LARGE SCALE EVALUATION OF BOLLGARD RESISTANCE TO MULTIPLE PESTS IN NORTH CAROLINA UNDER GROWER CONDITIONS

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Abstract

In a two-year, large-scale evaluation of the efficacy of Bollgard vs. conventionally-protected cotton under grower conditions in North Carolina, 115 Bollgard and 115 conventional cotton fields were evaluated for bollworm (*Helicoverpa zea*) (Boddie), European corn borer (ECB) (*Ostrinia nubilalis*) (Hubner), fall armyworm (FAW),(*Spodoptera frugiperda*) (J.E. Smith) and stink bug, primarily *Acrosternum hilare* (Say) and *Euschistis servus* (Say) damage to bolls in 1996 and in 1997. In each field, a 100-boll sample was evaluated for damage from the above species. Conventional cotton fields were grown in close proximity to the Bollgard fields, and typically managed the same producer. Essentially all of the Bollgard fields were NuCOTN 33b in both years. For an indication of longer term historical damage from these pests, the 1996 and 1997 Bollgard vs. conventional damaged boll evaluations were compared to long-term damaged boll surveys taken in conventionally-protected cotton fields in North Carolina from 1985 through 1995. The sample size of these latter historical conventional fields ranged from 214 fields in 1985 to 297 cotton fields in 1996.

In 1996, the 115 Bollgard fields sustained just under half as much damage from bollworms, 2.30% (vs. 4.62%) as did the 115 pyrethroid-protected fields; in 1997 bollworm damage to Bollgard fields was 0.97% vs. 3.75% in the conventional fields. However, the Bollgard fields expressed about 4-fold higher levels of stink bug damage than the conventional fields in both 1996 (3.03% vs. 0.75%) and in 1997 (2.23% vs. 0.53%). European corn borer (ECB) and fall armyworm (FAW) damage in the Bollgard fields were 1/10 and 4/10 to 2/3 of the boll damage found in the conventional fields, respectively. Total boll damage was 5.41% in the 115 Bollgard fields and 5.81% in the 115 pyrethroid-protected fields in 1996 and 3.54% and 5.32% in the Bollgard and conventional fields, respectively, in 1997.

Based upon a large-scale consultant and grower survey, 0.58 and 0.48 insecticide applications (all pyrethroids) were used on the Bollgard fields in 1996 and in 1997, respectively, while conventional fields were treated an average of 3.06 and 1.99 times, respectively, in 1996 and in 1997 with foliar insecticides, essentially all pyrethroids.

Given seed, technology fee, scouting, insecticide and application costs and the insect damage of the respective technologies, insect control costs (not including thrips, aphid, mite and plant bug control) on Bollgard vs. conventional cotton were $39.83 vs. $30.87/acre in 1996 and $38.82 vs. $30.83/acre in 1997, respectively.

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Introduction

Although Bollgard has an economic advantage in insect control over untransformed conventional cotton in areas where tobacco budworms are present at moderate to high levels and have become resistant to pyrethroids and other compounds (Layton, et al, 1997, Benedict, et al, 1993, and others), the utility of this technology is far less clear in areas of lower caterpillar pressure and/or in areas or situation in which bollworms are the primary target of cotton producers, such as the upper southeastern cotton-producing states; South Carolina, North Carolina and Virginia. In these states, a number studies can now be cited on the efficacy of transgenic Bollgard cotton on various lepidopterous larvae. However, most of these component-oriented studies have dealt with the bollworm complex, or with only single species (Durant, 1994; Lambert, et al., 1996, 1997; Mahaffey, et al., 1995; Turnipseed et al., 1995; Turnipseed and Greene, 1996). Three published research studies focused on the complex of late-season, boll-damaging pests (Mahaffey, et al., 1994 ; Bacheler and Mott, 1996, 1997), although the first two of these studies were conducted in replicated small plots which were modified to enhance insect pressure. Only two studies on the efficacy of Bollgard cotton compared to conventionally-protected cotton in a moderate to large scale commercial setting have been published from the southeastern region, both encompassing a single year's insect and agronomic conditions (Bacheler, et al., 1997; Roof, et al., 1997).

