-2003 from simulated yield data on Bt cotton were $1,072; non-Bt cotton with insecticide spray(s), $992; and non-Bt cotton without insecticide spray(s), $453. The CV was 0.168 for Bt cotton, 0.122 for non-Bt cotton with insecticide spray(s), and 0.146 for non-Bt cotton without insecticide spray(s). Simulation results for mean returns and relative risk were similar to those obtained with the observed data (compare Tables 1 and 2).

Using observed data, farm returns above insecticide costs for an average-sized farm (293 hectares) planting Bt and non-Bt (conventional) cotton in the Mississippi Delta for 1997-2000 were calculated under different scenarios with differing refuge levels for “spray” and “no spray” regimes, respectively (Tables 3 and 4).

Table 2. Per-hectare returns above insecticide costs from simulated yields on Bt and non-Bt (refuge) cotton in the Mississippi Delta, 1983-2003.

Year	Bt returns	Non-Bt returns	
		with insecticide application(s)	without insecticide application(s)
1983	$1,197	$1,029	$473
1984	$1,429	$1,420	$688
1985	$1,278	$1,248	$594
1986	$982	$913	$409
1987	$1,473	$1,365	$658
1988	$1,293	$1,141	$535
1989	$1,191	$1,191	$562
1990	$1,274	$1,172	$552
1991	$1,455	$1,393	$673
1992	$1,099	$1,085	$504
1993	$869	$753	$321
1994	$1,210	$1,106	$515
1995	$1,101	$916	$411
1996	$1,243	$1,097	$511
1997	$1,407	$1,298	$621
1998	$1,164	$1,059	$490
1999	$1,064	$999	$457
2000	$930	$910	$408
2001	$916	$886	$394
2002	$1,152	$1,022	$469
2003	$1,288	$1,149	$539
Mean	$1,072	$992	$453
SD[1]	$180	$121	$66
CV[2]	0.168	0.122	0.146

[1]SD = Standard Deviation.
[2]CV = Coefficient of Variation = SD/Mean.

Table 3. Total farm returns above insecticide costs under various refuge scenarios in the Mississippi Delta, 1997-2000, without insecticide spray application(s): Regime 1.[1]							
z [2]	1997	1998	1999	2000	Mean	SD[3]	CV[4]
			Without Insecticide Spray (τ = 0)				
0	$315,884	$292,472	$247,604	$253,547	$277,377	$32,480	0.117
1	$313,845	$290,520	$245,836	$251,754	$275,489	$32,351	0.117
5	$305,688	$282,711	$238,761	$244,580	$267,935	$31,834	0.119
10	$295,492	$272,951	$229,917	$235,614	$258,494	$31,188	0.121
20	$275,100	$253,429	$212,230	$217,680	$239,610	$29,895	0.125
26	$262,865	$241,717	$201,617	$206,920	$228,280	$29,120	0.128

[1]An average-sized cotton farm in the Mississippi Delta (293 hectares) is assumed, where both Bt and non-Bt cotton are grown.
[2]Percentage of non-Bt cotton planted as refuge.
[3]SD = Standard Deviation.
[4]CV = Coefficient of Variation = SD/Mean.

Consider the case when no sprays were applied [i.e., $\tau = 0$ in equation (2)] as Regime 1. This is shown in Table 3 for observed data (1997-2000). Similarly, the case when sprays were applied [i.e., $\tau = 1$ in equation (2)] may be considered as Regime 2 (Table 4). As shown in Tables 3 and 4, for each regime, higher mean net returns were obtained from lower refuge requirements. However, in each year, considerably smaller decreases in returns were observed with increased refuge requirements when sprays were applied (i.e., in Regime 2). CVs were similar in both regimes. Thus, lower refuge percentages provided higher mean returns without increased risk regardless of whether insecticide sprays were allowed.

With simulated data for the period 1983-2003, for any increase in z, mean returns decreased at successive levels of refuge (z) regardless of spray application(s). Insecticide sprays caused mean returns to remain relatively more stable and CVs to decrease, similar to observed data. That is, for any positive refuge level, mean returns were generally higher (while CVs remained about the same) when an insecticide was sprayed (i.e., for $\tau = 1$) than when it was not (i.e., for $\tau = 0$), signifying higher returns without increased risk when insecticides were allowed. This is consistent with the results previously discussed with observed data. (Detailed results on these simulations may be obtained from the authors upon request.)

