1940 The impact of high adoption of Bollgard®II cotton on pest management in Australia

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The adoption of Bt cotton varieties carrying resistance genes for *Helicoverpa punctigera* (Wallengren) and *H*. *armigera* (Hübner) by Australian cotton growers has been high. This has been particularly evident since 2004/05 when varieties carrying two Bt-genes (Bollgard®II) replaced varieties carrying a single Bt-gene (Ingard®). Conventional non-Bt cotton varieties have now been almost replaced by Bollgard®II varieties in Australia. The objective of this paper is to demonstrate the broad impact that Bt cotton, particularly Bollgard®II, has had on pest management in the Australian cotton industry. Data from annual unpublished and published reports on pesticide use and the performance Bt cotton in Australia were used to show the impacts of Bt cotton on the quantities and types of insecticide and acaricide applied, on the changes in target pest and on reasons growers choose to use the technology. In comparison to conventional non-Bt cotton, the adoption of Ingard® and Bollgard®II has reduced the average quantities of insecticide/acaricide applied by just over two-fifths and just over four-fifths respectively. While Ingard® was not fully effective in controlling *Helicoverpa* spp., Bollgard®II has been very effective and only requires chemical control for a range of sucking pests. The changes in pest management in Australian cotton since Bollgard®II replaced Ingard® in 2004 have been significant. Bollgard®II cotton requires less chemical spraying and while many cotton growers choose to plant it because of this benefit, they increasingly consider lifestyle benefits and improvements to worker safety as important reasons to plant it.

Keywords: Bt cotton, Ingard®, Bollgard®II, pest management, IPM

Introduction

Cotton growers in Australia have developed a highly efficient farming system that enables them to consistently produce some of the highest cotton yields in the world. In order to achieve these high yields Australian growers have had to effectively manage a range of major and secondary pests. A decade ago there was a strong reliance on insecticides for effective pest control, particularly for the Lepidopterous pests *H*. *punctigera* and *H*. *armigera* (Fitt 1994). Problems associated with a dependence on insecticide-based pest control practices include high cost, residuals, resurgence and resistance and were the initial driving factors for the early introduction of single Bt insecticidal gene INGARD® varieties in Australia in 1996. Since then, adoption of Bt cotton varieties by Australian cotton growers has been close to the maximum “capped” areas permitted by regulators. The cap was initially 10 percent of the planted area in 1996/97and was increased to a plateau of 30 percent in 2000/01 a level at which it was maintained until the 2003/04 season when Ingard® varieties were completely replaced with two Bt-gene Bollgard®II varieties. The removal of this cap led to rapid adoption of Bt varieties by Australian growers with 86 percent of the national crop planted to them in the 2006/07 season (Monsanto Australia Ltd Outlook Newsletter December 2006).

After Australian cotton growers had gained some experience growing Bt cotton, additional reasons for the high level of adoption were found to include the ease of integration of the technology into IPM strategies, the increased ease of management, environmental benefits (e.g. a reduction in pesticide residues onto non-target areas, in soil and water) and economic benefits (e.g. reduced costs, increased yields) (Pyke and Fitt 1998; Clark, 1999, Doyle *et al,* 2002). In an assessment of cotton grown in Australia between 1997/98 and 2003/04, Knox *et al* (2006) demonstrated that there was a 64 percent reduction in environmental impact in Bt cotton compared with conventional non-Bt cotton. This study also showed that for the 2002/03 and 2003/04 seasons the environmental impact value for Bollgard®II cotton was 79 percent less than conventional non-Bt cotton. These large differences in environmental impact are a result of major changes in pest arthropod management associated with the adoption of Bollgard®II varieties.

This paper aims to demonstrate what some of the management changes associated with the adoption of Bt cotton, particularly Bollgard®II have been. This is achieved by comparing insecticide/acaricide use in relation to quantity applied, target pest and chemical type.