Our paper reports on large-scale whole-field comparisons of the efficacy of Bollgard vs. conventionally-protected, untransformed cotton against multiple pests under grower conditions during a period of both atypically high and low bollworm pressure, 1996 and 1997, respectively.

Materials and Methods

Paired Comparison Evaluations

In 1996 and 1997, 115 representative Bollgard cotton fields were located in 21 and 17 counties, respectively, throughout North Carolina with the assistance of independent crop consultants and county agents. A second sample of 115 untransformed, conventionally-protected fields, grown in close proximity to the Bollgard fields and typically managed by the same producer, was also selected both years (n = 460 fields total). To archive the long-term temporal (year to year) and spatial (different North Carolina regions of cotton production) impact of late-season bollworms, European corn borers, fall armyworms and stink bugs, damaged boll ratings from a survey begun in 1985 were also utilized. In

1985, 214 conventionally-protected cotton fields were assessed for boll damage. This sample size was increased slightly each year- 297 conventional cotton fields were used in 1996.

A sample of 100 bolls was inspected for damage by bollworms, ECB, FAW and stink bugs, just prior to boll opening as described by Bacheler and Mott (1995).

Consultants' Bollgard Cotton Survey

All licensed independent crop consultants and a sample of 20 randomly-selected cotton producers were surveyed by mail in 1996 and 1997 and asked 1) their total cotton acreage, 2) acres of Bollgard and untransformed, non-Bt cotton, 3) number of treatments employed for Bollgard and conventional cotton and 4) an estimate of the additional scouting costs required for monitoring Bollgard cotton to obtain background information on how Bollgard cotton was managed. These samples constituted approximately 38% of North Carolina's total cotton acreage.

Results

Bollgard vs. Conventional Cotton Comparisons

The conventional cotton fields required 3.03 and 1.99 insecticide treatments (almost all pyrethroids; excluding thrips at-planting and foliar treatments) in 1996 and 1997, respectively, while the Bollgard fields required 0.58 and 0.48 insecticide treatments in 1996 and 1997, respectively (Figure 1). The long-term (1985 to 1997) insecticide average for conventional cotton 2.83 applications, with a range of 1.83 to 3.8 applications.

Bollworm damage to conventional cotton was 4.62 vs. 2.3% damaged bolls in conventional vs. Bollgard cotton in 1996, and 3.75 vs. 0.97% damaged boll in conventional vs. Bollgard cotton in 1997, respectively (Figure 2). Thus, the Bollgard cotton sustained 2- to 3-fold less boll damage than the conventional cotton, as managed by North Carolina cotton producers in 1996 and 1997. The long-term boll damage to conventional cotton was 3.95%, with a range of 1.25 to 6.6%.

European corn borer (ECB) damage to conventional cotton was 0.34 vs. 0.03% damaged bolls in conventional vs. Bollgard cotton in 1996, and 0.18 vs. 0.006% damaged bolls in conventional vs. Bollgard cotton in 1997, respectively (Figure 3). Thus, the Bollgard cotton sustained 11 to 30-fold less ECB boll damage than the conventional cotton, as managed by North Carolina cotton producers in 1996 and 1997. The long-term boll damage to conventional cotton was 1.46%, with a range of 0.18 to 6.2%.

Fall armyworm (FAW) boll damage to conventional cotton was 0.1 vs. 0.06% damaged bolls in conventional vs. Bollgard cotton in 1996, and 0.86 vs. 0.33% damaged bolls in conventional vs. Bollgard cotton in 1997, respectively (Figure 4). Thus, the Bollgard cotton sustained approximately 38 to 60% as much damage to FAW as did the conventionally-protected cotton fields, even though the conventional cotton fields were treated more with pyrethroids. The long-term boll damage caused by FAW was 0.66% damaged bolls, and the range 0.0 to 2.4%.

