COMPARATIVE EVALUATION OF ECONOMIC AND ENVIRONMENTAL IMPACTS OF TRANSGENICALLY MODIFIED CROPS WITH SYNTHETIC CHEMICALS FOR INSECT CONTROL ON COTTON

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Abstract

This presentation combines both a review of the literature and original data from our research. The comparative efficacy of *Bacillus thuringiensis* (Berliner) traits Bollgard, Bollgard II, WideStrike, and non-Bt expressing cotton, *Gossypium hirsutum* L., for control of the noctuid complex of bollworm, *Helicoverpa zea* (Boddie), fall armyworm, *Spodoptera frugiperda* (J. E. Smith), beet armyworm, *Spodoptera exigua* (Hübner), and cabbage looper, *Trichoplusia ni* (Hübner), were evaluated in the Lower Rio Grande Valley of Texas during 2005-2009. Noctuid larval survival and damage to leaves on non-Bt cotton were 3.6-fold greater than on Bollgard II or WideStrike cotton and 1.5-fold greater than on cotton varieties with the Bollgard trait. Transgenic cotton has reduced the need for conventional insecticides with benefits to human health and the environment. The revenue differences between Bt and conventional cotton for last four years in LRGV of Texas was $214.3/ha and profit about $94.9/ha. We also analyzed cotton noctuid losses between Bt and conventionally grown cotton in the USA summary of all states and Texas summary of all regions.

Introduction

Cotton, *Gossypium hirsutum* L., is an important fiber crop of the USA being cultivated on 4.5 million hectares (average for 2006-2010) representing approximately 1/8 of the global area of 35 million hectares under this crop. After China (7.8 million tons production) and India (4.9 million tons production), the USA is the largest producer (2.8 million tons) from total world production 23.2 million tons in 2008-2009 (Cotton Incorporated 2009). One of the practical means of increasing crop production is to minimize the pest-associated losses. Estimates of crop losses vary widely by location and year, but about one-third of potential global agricultural production of food, fiber, and feed in developing countries is destroyed annually by over 20,000 pest species. Total annual losses are estimated at about $300 billion. Estimates of average yield loss range from 30 to 40% and generally much higher in many tropical and subtropical countries (Oerke, 2006). Pest-associated losses in the USA are currently estimated at 14% of total agricultural production and the total costs of pesticides applied for pest control valued at $10 billion annually (Sharma and Ortiz, 2000). Massive application of pesticides not only leaves harmful residues in the food, but also causes adverse effect on non-target organisms and the environment. The use of genetically modified (GM) cotton that expresses an insecticidal protein derived from *Bacillus thuringiensis* (Berliger) is revolutionizing global agriculture (Head et al., 2005). Global adoption of GM cotton has risen dramatically from 0.8 million ha in 1996 to 15.5 million ha in 2008, constituting 12.4% of total global hectares under GM crop. Bt cotton is the fourth most dominant transgenic crop at the global level and is commercially cultivated in 15 countries (James, 2008). In the last 5 years (2006-2010) in the USA about 65.8% of planted cotton was genetically modified; in Texas – 42.8%, and in the Lower Rio Grande Valley (LRGV) of Texas – 30.5% (Williams, 2007-2011). Assessing the efficacy of Bt cotton under new environmental and management regimes is important to growers because insect pressure varies by geography and weather conditions. There is incomplete information about diversity of noctuid species and their distribution during the cotton growing season in the LRGV of Texas. Information about effectiveness of Bt cotton varieties on different densities of noctuids in LRGV is also fragmentary and insufficient. Transgenic plants reduce the need for conventional insecticides, providing benefits for human health and the environment. But the real economic and environmental impacts of GM crops used in combination with synthetic chemicals need further investigation. The objectives of this study were to (1) determine the seasonal species composition of noctuidae and their densities that affect cotton in LRGV, (2) evaluate response of transgenic cotton to noctuids in the LRGV, and (3) assess the economic and environmental impact of GM cotton in LRGV, Texas summary of all regions, and USA summary of all States.

Materials and Methods

A five-year field study (7-8 plots about 1.5-3.0 acres each) was initiated in 2006 in LRGV. Field trials were conducted at the North and South Farms of the Kika de la Garza Subtropical Agricultural Research Center, ARS-USDA, in Weslaco, Texas. Individual plots were 76.2-101.6 cm between rows and 75-100 m long. Planting date, seeding rate, fertilizer, furrow irrigation, and other production factors were maintained according to local agronomic practices (Blue Book. 2006-2010).