Materials and Methods

Cotton Consultants Australia Inc. (CCA) survey their members annually to compile data on cotton area, varieties planted and spray applications for all Australian cotton growing regions. Between 1998 and 2006 the unpublished CCA Market Audit reports have covered between 45 and 76 percent of the total cotton crop planted in a season. The chemical application data from the surveys were weighted for each production area for each season using the official industry values for the planted area in each region compiled by the Australian Cotton Industry Council. After these adjustments, the data for dryland and irrigated cotton-growing regions were pooled to reflect seasonal insecticide and acaricide application rates per hectare of conventional non-Bt, Ingard® and Bollgard®II cotton for the whole Australian crop. Seasonal insecticide and acaricide use estimates were then used to calculate the quantities of active ingredient (a.i.) in kg per hectare for each product based on information on the label or obtained from the manufacturer. Total seasonal insecticide plus acaricide quantities for the whole Australian crop were then calculated per season.

Each year since 1998, the Cotton Research and Development Corporation (CRDC) has commissioned the CCA to survey their members and prepare a report on the performance of Bt cotton in Australia. The detailed data on yield, spray applications and target pests is derived from records submitted by CCA members on paired samples of Bt cotton and conventional non-Bt cotton crops. Each pair of Bt and non-Bt crop samples is chosen from fields on the same farm with similar soils and agronomic management to reduce the likelihood that factors other than pest management has contributed to the results. The CCA data used in this paper comparing Bollgard®II and conventional spray, target pest and product use was extracted from reports covering the 2003/04, 2004/05 and 2005/06 seasons (Doyle *et al,* 2005 and Doyle and Coleman, 2006). Data on the number of spray applications targeting *Helicoverpa* spp. and non-*Helicoverpa* spp, pests from these CCA reports were combined with unpublished data from Monsanto Ltd to increase the sample size for each of these seasons.

Data summarizing the reasons for growing Bt cotton were derived from the CCA reports by Clark 1999, Doyle *et al,* 2002 and Doyle and Coleman*,* 2006.

Results and Discussion

Figure 1 shows the percentage of the total area of the Australian cotton crop planted to non-Bt conventional, single Bt-gene Ingard® and two Bt-gene Bollgard®II cotton varieties for the twelve cotton seasons 1996/97 to 2006/07. It shows the effect of the staged approach taken by capping the areas of single Bt-gene varieties permitted. This was aimed at minimising the risk that resistance would develop in *H. armigera* populations before more effective and robust two Bt-gene varieties were introduced. The removal of the cap after the 2003/04 season was associated with a rapid adoption of Bollgard®II technology in subsequent seasons.

Figure 2 shows the estimated annual quantities of insecticide and acaricide applied to the Australian cotton crop in kg active ingredient per hectare between 1995/96 and 2005/06. These estimates were calculated from the usage statistics on non-Bt conventional and Bt cotton for up to sixty six individual products and show that insecticide and acaricide use has declined steadily since the late 1990s. The factors contributing to this decline were primarily the increasing adoption of Bt cotton, the introduction of newer insecticides with low application rates (e.g. ememectin benzoate, spinosins and indoxacarb) and the adoption of improved integrated pest management (IPM) practices.

Figure 3 compares the annual quantities of insecticide and acaricide applied to conventional, Ingard® and Bollgard®II areas of the Australian cotton crop in kg active ingredient per hectare between 1995/96 and 2005/06. In comparison to the average usage on conventional crops, average usage on Ingard® crops over the eight seasons 1995/96 to 2003/04 was 44 percent lower. Over the four seasons 2002/03 to 2005/06, average insecticide/acaricide usage was 82 percent less on Bollgard®II than on conventional crops. The efficacy of Ingard® varieties in controlling *Helicoverpa* spp. declined as the season progressed and some spraying for these pests was required in most seasons. This is reflected in the similar trends shown in Figure 3 for the seasonal insecticide/acaricide use estimates for conventional and Ingard®. In contrast, Bollgard®II cotton varieties generally display very effective, season-long control of *Helicoverpa* spp. and only require chemical control for a range of sucking pests. Further demonstration of the difference in pest management between Bollgard®II and convention cotton is shown in Figure 4 which compares frequency distributions (expressed as the percentage of paired fields of conventional and Bollgard®II cotton that received a specified number of sprays) for the seasons 2003/04, 2004/05 and 2005/06 combined. In addition to benefits linked to IPM, environment and economics, the reduction in spraying required on Bollgard®II crops is becoming more strongly associated with lifestyle and worker safety benefits by cotton growers (Table1).