Stink bug damage was 0.75 vs. 3.03% damaged bolls in conventional vs. Bollgard cotton in 1996, and 0.53 vs. 2.23 % damaged bolls in conventional vs. Bollgard cotton in 1997, respectively (Figure 5). Bollgard cotton sustained approximately 4-fold higher stink bug damage than conventional cotton in both 1996 and 1997. The long-term boll damage to conventional cotton by stink bugs was 0.58%, with a range of 0.2 to 2.24%.

Overall boll damage to the conventional and Bollgard fields was 5.57 and 4.49%, respectively, for 1996 and 1997 averaged, an advantage of approximately 1% (Figure 6) for Bollgard cotton, as managed by cotton producers.

Consultants' Bollgard Cotton Survey

The responding consulting firms working on cotton managed 7,418 and 7,596 acres of Bollgard in 1997 and 1997, respectively. In both years, Bollgard cotton was planted to approximately 3% of North Carolina's total cotton acreage, or about 19,000 and 20,000 acres in 1996 and 1997, respectively. In 1996, 44% of the Bollgard acreage was untreated, 53% treated a single time, and the remaining 3% treated twice, for an average of 0.58 applications. In 1997, 54% of the Bollgard acreage was untreated, 44% treated once, and the remaining 2% treated twice, for an average of 0.48 applications. No Bollgard cotton was treated for early (June through early July) tobacco budworms by this group, although only 7.1% and 0.5%of the non-Bollgard acreage was treated for budworms by consultants in 1996 and 1997, respectively (JSB, Cotton Insect Losses). Additionally, almost no Bollgard cotton was treated specifically for stink bugs. In 1996 and 1997, conventional cotton managed by crop consultants was treated an average of 3.06 and 1.99 times per acre, respectively, almost exclusively for bollworms.

In a small informal survey of approximately 20 producers and 12 county agents in 1996 and 1997, which accounted for about 40,000 acres of cotton not managed by consultants, the average number of foliar insecticide applications on conventional cotton was 2.9 and 1.95, respectively, very close to the figures supplied by the independent crop consultants.

Consultants indicated that a realistic estimate of the extra cost for scouting Bollgard cotton, taking into consideration the higher monitoring frequency, the more exacting and different monitoring requirements (not overreacting to eggs or to the tiny 1st-stage larvae, judging what constitutes a 2nd-stage larva, monitoring for stink bugs, etc.), would be in the range of $2.50 to $5.00 per acre compared with conventionally-protected non-Bollgard cotton. However,

given an anticipated producer/client reluctance to pay this much of a scouting cost increase, the consultants actually charged their clients just under $1.00 per acre for scouting Bollgard cotton in 1996 and in 1997, with most collecting identical scouting fees for both Bollgard and conventional cotton.

Economic Comparison of Bollgard vs. Conventional Cotton

Tables 1 and 2 show a simplified economic comparison of insect control of Bollgard vs. conventional cotton based upon data collected from the damaged boll surveys. An explanation of the costs and fees associated the Bollgard and conventional cotton are provided in the footnotes of each table. The Bollgard cotton required extra costs for the transformed seed, scouting and the technology fee, while the conventional cotton cost more than the Bollgard cotton insect damage, for early season budworm control (the Bollgard cotton was not treated for early budworms in either year), for late season caterpillar control. Applications for thrips, plant bugs, cotton aphids and spider mites were the same for both technologies, and thus 'zeroed out'.

