The performance of Bt transgenic (INGARD®) cotton in Australia over six seasons

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ABSTRACT

Bt transgenic cotton varieties containing a CryIAc gene owned by Monsanto (tradename INGARD®) have been grown commercially in Australia for six consecutive seasons. This technology has been introduced gradually in staged releases starting at 10% of total planted area in 1996/97 and reaching 30% in 2000/2001. Since then, INGARD® cotton plantings have been capped at 30% of the total cotton planted in any one season and will remain so until transgenic cotton with two Bt genes becomes available. The initial staged releases reflect the cautious approach taken by Australian regulators to the first transgenic crop grown in Australia while the establishment of a cap is a result of a restriction imposed and supported by the industry and aimed at preventing the development of resistance to the single gene technology. Following harvest each season, the Cotton Research and Development Corporation commissioned Cotton Consultants Australia to survey its members to measure the performance of INGARD® cotton. Various indicators have been used to measure INGARD® performance compared to conventional cotton. These include: the number of pesticide applications for Helicoverpa *spp. and other pests; the types of pesticides used; pest management costs; yields; and economic benefits or costs. At regional and industry level, the average performance of INGARD® has been consistent. Yields have been similar to conventional cotton with total pesticide use reduced by between 45% and 60%. However, when comparisons of INGARD® and conventional cotton are taken to the individual field level, performance results have been highly variable. Although this variability in performance has been a challenge to Australian cotton farmers, there is evidence from the 2000/01 and 2001/02 seasons that it is declining. This suggests that both INGARD® performance and management of the technology is improving. In addition, the adoption of integrated pest management practices by Australian cotton farmers has accelerated in recent years and it appears that INGARD® cotton, due to its reduced requirement for pesticides, has contributed to this trend.*

Introduction

INGARD® cotton varieties, carrying the Cry1Ac gene from Monsanto, have been grown commercially in Australia since the 1996/97 season. The introduction of these varieties has been managed conservatively by the National Registration Authority (NRA) and the Australian cotton industry in order to minimize the potential for key pests to develop resistance to the Bt toxin. Part of this conservative approach has been a limitation placed on the area of INGARD® that can be planted each season. In a series of staged increases, starting at 10% of total planted area in 1996/97, INGARD® cotton area reached 30% of the total area planted in 2000/2001. Since then, INGARD cotton plantings have been capped at 30% of the total cotton area planted in any one season (Table 1) and will remain so until transgenic cotton with two Bt genes becomes available in 2003/04 (Fitt, 2003). In 1996/97, the field efficacy of INGARD® cotton was more variable than expected. As a result of this unexpected variability, the Cotton Research and Development Corporation (CRDC) decided to assess the commercial performance of INGARD® in the 1996/97 season. Following each of the next five seasons, the CRDC continued to commission an end-of-season performance survey. Data for each survey was gathered, collated and analyzed by Cotton Consultants Australia (CCA). This paper uses these survey results to provide an overview of the first six seasons of commercial Bt cotton production in Australia.

Measurements of performance

At the end of each cotton season, CCA sent a survey form to each of its members to gather data on the commercial performance of INGARD® cotton. The CCA membership was asked to provide a range of data including pest management statistics, agronomic details and yield for one or more INGARD® cotton fields each compared to a conventional cotton field on the same farm in which the variety was the non-transgenic equivalent and in which agronomic management had been similar. These data were then used to develop a range of performance measures of INGARD® compared to conventional cotton including: pesticide use, differences in the pest spectrum requiring control, pest control costs, yields and the economic benefit or cost of growing INGARD®. Before any comparisons of pest control costs, yield and economic performance were made, the INGARD®/conventional "paired" samples submitted were screened to determine if they could be considered valid, that is that they could be equated in terms of varietal background and agronomic management not related to pest control. In addition, a range of qualitative data were gathered on aspects such as why INGARD® was grown, effectiveness of the resistance management plan for INGARD®, management of refuges and quality of the service provided by Monsanto and their agents. This paper summarizes some of the results extracted from a series of reports published by CRDC and based on the annual survey responses from CCA members (Long *et al.*, 1997, Clark *et al*., 1998; Pyke, 1999; Kwint and Pyke, 2000; Doyle, Reeve and Barclay, 2002; Doyle, *Reeve and Bock, 2002).*