The effectiveness of Bollgard®II technology for the control of *Helicoverpa* spp. is shown in Figure 5 which compares the average number of sprays applied per season for these pests to conventional and Bollgard®II crops.

Figure 6 compares the average number of sprays applied to conventional and Bollgard®II crops for a range of pests other than *Helicoverpa* spp. including: green mirids (*Creontiades dilutus* Stål), cotton aphid (*Aphis gossypii* Glover), two-spotted mite (*Tetranychus urticae* Koch), thrips (*Thrips tabaci* Lindeman and *Frankliniella schulzei* Trybom), green vegetable bug (*Nezara viridula* Linnaeus), jassids (*Austroasca viridigrisea* Paoli and *Amrasca terraereginae* Paoli), and silverleaf whitefly (*Bemisia tabaci* Type B). Conventional crops consistently require fewer sprays for these pests as a result of the coincidental control provided by the larger number of sprays targeting *Helicoverpa* spp. Figure 7 compares the percentage of sprays applied for target pests in conventional and Bollgard®II cotton in Australia averaged over the three seasons 2003/04, 2004/05 and 2005/06. This demonstrates that *Helicoverpa* spp. are the major pest in conventional cotton while mirids are the dominant target pests in Bollgard®II cotton. The differences pest management between conventional and Bollgard®II can also be measured by the types of insecticide and acaricide applied to control target pests. Figure 8 compares the number of sprays of different insecticide and acaricide products or groups applied to conventional and Bollgard®II cotton in Australia averaged over the three seasons 2003/04, 2004/05 and 2005/06.

Conclusions

The rapid adoption of Bollgard®II has fundamentally changed pest management of cotton in Australia and many of these changes are seen as beneficial. However, some challenges remain, particularly the need to continue to manage Bollgard®II for a range of sucking pests. This highlights that it will be important for Australian cotton growers to continue applying the current discipline in their IPM systems if the advantages that Bt technology has already delivered are to be maintained.

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Table 1. Major reasons and benefits Australian cotton growers have identified for growing Bt cotton

Season	*No. responses*	*Environmental benefits*	*Insect management benefits*	*Lifestyle, OH&S benefits*	*Economic & yield benefits*
1998/99	**125**	**80%**	**10%**	**10%**	**0**
2001/02	**173**	**27%**	**28%**	**17%**	**28%**
2005/06	**121**	**24%**	**18%**	**36%**	**22%**

List of Captions for Figures

Figure 1. Percentage of the total area of the Australian cotton crop planted to conventional, Ingard® and Bollgard®II cotton varieties.

Figure 2. Annual quantities of insecticide and acaricide applied to the Australian cotton crop between 1995/96 and 2005/06.

Figure 3. Annual quantities of insecticide and acaricide applied to conventional, Ingard® and Bollgard II® areas of the Australian cotton crop between 1995/96 and 2005/06.

Figure 4. Frequency distribution, expressed as the percentage of conventional and Bollgard®II cotton fields that received a specified number of sprays, in Australia for the seasons 2003/04, 2004/05 and 2005/06 combined