In 1996, Bollgard vs. conventional cotton costs (with insect damage costs taken into consideration), were $39.83 vs. $30.87, respectively. At $9.20 per acre for a single treatment (pyrethroid plus application cost), an average break-even point for Bollgard cotton would have been 4.33 applications: $39.83/$9.20 = 4.33 (Table 1). In 1997, Bollgard vs. conventional cotton costs (with insect damage costs taken into consideration), were $38.82 vs. $30.83, respectively for an average break-even point for Bollgard cotton of 4.22 applications: $38.82/$9.20 = 4.22 (Table 2). With these insect control cost comparisons, yield and quality information were not taken.

Regional North Carolina Bollworm Damage Comparisons

Interestingly, the relative efficacy trend of Bollgard vs. conventional cotton was similar when comparisons were made in different parts of the state in 1996, even though these areas differed in their boll damage (Figure 7). Bollgard cotton sustained approximately 57, 30, 55 and 38% as much boll damage from bollworms as did the conventionally-protected cotton in the piedmont, the western piedmont, the central and southeast coastal plain and the southern regions of the state, respectively.

Conclusions

Across a large sample of 460 cotton fields managed by North Carolina producers in 1996 and 1997, Bollgard cotton, which was treated an average of 0.52 times with pyrethroids, sustained consistently less boll damage by bollworms and European corn borers than did conventionally-protected cotton which was treated an average of 2.51 times. These results took place in an atypically very heavy (1996) and a very light (1997) year for bollworms, as measured by light trap counts of adult moths, egg deposition, damage to untreated checks in replicated tests and general observations. It would appear that this technology, when protected from bollworms as needed, offers North Carolina producers bollworm control generally greater than with pyrethroids alone.

Fall armyworms were also held to somewhat lower levels in the less-treated Bollgard cotton, suggesting that at least partial control of falls was evident with this technology under grower conditions. European corn borers were almost totally eliminated in Bollgard cotton. These pests should present no problem wherever this technology is used, provided genetic resistance to the Bollgard endotoxin is not a factor.

Although boll damage due to stink bugs was not alarming in Bollgard cotton during the past two years, the 2.2 to 3.3% boll damage in the Bollgard cotton fields was approximately 4-fold higher than in the conventional cotton fields. Even at this damage level, scouting efforts directed specifically toward stink bugs is in order, particularly in Bollgard fields not treated for bollworms. Stink bug damage to bolls was only present at moderate levels across the board North Carolina in 1996 and 1997 (0.75 and 0.53%). In a year like 1987 which experienced a mean of 2.24% stink bug damage in conventional producer-managed cotton fields, untreated Bollgard fields could be expected to average 8 to 10% boll damage. The potential for greater stink bug damage than experienced on Bollgard cotton in 1996 and 1997 is high.

Because of the high (for our region) $32.00 fee for the use of Bollgard technology, even when one considers the lower boll damage and the greater overall efficacy with this technology under actual grower conditions, a producer would need to make over 4 applications for caterpillars to break even with Bt cotton. Aside from situations where the deployment of Bollgard cotton is logical (out-of-the-way and/or difficult to treat fields, cotton planted near schools, hospitals or other public areas, cotton grown adjacent to aquatic systems, etc), Bt technology, at $32.00 per acre, will be hard to sell to the mainstream cotton producer in North Carolina who traditionally pays less than $27.00 for caterpillar control.

Acknowledgment

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References

Bacheler, J.S. and D.W. Mott 1995. Annual fluctuations in late season boll damage from major lepidopterous pests in North Carolina: a ten-year perspective, pp. 783-786. In, D.J. Herber (ed.) Proc., 1995 Beltwide Cotton Conferences. National Cotton Council, Memphis, Tenn.

Bacheler, J.S. and D.W. Mott 1996. Potential utility and susceptibility of transgenic *B.t.* cotton against bollworms, European corn borers, fall armyworms and stink bugs in North Carolina., pp. 927-931. In, P. Dugger and D.A. Richter (eds.) Proc., 1996 Beltwide Cotton Conferences. National Cotton Council, Memphis, Tenn.