To demonstrate how observed and simulated farm returns compare with each other — for the case when $z = 26\%$ — the observed farm returns for 1997-2000 both with and without insecticides are depicted in Figure 1. The corresponding results for simulated data are shown in Figure 2. Both observed and simulated returns had downward slopes and similar average differences in returns between the "spray" and "no spray" regimes. For 1997 through 2000, observed farm returns (above insecticide costs) were $308,822,

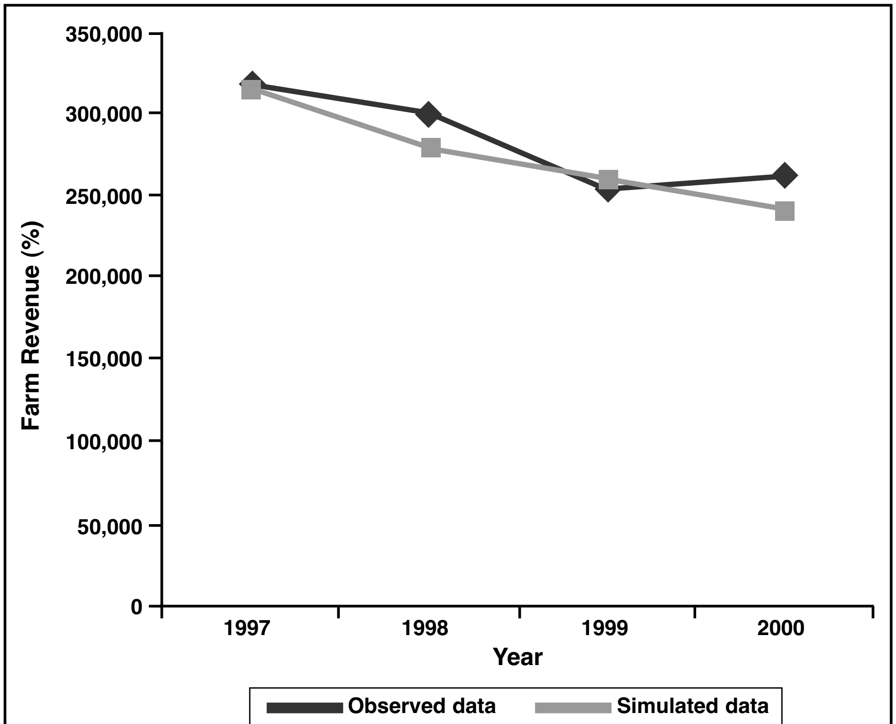

Figure 1. Observed farm-level returns above insecticide costs from Bt and non-Bt cotton, with and without insecticide spray application(s), in the Mississippi Delta for the period 1997-2000, with 26% non-Bt cotton (refuge).

Table 4. Total farm returns above insecticide costs under various refuge scenarios in the Mississippi Delta, 1997-2000, with insecticide spray application(s): Regime 2.[1]							
z [2]	1997	1998	1999	2000	Mean	SD[3]	CV[4]
			With Insecticide Spray (□= 1)				
0	$315,884	$292,472	$247,604	$253,547	$277,377	$32,480	0.117
1	$315,613	$292,152	$247,281	$253,248	$277,074	$32,496	0.117
5	$314,526	$290,874	$245,986	$252,049	$275,859	$32,557	0.118
10	$313,168	$289,275	$244,368	$250,551	$274,341	$32,634	0.119
20	$310,452	$286,078	$241,131	$247,554	$271,304	$32,789	0.121
26	$308,822	$284,160	$239,189	$245,756	$269,482	$32,882	0.122

[1]An average-sized cotton farm in the Mississippi Delta (293 hectares) is assumed, where both Bt and non-Bt cotton are grown.
[2]Percentage of non-Bt cotton planted as refuge.
[3]SD = Standard Deviation.
[4]CV = Coefficient of Variation = SD/Mean.