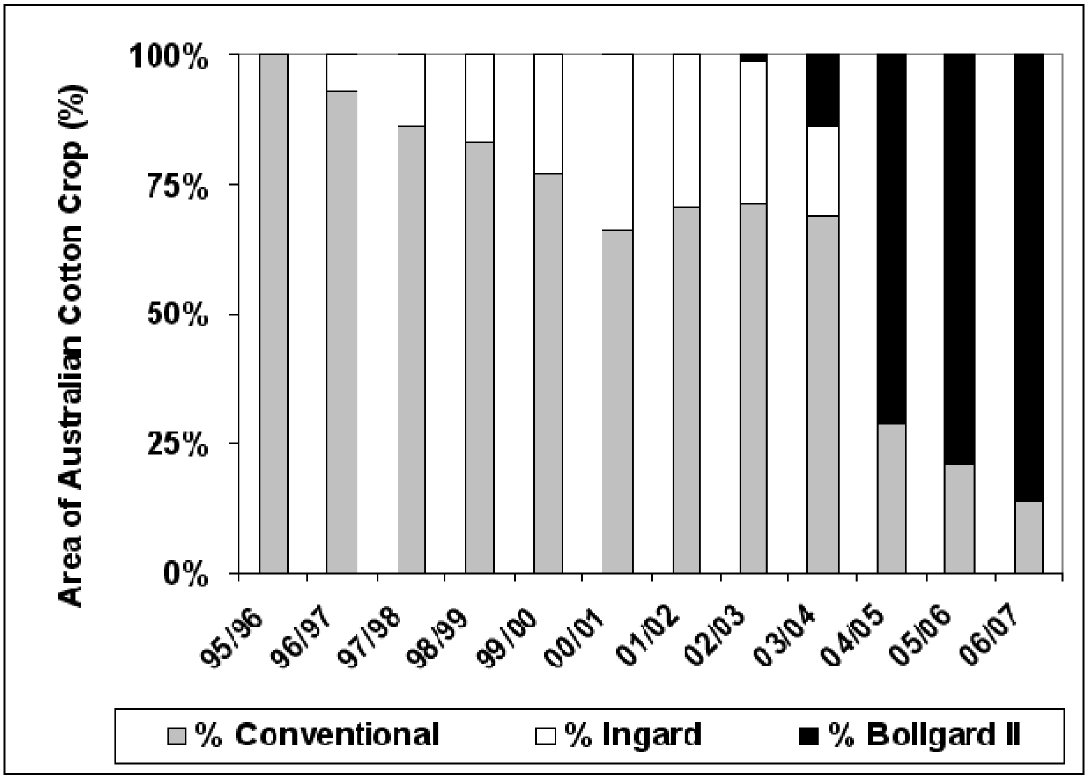
Figure 5. Number of sprays applied to conventional and Bollgard®II crops for *Helicoverpa* spp.

Figure 6. Number of sprays applied to conventional and Bollgard®II crops for all pests other than *Helicoverpa* spp.

Figure 7. Percentage of total sprays applied for target pests in conventional and Bollgard®II cotton in Australia averaged for seasons 2003/04 to 2005/06

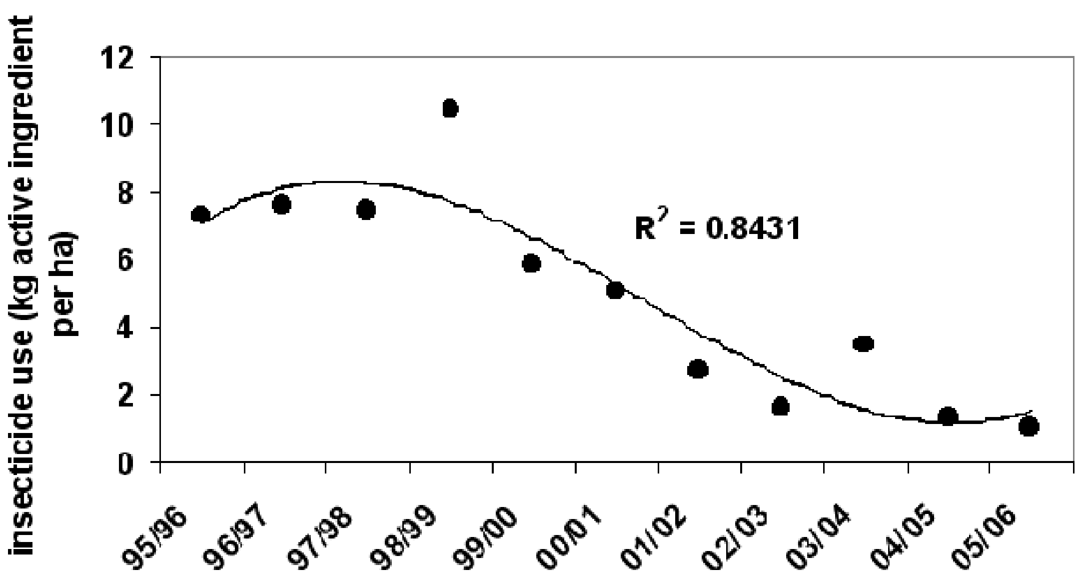
Figure 8. Average number of sprays of different insecticide and acaricide groups applied to conventional and Bollgard®II cotton in Australia between 2003/04 to 2005/06.