Pesticide use and pest spectrum

A range of pests and mites attack cotton in Australia, although only about six require pesticide applications on a regular basis to maintain economic control in most regions (Pyke and Brown, 1996). Two of these, the larvae of *Helicoverpa armigera* Hübner and *H. punctigera* Wallengren, are major pests and always require some pesticides for control in all regions. The others can be important pests and often require pesticides for control, they include: thrips (*Thrips tabaci* Lindeman and *Frankliniella schulzei* Trybom) mirids (*Creontiades dilutus* Stal), aphids (*Aphis gossypii* Glover) and mites (*Tetranychus urticae* Koch). In addition to these major and important pests, a number of minor or sporadic pests required some pesticides for control in one or more of the six seasons, these included cotton tipworm (*Crocidosema plebejana* Zeller), jassids (*Austroasca viridigrisea* Paoli and *Amrasca terraereginae* Paoli), green vegetable bug (*Nezara viridula* Linnaeus) and silverleaf whitefly (*Bemisia tabaci* Type B). Figure 1 compares the average number of pesticide spray events made to INGARD® and conventional cotton crops for each season, 1996/97 to 2001/02. INGARD® cotton was associated with a reduction in pesticide use in all seasons ranging from 38 percent in 1998/99 to 64 percent in 2001/02. Cotton pest populations in Australia vary from season to season often in response to the variable rainfall patterns experienced. For instance, during the six seasons discussed here, 1998/99 was the most severe for pests due to the wet winter and spring of 1998, which resulted in abundant alternative host crops and weeds for *Helicoverpa* spp., aphids, mirids and mites leading to high early season numbers all cotton districts. Of the other seasons, four were more moderate or average for pest severity (1996/97, 1997/98, 1999/00, 2000/01), while 2001/02 was a season of lower pest severity.

INGARD® and adoption of integrated pest management

The severe pest season experienced in 1998/99 provided an impetus for the cotton industry in Australia to increase the adoption of integrated pest management (IPM) practices. In 1999, all sectors of the industry collaborated with the Australia Cotton Cooperative Research Centre to produce a comprehensive set of IPM guidelines for the industry (Wilson and Mensah, 1999). The IPM practices adopted by individual and collaborative groups of Australian cotton growers since 1998/99 include a range of non-chemical and chemical approaches with the key focus on reducing the use of broad-spectrum pesticides in favor of narrower spectrum or selective products. The latter are considered being less disruptive to predatory beneficial species (Wilson *et al*., 2002). By preserving naturally occurring populations of beneficials, additional non-chemical mortality factors are introduced and can be exploited thus reducing the need to rely on pesticides for maintaining pests below economic threshold levels. Australian cotton growers have found that the reduced requirement for pesticides in INGARD® cotton early to mid season is very compatible with this approach to IPM. Consequently, the steady progress made to reduce pesticide use in conventional cotton in Australia since 1998/99 has usually been surpassed in INGARD® crops (Hoque *et al*., 2002). In Figure 2[1]*, spray applications made to conventional (Figure 2a) and INGARD® (Figure 2b) cotton for each of the six seasons, 1996/97 to 2001/02, have been divided into two categories: broad-spectrum sprays and selective sprays. Pesticides were placed into these categories using pesticide selectivity rankings developed for the Australian cotton industry. The broad-spectrum pesticide category in Figures 2a and 2b includes all products with a moderate-high, high and very high impact ranking on predatory beneficial species and the selective pesticide category includes all products with a moderate-low, low and very low ranking (Wilson *et al*., 2002). Figure 2 clearly shows that not only has pesticide use declined over the six year period, but the proportion of broad-spectrum pesticides used has declined also, particularly since 1999. This serves as an indicator that the adoption of IPM practices in the Australian cotton industry is meeting with success and also that INGARD® cotton provides a solid foundation on which to build an IPM system.