$284,160, $239,189, and $245,756, respectively, for the "spray" regime (τ = 1). For the same period, observed farm returns were $262,865, $241,717, $201,617, and $206,920, respectively, for the "no spray" regime (τ = 0). The average difference in returns was $41,202. For the simulated data shown in Figure 2, farm returns were $401,679, $333,639, $297,753, and $279,045, respectively, for the "spray" regime (τ = 1). Simulated farm returns were $367,397, $306,309, $275,435, and $258,266, respectively, for the "no spray" regime (τ = 0). The average difference in returns was $26,177, only $15,025 lower than the average difference in returns obtained from the observed data. Thus, the simulated results for a broader geographical area compare well with actual observed data.

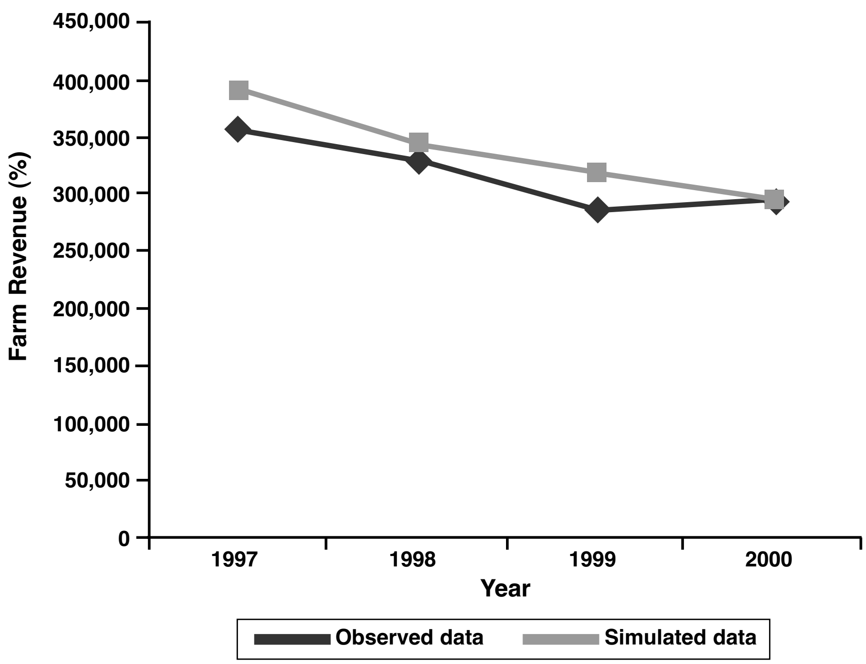

Figure 2. Simulated farm-level returns above insecticide costs from Bt and non-Bt cotton, with and without insecticide spray application(s), in the Mississippi Delta for the period 1997-2000, with 26% non-Bt cotton (refuge).

Conclusions and Further Research

Higher farm returns with less risk were apparent for Bt cotton with lower refuge requirements compared with non-Bt cotton for both observed and simulated data. For non-Bt cotton, the application of insecticides resulted in higher returns than without application.

Mean-variance results indicated that, regardless of sprays, a lower refuge percentage gave higher mean returns, even for the short period of time for which on-farm data were available (4 years). When coefficients of variation (CVs) were considered, risk was not increased with higher mean returns.

Comparing across regimes, for any positive refuge percentage (z), spray applications ($\tau = 1$) provided higher mean returns than no applications ($\tau = 0$). Considering relative risk, as given by a CV comparison between regimes, for any positive z, returns were not only higher but also relatively stable when insecticides were applied. However, if there were no restrictions on refuge requirements, a lower z would be preferred regardless of spray applications for both observed and simulated data.

While results may seem somewhat intuitively obvious to those involved in agriculture, this may not be the case for those not involved in daily agricultural activities, especially regulatory agencies. Additionally, to the authors' knowledge, this analysis is the only documentation of the costs of refuges to cotton producers.

One limitation of this current study is the lack of availability of individual farm yield data for any longer than 4 years. Another limitation of the current research is the lack of available pest loss data. Additional entomological research on the actual yield losses (or lack thereof) on non-Bt cotton in light of approximately 80% of the total U.S. cotton acreage being planted to Bt varieties might suggest a different yield loss for unsprayed areas and thus lead to different conclusions.

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