Fig. 1



100%
75%
50%
25%
0%
Area of Australian Cotton Crop (%)
95/96
96/97
97/98
98/99
99/00
00/01
01/02
02/03
03/04
04/05
05/06
06/07
% Conventional
% Ingard
% Bollgard II

Fig. 2



insecticide use (kg active ingredient per ha)
12
10
8
6
4
2
0
R2 = 0.8431
95/96
96/97
97/98
98/99
99/00
00/01
01/02
02/03
03/04
04/05
05/06

Fig. 3

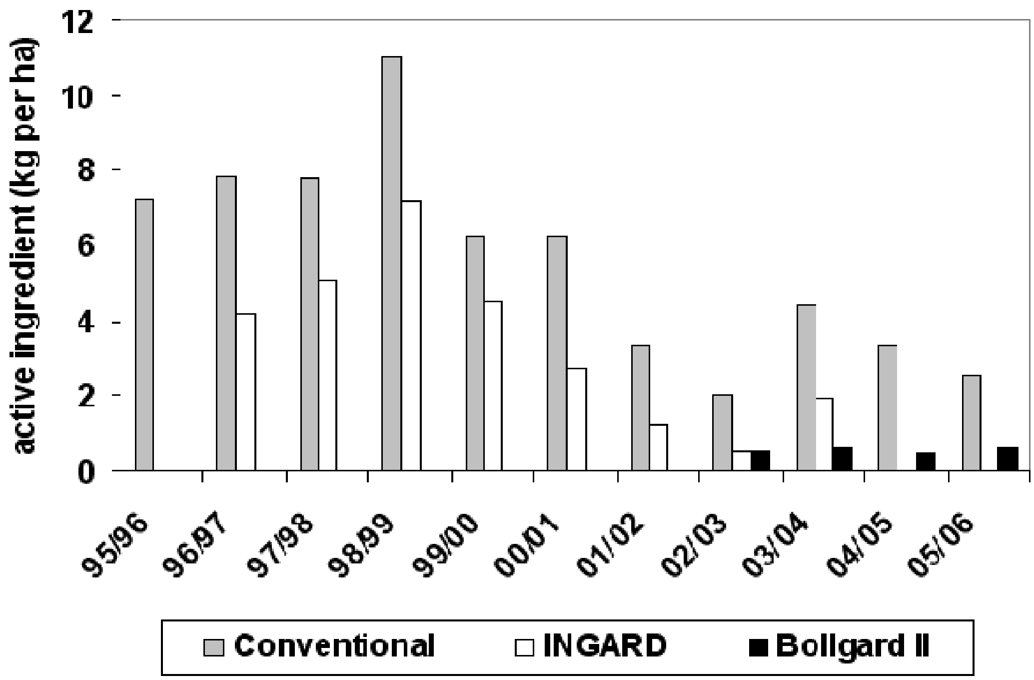

12
10
8
6
4
2
0
active ingredient (kg per ha)
95/96
96/97
97/98
98/99
99/00
00/01
01/02
02/03
03/04
04/05
05/06
Conventional
INGARD
Bollgard II