In Australia most of the insecticide use in cotton is targeted at the control of *H. armigera* and *H. punctigera*. This is illustrated in Figure 3 in which the average number of insecticide sprays applied per season for *Helicoverpa* spp. to INGARD® and conventional cotton is compared. Over the six seasons, spraying for *Helicoverpa* spp. in INGARD® was 56 percent lower than conventional cotton (ranging from a 43 percent lower in 1998/99 to 80 percent lower in 2001/02). However, the fact that INGARD® crops require spraying for *Helicoverpa* spp. demonstrates that the technology has not provided season long protection from these pests. Prior to commercial release in 1996 it was known that efficacy of varieties expressing the CryIAc Bt protein was not consistent through the growing season on Australian *Helicoverpa* spp. (Fitt *et al*., 1994, Fitt 2003). INGARD® efficacy was expected to decline through the latter part of boll maturation period, to a point in the last one quarter to one third of the growing season where survival of larvae was little different to that in non-transgenic cotton. In 1996/97, this proved to be what occurred in many INGARD® crops, but in others efficacy appeared to decline in mid season or during early boll setting. This unexpected, early variability in efficacy created a number of difficulties in INGARD® cotton management in that first season particularly decisions on when to commence supplementary control with insecticides. In many cases these con-

*[1] *It should be noted that each spray event, as shown in Figure 1, can include the application of more than one pesticide and be made for one or more pests. When the information for each spray event is re-categorised in some way as it is in Figures 2 to 4 in this paper, the numbers of pesticides applied will differ from the number of spray events.*

trol measures were introduced too late to prevent some insect damage and, in association with the limited selection of INGARD® varieties available in that introductory season, was a contributor to the poor economic performance of many INGARD® crops relative to their conventional comparisons (Long *et al.*, 1997). Economic performance is discussed in more detail later in this paper, but is mentioned here to highlight the point that reduced insecticide use for *Helicoverpa* spp. control is only one indicator of successful performance of INGARD® cotton and does not guarantee an economic benefit to the grower.

Figure 4 shows the average number of pesticides applied for pests other than *Helicoverpa* spp. In most seasons, the differences between INGARD® and conventional cotton for controlling the full range of other pests have been small, except the 1998/99 season, which was the most severe pest season of the six. In that season, fewer sprays for other pests were required in INGARD® largely because it provided effective control of cotton tipworm, whereas in conventional crops tipworm control relied on the use of insecticides. Compared to the numbers of pesticides applied for control of *Helicoverpa* spp., the relative numbers applied for all other pests combined have been much lower, particularly in conventional crops but also in INGARD® crops. When averaged over the six seasons, spraying for all non-*Helicoverpa* pests combined was 8 percent lower in INGARD® compared to conventional crops. For any individual non-*Helicoverpa* pest, spray numbers in any season have generally been less than one and the only consistent trend observed was for slightly more spraying in INGARD® for mirids (five seasons out of 6). No such trends were apparent for aphids, mites or thrips. In the 2001/02 season sprays for a range of other minor or sporadic pests were recorded indicating that INGARD® required 0.7 sprays and conventional 0.4 sprays for these pests. These minor pests included green vegetable bug and jassids, which were present in most cotton growing areas particularly where IPM practices had reduced spraying for other pests to very low levels (L. Wilson, personal communication). One other insect that may become a more significant pest in the future and disrupt some of the progress made with IPM is the silverleaf whitefly, an introduced pest that reached outbreak level populations on some farms in central Queensland cotton growing areas in 2001/02.

Pest control costs

Pest control costs include the estimated costs of the pesticides applied, application costs and the licence fee paid by growers of INGARD® to Monsanto. Figure 5 compares the average difference between conventional and INGARD® insect control costs showing that in the first two seasons it cost more to grow INGARD® crops, but over the next four seasons it cost less. In the 2000/01 and 2001/02 seasons, average INGARD® cotton pest control costs were considerably lower than conventional. A number of factors have influenced this trend for reduced pest control costs including: a reduction in the licence fee (Table 1); the increasing uptake of IPM practices by Australian cotton growers; less severe pest infestations; and the introduction of new INGARD® varieties with improved performance.