Pheromone traps were used seasonally to monitor species composition of noctuids in the LRGV. Ten traps per insect species [bollworm (BW), *Helicoverpa zea* (Boddie), and tobacco budworm (TBW), *Heliothis virescens* (Fabricius); fall armyworm (FAW), *Spodoptera frugiperda* (J. E. Smith); beet armyworm (BAW), *Spodoptera exigua* (Hübner)] were installed 1.2 m above the ground on support poles with 50 m between traps around the perimeter of plots. Each trap contained a dispenser and Pherocon cap (Trece, Inc., Salinas, CA) specific for each species. Dispensers were replaced every two weeks and traps were checked weekly.

Bt cotton types, traits, and varieties used in the experiments were: non-Bt trait (DP5415RR, AMX262R, and PHY425RF), Bollgard trait (NuCOTN33B and DP444BG/RR), Bollgard II trait (DP424BGII/RR and AMX1532), and WideStrike trait (PHY485WRF). Applications of insecticides against noctuids on non-Bt and Bt cottons were based on the economic threshold levels (Norman and Sparks, 2003, Castro et al. 2007; Greenberg and Alejandro, unpublished data). Methoxyfenozide (Intrepid® 2F) was applied at 0.11 lb ai/ac, or thiodicarb (Larvin® 3.2F) was applied at 0.75 lb ai/ac. For boll weevil control malathion (Fyfanon ULV9.9) was applied at 0.76 lb ai/ac according to the Boll Weevil Eradication Program.

The noctuid complex and damage to cotton plants were monitored each week beginning 40 days after planting and until defoliation. Monitoring consisted of walking diagonally from one corner of a plot to another. Five stops and five plants per stop were examined at random per each replication per treatment for a total of 75 plants from three replications per treatment. The total number of leaves per plant and leaves with feeding damage were recorded. The percentage of damaged leaves was calculated from the total leaves per plant. The rate of leaf damage was estimated based on the following categories defined by Greene et al. (1969): 0 = no apparent damage, 1 = minor feeding damage or ≤1% leaf area eaten, 2 = minor-moderate feeding damage or 1.1-5.0% leaf area eaten, 3 = moderate damage or 5.1-10.0% leaf area eaten, 4 = moderate-heavy damage or 10.1-30.0% leaf area eaten, and 5 = heavy damage or >30.0% leaf area eaten. The number of larvae per plant (100 plants per treatment) was estimated by shaking larvae onto a white drop cloth and recording the species. Damaged fruit (squares and bolls) was estimated from plants (75 plants per treatment) and collected from the ground. Fallen fruit was collected per 1 m^2 at 50 randomly selected sites. The number of damaged fallen fruit, insect species that damaged them, and number of live larvae in damaged fallen fruit were recorded. Identification of insects and their damage was according to Bohmfalk et al. (2002). Hand harvested cotton samples were processed using an Eagle laboratory gin (Continental Gin Co., Birmingham AL) to determine lint yield on Bt and conventional cotton plots.

Data were analyzed using one-way analysis of variance. Whenever significant F values were obtained, means were separated by Tukey's studentized range honestly significant difference (HSD) test ($\alpha = 0.05$). T-tests were used to test for significance between pairs of means (Wilkinson et al. 1992). We also analyzed cotton noctuid loss data between Bt and conventional cottons in the USA summary of all states and Texas summary of all regions as reported in the Proceedings of Beltwide Cotton Conferences (insecticide diversity and cotton losses due pests; yield, insecticides used, number of chemical sprays against lepidopteran, pest control cost, revenue (price, $/1kg cotton lint*yield), and profit (revenue – total pest cost).