Fig. 4

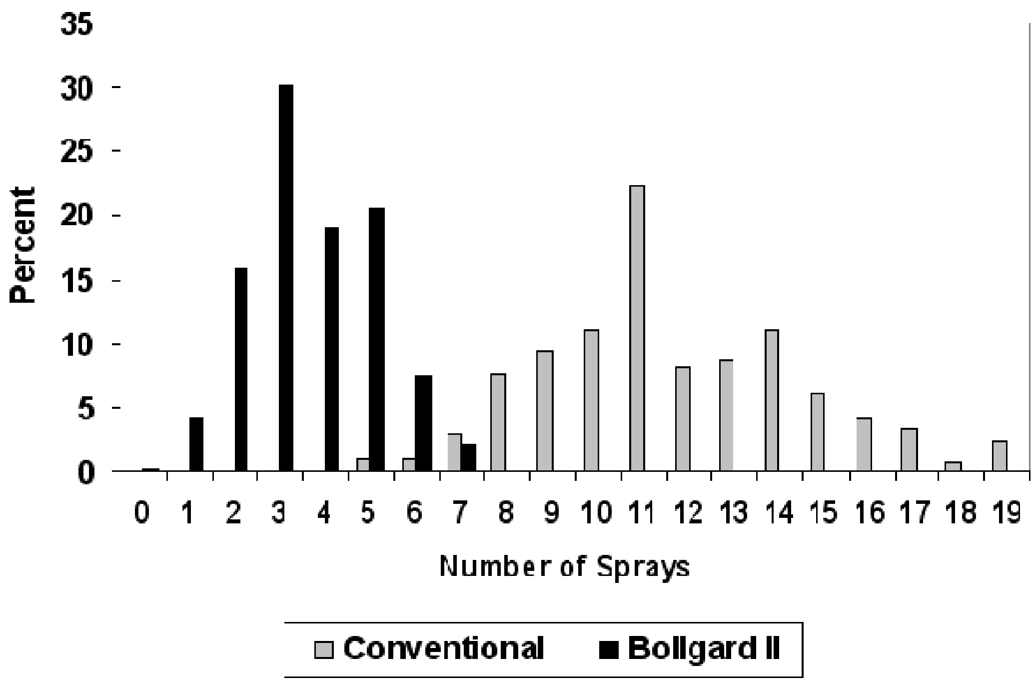

35
30
25
20
15
10
5
0
Percent
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19
Number of Sprays
Conventional
Bollgard II

Fig. 5

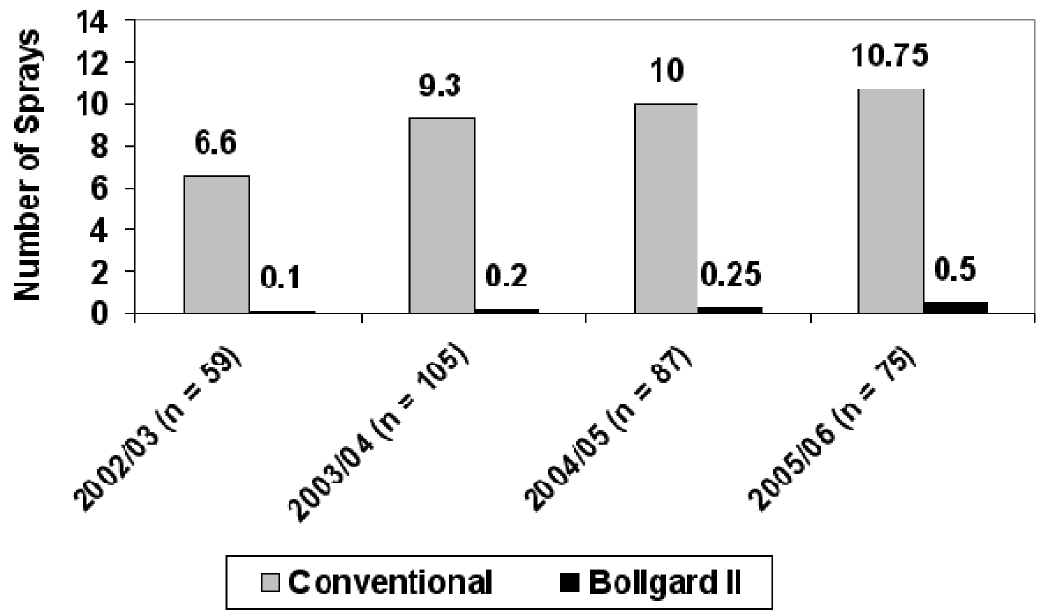

Number of Sprays
14
12
10
8
6
4
2
0
6.6
0.1
9.3
0.2
10
0.25
10.75
0.5
2002/03 (n = 59)
2003/04 (n = 105)
2004/05 (n = 87)
2005/06 (n = 75)
Conventional
Bollgard II