Yields

Figure 6 gives the average yields for the INGARD® and conventional crop comparisons in the survey for each year. In 1996/97 and 1998/99 average yields for INGARD® were between 5 and 10 percent lower than conventional yields and, for all other years, yield differences were within plus or minus five percent of conventional cotton. INGARD® yields in the introductory season (1996/97) were adversely affected by lack of experience in managing its variable efficacy and limited availability of varieties suitable for all regions (Long *et al.*, 1997). Statistical analysis of the yield data from all regions combined was conducted for the 2001/02 season and showed that INGARD® yields were significantly higher than conventional (Doyle *et al.*, 2002).

Economic benefit or cost

Figure 7 shows the economic performance of growing INGARD® in terms of the average return from the paired comparisons for each year. This has been calculated by averaging the difference between the return from the INGARD® and conventional crop for all valid comparisons received for each year. An economic "cost" is incurred when the return from INGARD® is less than conventional and a "benefit" when returns exceed conventional. The number of comparisons ranged from 103 in 1997/98 to 229 in 2001/02 (Table 1). This analysis assumes that all agronomic inputs other than insect/mite control costs are the same for each comparison and that there were no differences in fiber quality. The value of cotton per bale used each year was based on an estimated "average" cotton price received for that season. The prices used ranged from AU $400/bale in 2001/02 to AU $500/bale in 1998/99. The figure shows that INGARD® performed poorly in the introductory year (1996/97) due largely to: a high licence fee; limited of choice in varieties (leading poorer yields in areas where available varieties were not well suited); and the general lack of experience on how to manage the high variable efficacy of INGARD®. The average returns were similar for INGARD® and conventional cotton over the next three years 1997/98 to 1999/2000. However, economic performance in the 2000/01 and 2001/02 seasons was considerably better than conventional and a number of reasons can be suggested for this: introduction of improved INGARD® varieties; less severe insect infestations; wider adoption of IPM practices; introduction of newer more

IPM compatible insecticides (eg. spinosad, indoxacarb, emamectin); and overall improvements in the management of INGARD® crops.

The average cost/benefit results in Figure 7 do not show the fact that INGARD® economic performance has been very variable. In most seasons, the individual paired comparisons have ranged from an economic cost of $1000/ha or more to an economic benefit of $1000 or more. Even in the seasons where the economic benefits were the highest, 2000/01 and 2001/02, the range in performance from worst to best exceeded $2000/ha. Figure 8 gives the percentage of comparisons for each year that recorded an economic benefit for INGARD®. This shows that in 1996/97 only 32 percent of comparisons produced an economic benefit, but by 2000/01 and 2001/02, this improved to approximately 80 percent of comparisons showing an economic benefit. Improved performance influenced why cotton growers chose to grow INGARD® cotton. Each year, survey respondents were asked to provide reasons why INGARD® was chosen instead of conventional cotton. Table 2 compares the responses given to this question in 1998/99 (after three seasons experience with INGARD®) to those given in 2001/02 (after six years experience with INGARD®). In 1998/99 consultants saw environmental benefits as the overwhelming reason their client growers grew INGARD® with none considering economic or yield increase benefits as a reason. By 2001/02 this had changed considerably with environmental benefits, economic and yield benefits and pest management/IPM reasons equally as important closely followed by reduced spraying.

Conclusions

During the first six years of commercial production of Bt cotton in Australia it has become an important component of the pest management system even though it has not occupied more than 30 percent of the total planted area. Australian cotton growers have been able to reduce insecticide sprays for *Helicoverpa* spp. by between 43 and 80 percent in fields planted to INGARD® cotton. Reduced spraying has lowered the overall potential for adverse environmental impacts associated with chemical use and has allowed cotton growers to plant INGARD® in situations that are less appropriate for conventional cotton production, for example close to environmentally sensitive areas.

When compared to conventional cotton, the environmental benefits and reduced spraying achieved when growing INGARD® have not always translated into economic benefits. The variable efficacy of INGARD® cotton against the Australian *Helicoverpa* spp. and the relatively high cost of the licence have been strong additional inducements for Australian growers to adopt more effective IPM practices. The success of these improved IPM practices is evident from the increased proportion of INGARD® crops that returned an economic benefit (32 percent in 1996/97 to almost 80 percent in 2001/02).