Results and Discussion

Insect diversity and cotton losses due to pests

In the U.S. arthropod pests alone reduced annually overall cotton yield by $307 million in 2006 and $160.5 million in 2010 (Texas - $ 40.3 and $33.5 million, and in the LRGV - $ 6.5 and $3.4 million) (Williams, 2007, 2011). Cotton production is mainly threatened by Lepidoptera insect attacks. In the USA, BW, TBW, FAW, and BAW are the major lepidopteran insect pests of cotton (Williams, 2006-2010). In LRGV, the most prevalent noctuids captured in the pheromone traps were BAW (63.8% average per year during 2007-2009), FAW (26.5%), BW (7.9%), and TBW (1.8%). Cotton losses from the heliothine complex nationwide were 49.3 million metric kilograms ($78.9

million and 28.1% from total insect losses), with 18.5 million metric kilograms ($29.6 million and 49.6% from total insect losses) in Texas, and 1.1 million metric kilograms in the LRGV ($1.8million and 63.0% from total insect losses) (Williams, 2008, 2009). During the last two decades, BAW has become an increasingly destructive secondary pest of cotton in the US. In 1998 alone, 2.1 million hectares of cotton were infested with beet armyworm and losses were $19.2 million. The FAW is a destructive migratory pest of many crops in the Western Hemisphere where it seems to be common and widespread (Sparks, 1979; Young, 1979). The cabbage looper, *Trichoplusia ni* (Hübner), is a secondary pest of cotton, causing yield losses of as much as 70% without control (Schwartz, 1985).

Economic and environmental impacts synthetic chemicals for insect control

Synthetic chemicals continue to be the main tool for insect control. Worldwide, about 3 billion kg of pesticides are applied each year with a purchase price of nearly $40 billion per year (Pan-UK, 2003). In the U. S., approximately 500 million kg of more than 600 different pesticides types are applied annually at a cost of $10 billion (Pimentel and Greiner 1997). Despite the widespread application of pesticides in the U. S. at recommended dosages, pests (insects, plant pathogens, and weeds) destroy 37% of all potential crops. Insects destroy 13%, plant pathogens 12%, and weeds 12%. In general, each dollar invested in pesticides control return about $4 in protected plants (Pimentel, 1997). Conventionally grown cotton uses more insecticides than any other single crop and epitomizes the worst effects of chemically dependent agriculture. Each year cotton producers around the world use nearly $2.6 billion worth of pesticides – more than 10% of the world's pesticides and nearly 25% of the world's insecticides (http://www.panna.org/files/conventionalCotton.dv.html).

On agricultural crops in the U. S. about 74.1 million kg of insecticides were used. Over half of this amount was applied to cotton fields, corresponding roughly to 7.3 kg/ha of active ingredient per hectare (Gianessi and Reigner 2006). In Texas, the direct insect management treatment cost is $115.6/ha, whereas in the LRGV, the direct cost is $168.9/ha (Williams 2005-2007). Although, pesticides are generally profitable in agriculture, their use does not always decrease crop losses. For example, despite the more than 10-fold increase in insecticide (organochlorines, organophosphates, and carbamates) use in the United States from 1945 to 2000, total crop losses from insect damage have nearly doubled from 7% to 13% (Pimentel et al., 1991). This rise in crop losses to insecticides is, in part, caused by changes in agricultural practices.

Most benefits of pesticides are based on the direct crop returns. Such assessments do not include the indirect environmental and economic costs associated with the recommended application of pesticides in crops. An investment of about $10 billion in pesticide control each year saves approximately $40 billion in U. S. crops, based on direct costs and benefits. However, the indirect costs of pesticides use to the environment and public health need to be balanced against these benefits. Based on the available data, the environmental and public health costs of recommended pesticide use total more than $9 billion each year (Table 1) (Pimentel, 2005). Users of pesticides pay directly only about $3 billion, which includes problems arising from pesticide resistance and destruction of natural enemies. Society eventually pays this $3 billion plus the remaining $9 billion in environmental and health costs.

Table 1. Total estimated environmental and social costs from pesticide in the USA

Costs	Millions of $/year
Public health impacts	1,140
Domestic animals deaths and contaminations	30
Loss due to the destruction of natural enemies	520
Cost of pesticides resistance	1,500
Honey bee and pollination losses	334
Crop losses	1,391
Fishery losses	100
Bird losses	2,160
Groundwater contamination	2,000
Government regulations to prevent damage	470
Total	9,645

Effectiveness of noctuids to different Bt types and traits of cotton

During the 2005-2007 seasons, the average percentage of leaf damage on non-Bt trait was 1.5-fold greater than on Bollgard trait and 3.6-fold greater than on Bollgard II- and WideStrike-traits. The seasonal average damaged fruit (attributed to bollworm 88.5% and to a lesser extent beet armyworm) on non-Bt cotton (15.2%) was about 4.6-fold greater than on WideStrike (3.3%), 3.8-fold greater than Bollgard II (4.0%), and 1.7-fold greater than Bollgard (9.0%). Damage by noctuids on abscised cotton fruit was 39.0% for non-Bt, 28.5% for Bollgard, 12.6% for Bollgard II, and 8.5% for WideStrike cottons. In non-Bt cotton, live larvae were 6.2-fold greater than on WideStrike, 4.5-fold greater than on Bollgard II, and only 1.7-fold greater than on Bollgard. Live larvae in fallen fruit were 92.6% bollworm and 7.4% beet armyworm (Greenberg and Adamczyk, 2010).