Bacheler, J.S., D.W. Mott and D. Morrison. 1997. Efficacy of grower-managed Bt cotton in North Carolina. pp. 856-858. In, P. Dugger and D.A. Richter (eds.) Proc., 1997 Beltwide cotton Conferences. National Cotton Council, Memphis, Tenn.

Benedict, J.H., D.R. Ring, E.S. Sachs, D. Altman, R.R. DeSpain, T. Stone and S.R. Sims. 1992. Influence of transgenic Bt cotton on tobacco budworm and bollworm behavior, survival and injury. pp. 891-895. In, D.J. Herber and D.A. Richter (eds.) Proc., Betlwide Cotton Conferences. National Cotton Council, Memphis, Tenn.

DuRant, J.A., 1994. Evaluation of treatment threshols for control of bollworms and tobacco budworms in transgenic *B.t.* cotton in South Carolina, pp. 1073-1075. In, D.J. Herber (ed.), Proc., 1994 Beltwide Cotton Conferences. National Cotton Council, Memphis, Tenn.

Lambert, A.L., J.R. Bradley, Jr. and John Van Duyn. 1996. Effects of natural enemy conservation and planting date on the susceptibility of *B.t.* cotton to *Helicoverpa zea* in North Carolina, pp. 931-935. in, P. Dugger and D.A. Richter (eds.), Proc., 1996 Beltwide Cotton Conferences. National Cotton Council, Memphis, Tenn.

Lambert, A.L., J.R. Bradley, Jr. and J.W. Van Duyn. 1997. Interactions of *Heliocoverpa zea* and Bt cotton in North Carolina, 870-873. In, P. Dugger and D.A. Richter (eds.), Proc. Beltwide Cotton Conferences. National cotton council, Memphis Tenn.

Layton, M.B., M.R. Williams and S. Stewart. 1997. Bt cotton in Mississippi: the first year, pp. 861-863. In, P. Dugger and D.A. Richter (eds.), Proc., 1997 Beltwide Cotton Conferences. National Cotton Council, Memphis, Tenn.

Mahaffey, J.S., J.S. Bacheler, J.R. Bradley, Jr. and J.W. Van Duyn. 1994. Performance of Monsanto's transgenic *B.t.* cotton against high populations of lepidopterous pests in eastern North Carolina, pp. 1061-1064. In, D.J. Herber and D.A. Richter (eds.), Proc., 1994 Beltwide Cotton Conferences. National Cotton Council, Memphis Tenn.

Mahaffey, J.S., J.R. Bradley, Jr. and J.W. Van Duyn. 1995. *B.t.* cotton: field performance in North Carolina under conditions of unusually high bollworm populations, pp. 795-798. In, D.J. Herber and J. Armour (eds.), Proc., 1995 Beltwide Cotton Conferences, Memphis Tenn.

Turnipseed, S.G., and J.K. Greene. 1996. Strategies for managing stink bugs in *B.t.* cotton, pp. 935-936. In, P. Dugger and D.A. Richter (eds.), Proc., 1996 Beltwide Cotton Conferences. National Cotton Council, Memphis, Tenn.

Turnipseed, S.G., M.J. Sullivan, J.E. Mann and M.E. Roof. 1995. Secondary pests in transgenic *B.t.* cotton in South Carolina, pp. 768-769. In, D.J. Herber (ed.), Proc., 1995 Beltwide Cotton Conferences. National Cotton Council, Memphis, Tenn.

Table 1. Simplified economic comparison of insect control of Bollgard vs. Conventional cotton based upon 1996 insect pressure and cost.

Input	Bollgard	Conventional
Seed	1.40	0.00
Scouting [1]	1.00	0.00
Technology Fee	32.00	0.00
Insect Damage [2]	0.00	2.09
Insect Control (Early budworm) [3]	0.00	0.63
Insect Control (Late-season insects)	5.43	28.15
Total	$39.83	$30.87

[1] Mean of collected scouting fees; [2] Cost of higher insect damage; [3] 7.1% acreage treated for early budworms. Application cost @ $9.20 / acre.