The same IPM principles that have been successful in INGARD® cotton have also been successfully applied in conventional cotton. The confidence Australian cotton growers have gained in preserving and exploiting naturally occurring beneficial predators has been strengthened by their experience with INGARD® cotton.

Despite some of the difficulties associated with learning to optimize the management of Bt cotton in Australia, the end result of the first six seasons is a positive one with reduced pesticide use and economic benefits for a large majority of growers. When two-gene Bt cotton varieties (Bollgard II™ from Monsanto) are released for commercial production in 2003/04, it is expected to herald further advances in reducing pesticide use and IPM adoption through improved efficacy and potential to plant a larger proportion of the total crop to Bt cotton. As with the introduction of any new technology, the introduction of Bollgard II™ may require some adaptation in management, however, the experience gained with INGARD® will prove to be invaluable for the Australian industry.

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Table 1. *INGARD® cotton production in Australia - areas, licence fees and number of paired fields compared in surveys.*

Season	Area of INGARD (% Total Cotton Area)	Area of INGARD Planted (ha)	INGARD Licence Cost (Net to grower $AUD)	No. paired fields used in yield and economic comparisons
1996/97	10%	30,000	245	210
1997/98	15%	65,000	210	103
1998/99	20%	85,000	155	110
1999/00	25%	125,000	155	149
2000/01	30%	180,000	155	130
2001/02	30%	125,000	170	229

Table 2. *Reasons for growing INGARD® - percentage of responses.*

Season	Number of responses	Environmental benefits	Insect management/ IPM Benefits	Reduced spraying benefits	Economic and yield benefits
1998/99	125	80%	10%	10%	0
2001/02	173	27%	28%	17%	28%

Figure 1. *Comparison of the average number of spray events in INGARD® and conventional cotton over six seasons.*

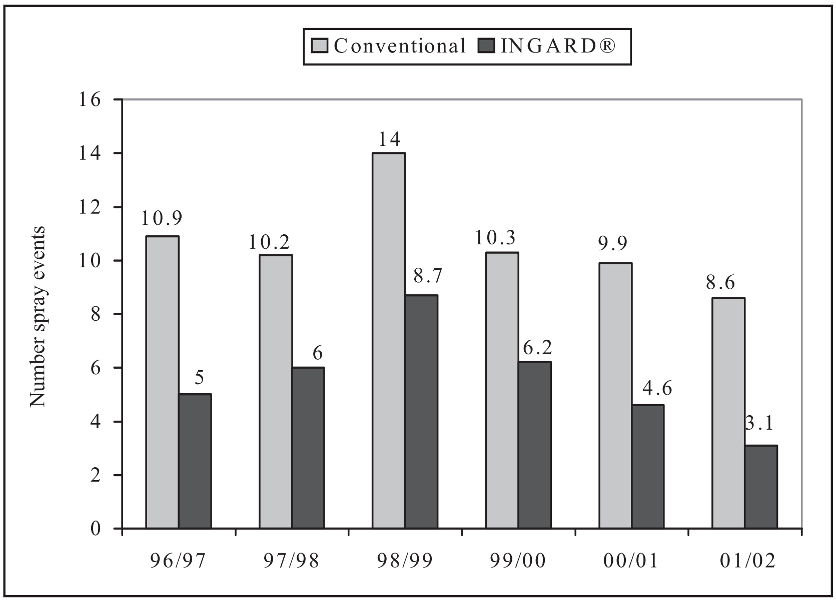

Figure 2a.
Average number of broad-spectrum and selective pesticide applications in conventional cotton over six seasons.