Fig. 6

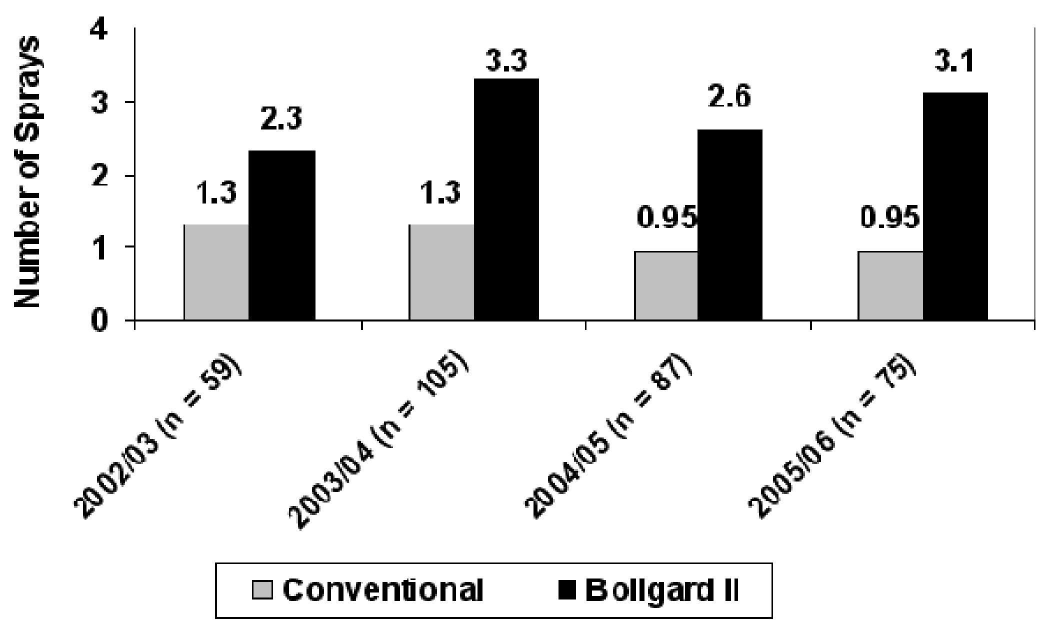

Number of Sprays
4
3
2
1
0
1.3
2.3
1.3
3.3
0.95
2.6
0.95
3.1
2002/03 (n = 59)
2003/04 (n = 105)
2004/05 (n = 87)
2005/06 (n = 75)
Conventional
Bollgard II