Table 2. Simplified economic comparison of insect control of Bollgard vs. Conventional cotton based upon 1997 insect pressure and cost.

Input	Bollgard	Conventional
Seed	1.40	0.00
Scouting [1]	1.00	0.00
Technology Fee	32.00	0.00
Insect Damage [2]	0.00	12.47
Insect Control (Early budworm) [3]	0.00	0.05
Insect Control (Late-season insects)	4.42	18.31
Total	$38.82	$30.83

[1] Mean of collected scouting fees; [2] Cost of higher insect damage; [3] 0.5% acreage treated for early budworms. Application cost @ $9.20 / acre.

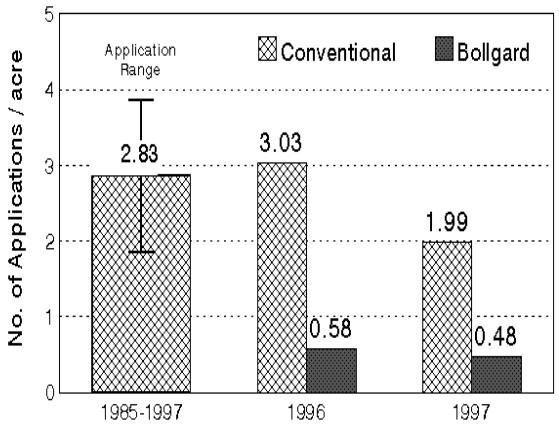

Figure 1. Comparison of application frequency for late season insects in 230 conventional vs. 230 Bollgard cotton fields in 1996-97, vs. 1985-1997 long-term average in North Carolina

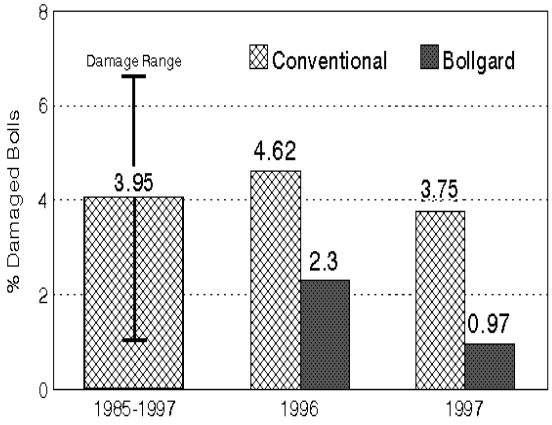

Figure 2. Boll damage by bollworms in 230 conventional vs. 230 Bollgard cotton fields in 1996-97, vs. 1985-97 long-term average in North Carolina

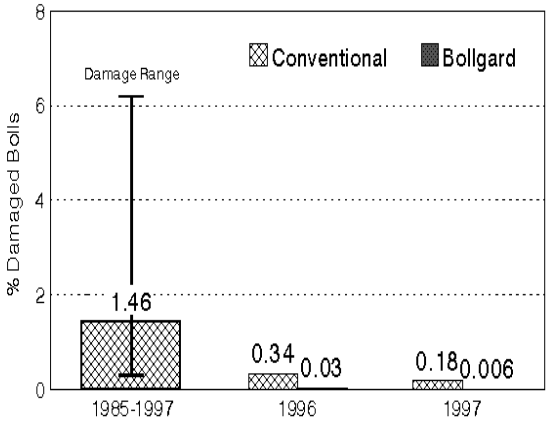

Figure 3. Boll damage by European corn borers in 230 conventional vs. 230 Bollgard cotton fields in 1996-97, vs. 1985-1997 long-term average in North Carolina