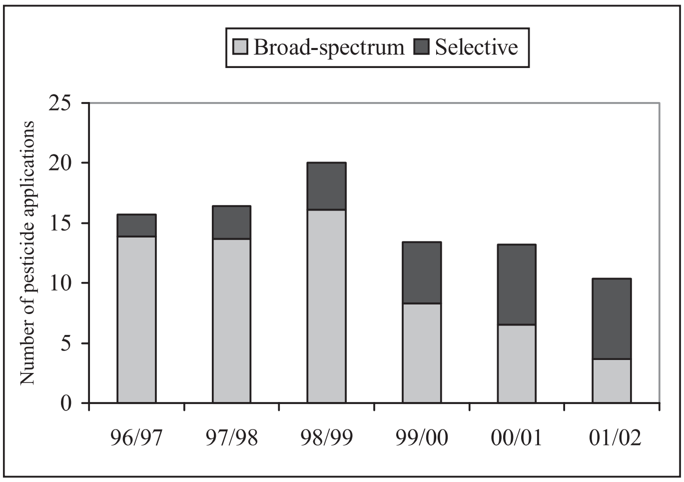

Figure 2b.
Average number of broad-spectrum and selective pesticide applications to ingard cotton over six seasons.

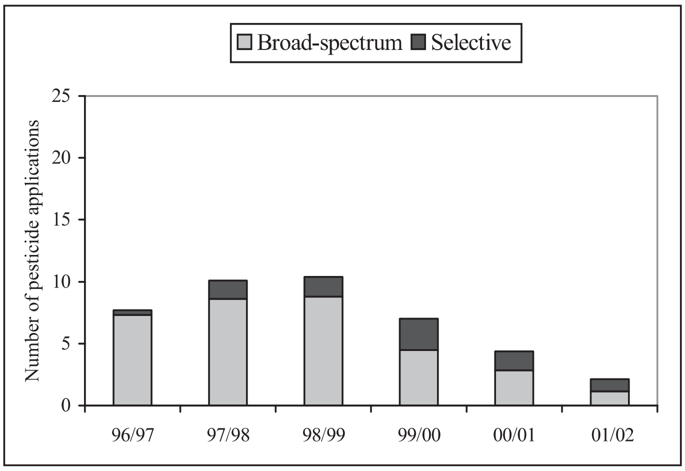

Figure 3.
Comparison of the average number of insecticide sprays applied for Helicoverpa *spp. to INGARD® and conventional cotton over six seasons.*

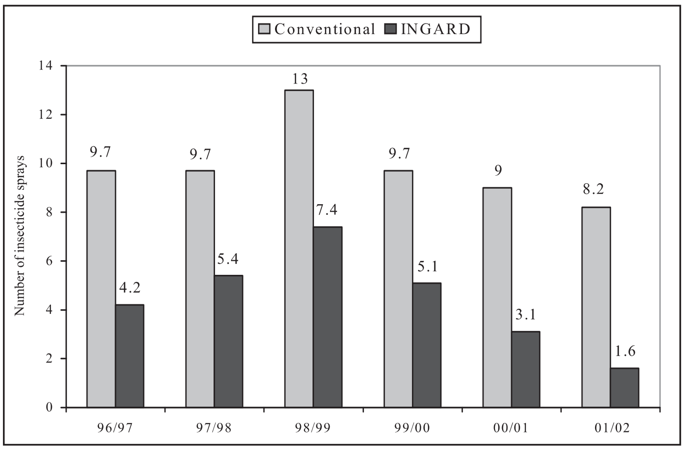

Figure 4.
*Comparison of the average number of insecticide sprays applied for non-*Helicoverpa *spp. pests to INGARD® and conventional cotton over six seasons.*

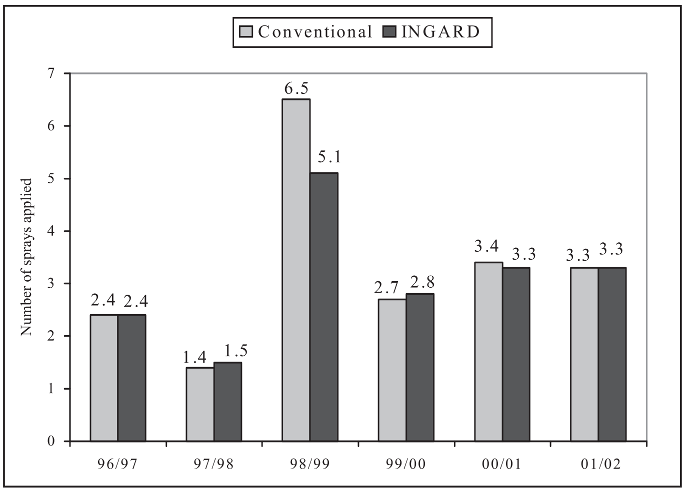

Figure 5.
The difference between INGARD® and conventional pest control costs for each of six seasons in Australian dollars per hectare.