Fig. 7

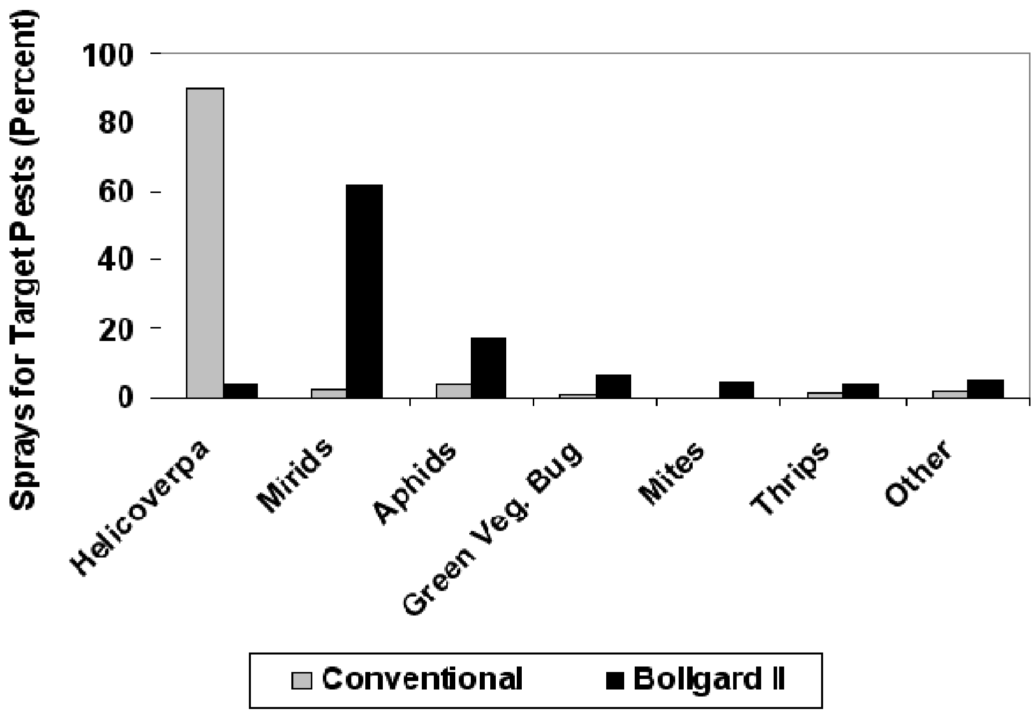
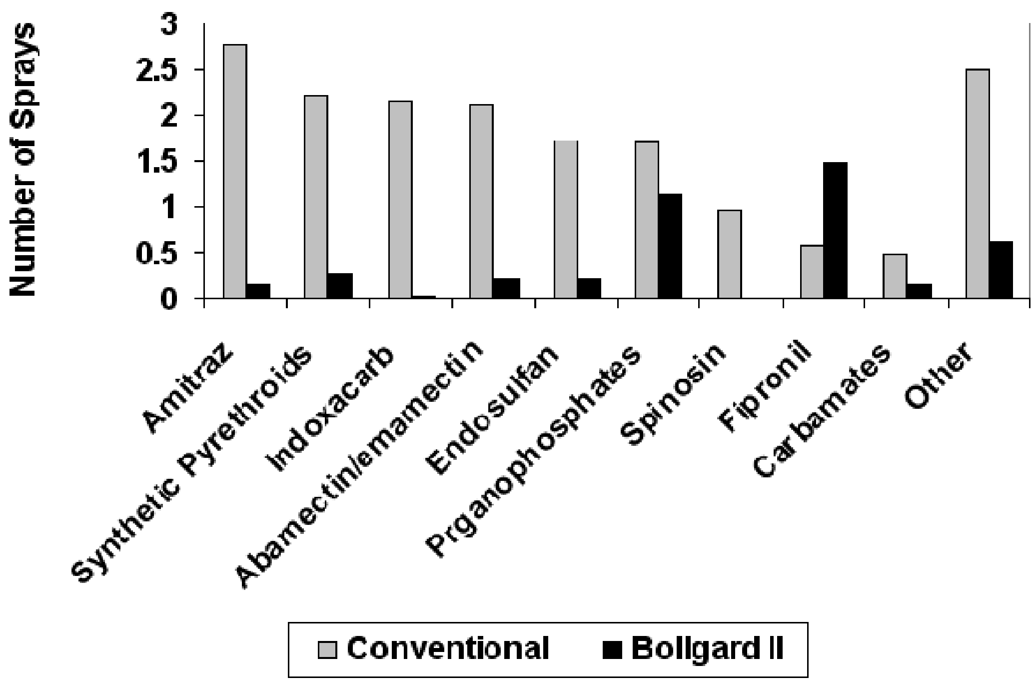

Sprays for Target Pests (Percent)
100
80
60
40
20
0
Helicoverpa
Mirids
Aphids
Green Veg. Bug
Mites
Thrips
Other
Conventional
Bollgard II

Fig. 8


Number of Sprays
3
2.5
2
1.5
1
0.5
0
Amitraz
Synthetic Pyrethroids
Indoxacarb
Abamectin/emamectin
Endosulfan
Prganophosphates
Spinosin
Fipronil
Carbamates
Other
Conventional
Bollgard II