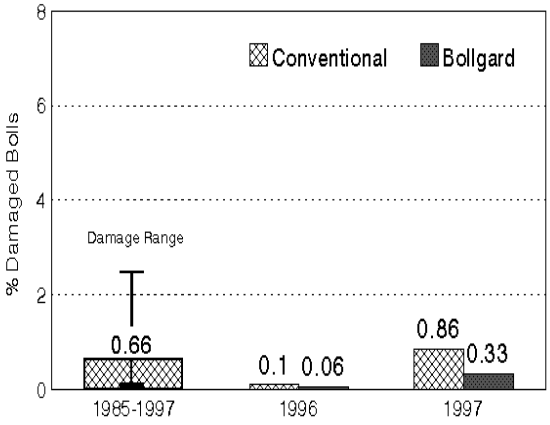

Figure 4. Boll damage by fall armyworms in 230 conventional vs. 230 Bollgard cotton fields in 1996-97, vs. 1988-1997 long-term average in North Carolina

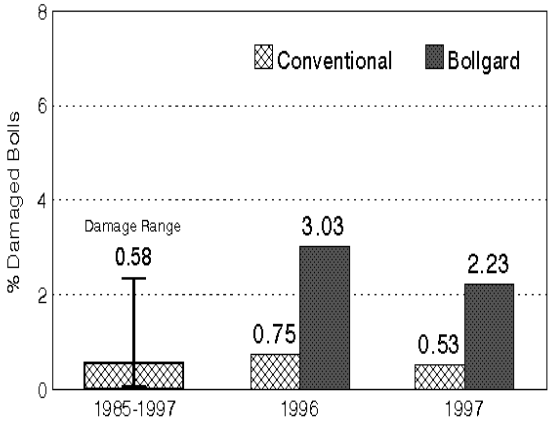

Figure 5. Boll damage by stink bugs in 230 conventional vs. 230 Bollgard cotton fields in 1996-97, vs. 1989-1997 long-term average in North Carolina

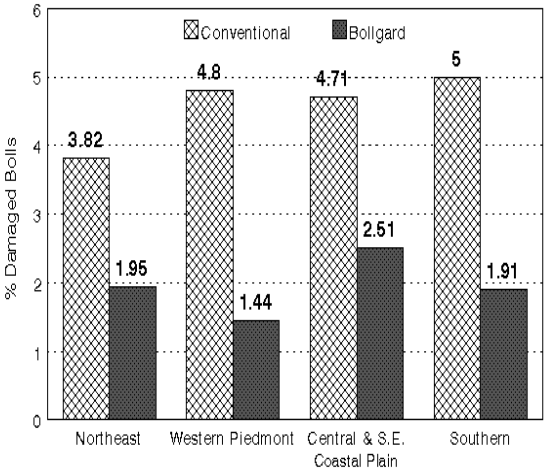

Figure 7. Bollgard vs. conventional damage to bolls by regions in North Carolina, 1996.

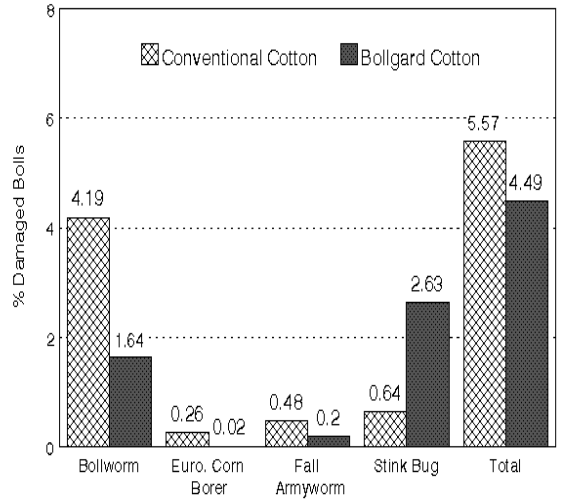

Figure 6. Boll damage by late season insects in 230 conventional vs. 230 Bollgard cotton fields in North Carolina, 1996-97