Insect infestations vary widely across time and space, and the relative performance of Bt cotton is highest when pest pressure is heaviest. In all bioassays in the laboratory, the mortality of neonate beet armyworm, cabbage looper, bollworm, and fall armyworm was greater on dual Bt (Bollgard II) varieties (average 85.4%) than on single Bt (Bollgard) cotton (average 45.3%). Bollworm was the most susceptible to Bollgard (average mortality 68.8±2.0%), while mortality of BAW, cabbage looper (CL), and FAW was 35.2±3.4%, 51.6±2.7%, and 49.3±1.1%, respectively. Mortality of BAW after feeding on Bollgard II and WideStrike was 75.4±2.7% and 73.0±4.6, respectively, and significantly less than that of CL (94.1±2.8% and 92.0±2.6, respectively), BW (91.7±4.9% and 89.0±4.3%, respectively), or FAW (89.5±1.4% and 85.0±3.5%, respectively) (Greenberg and Alejandro, 2011; Greenberg et al., 2011).

Economic and environmental impacts transgenically modified cotton for insect control

Development and deployment of transgenic plants with insecticidal genes will lead to: (1)reduced amount of insecticides applied for lepidopteran control, (2) reduced exposure of farmers, farm labor and non-target organisms to the pesticides, (3) increased activity of natural enemies, (4) reduced amounts of pesticide residues in the food, and (5) a safer environment. An important advantage of Bt over chemical control of pests is that it prevents insects from damaging the cotton plants because the Bt control is always present in the plant. Bt crops also benefit from decreased dependence on weather conditions that affect the timing and effectiveness of insecticide applications. Chemical pest control is less effective and will generally result in crop losses in the presence of insect infestation. Farmers apply chemical controls only after noticing the presence of pests on the cotton plants, by which time damage has already occurred. As a result, Bt varieties have superior yield performance over a wide range of growing conditions (Fernandez-Cornejo and McBride, 2000).

Field studies of the performance of Bt cotton have been completed in Mexico (Traxler et al., 2003), Argentina (Qaim and de Janvry, 2003), Australia (Fitt, 2001), South Africa (Ismail et al., 2001), China (Pray et al., 2001), India (Qaim and Zilberman, 2003), and USA (Alejandro, based on analizing data Williams, 2008-2010, and his observations). The results were described in Table 2.

Table 2. Performance differences between Bt and conventional cotton

	Argentina	Australia	China	India	Mexico	South Africa	USA	Texas USA	LRGV Texas
(Bt – conventional)									
Lint Yield, kg/ha	+531	-122	+523	+699	+170	+91	+181.0	+118.2	+150.4
Insecticide use, %	-47	n/a	-65	-41	-77	-33	-59.4	-74.7	-60.3
Chemical sprays, #	-2.4	-4.8	n/a	-3.0	-2.2	n/a	-2.1	-1.8	-2.5
Revenue, $/ha	+121	n/a	+13	n/a	+248	n/a	+257.9	+168.4	+214.3
Pest control, $/ha	-34.85	-80	-230	-30	-157	+4.5	-16.2	-9.6	-38.9
Profit, $/ha	+22.9	-46	+470	+135	+335	+29	+140.9	+77.8	+94.9

Summary

Traxler et al. (2003) estimated that the benefits gained from the introduction of Bt cotton fluctuates from year to year, but averaged $215 million. In the USA, the number of pesticide applications used against lepidopteran pests in conventional cotton has fallen from 4.3 in 1995 to 0.7 in Bt cotton in 2009, which can provide significant environmental benefits including the potential for increased income, convenience of the system, potential to have less spray equipment, improved insect control, reduced natural target organisms exposure, improve water quality, and reduce energy use.

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