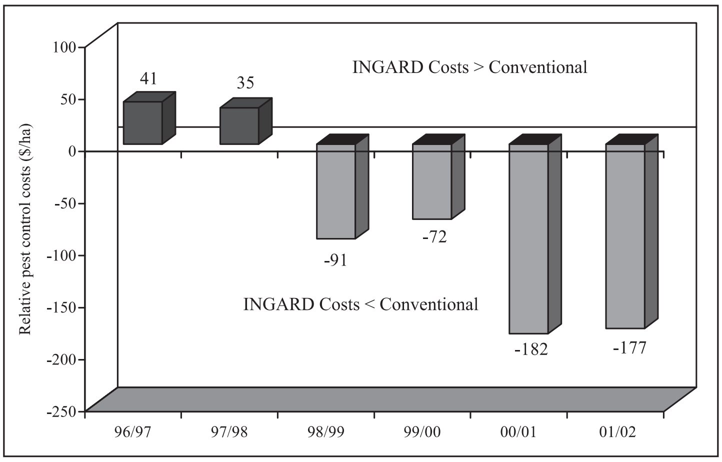

Figure 6.
Comparison of average yields for INGARD® and conventional cotton over six seasons in bales per hectare.

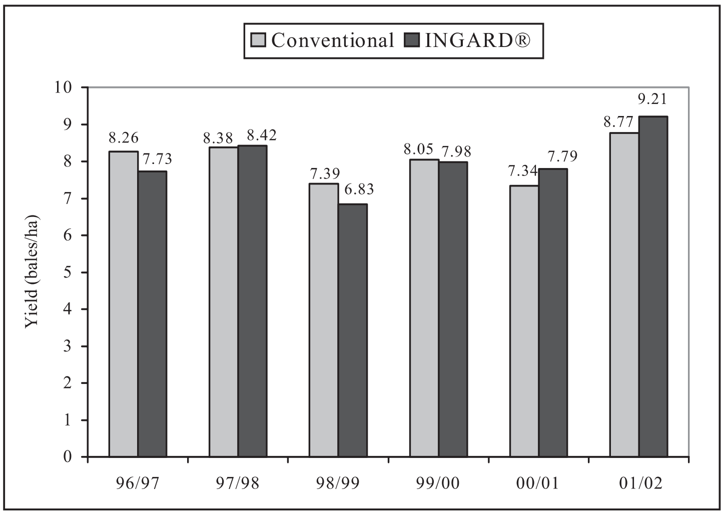

Figure 7.
Economic benefit or cost per season in Australian dollars per hectare - calculated from the seasonal average difference in net returns for ingard and conventional cotton paired comparisons.

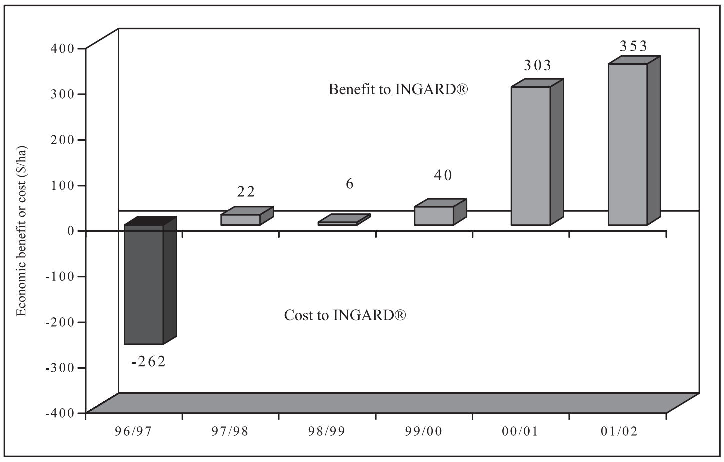

Figure 8.
Percentage of paired INGARD®/conventional cotton comparisons showing a benefit to INGARD®.