An Overview of *Helicoverpa* Pest Management Research in Cotton in Central Queensland: 1996-2004

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Introduction

Helicoverpa armigera (Hübner) and *H. punctigera* (Wallengren), (Lepidoptera: Noctuidae), commonly called heliothis, have historically been the primary focus of cotton pest management in Australia (Fitt 1994; 2000). The full commercial release of second-generation Bt cottons (BOLLGARD II®), scheduled for the 2004-05 season, is set to radically change the hierarchy of key insect pests of cotton by ending the dominance of heliothis. By virtue of its highly effective built-in chemical defence resulting from stacked Bt genes, BOLLGARD II® is widely expected to be much less susceptible to heliothis damage than conventional or first-generation Bt cottons (INGARD®).

Central Queensland (CQ) cotton growers are among those that stand to benefit enormously from access to the new technology. Among the key benefits of the new technology are a significant reduction in insecticide use and the resulting benefit to the CQ environment and its inhabitants. However, access to new technology in the CQ region comes with a price tag that involves diligent adherence to the regions unique area-wide heliothis management program and Bt resistance management strategy. Support for and compliance with these and other best practice options requires an understanding of the factors underwriting access to Bt cotton technology and, often, a gentle reminder of the way things used to be.

The objective of this paper is to provide a historical overview of heliothis research conducted in CQ since 1996, leading up to the current situation and the imminent release of BOLLGARD II® in the region.

The Pre-Bt Cotton Years

The cotton industry in CQ was at a crossroads in 1996. It was not uncommon for cotton crops to be sprayed 18, even 20 times during a season. Insecticide resistance levels were increasing rapidly and there were few new chemical insecticide products coming on to the market. The ferocity of the heliothis problem on cotton was largely a reflection of cropping practices in the region. A continuity of overlapping crops, all of which are good hosts of heliothis, facilitated dispersal from one to the other culminating in a population explosion from late December onwards each year. This situation has not changed significantly over the last eight years. A detailed description of the heliothis problem and the characteristics of the cropping system in CQ can be found in Sequeira (2001).

1996 was also the year that a limited commercial release of INGARD® was announced. However, the commercial release area did not include the CQ region - Emerald irrigation area (EIA) and Dawson/Callide valley. CQ was excluded for fears that the probability of heliothis developing resistance to the product was higher in this and other northern warm climate areas than in southern Queensland and northern New South Wales where the winters are milder. The potentially higher resistance development risk was attributed to, among other factors, greater abundance and a substantially lower frequency of diapause in CQ populations of heliothis. The lack of significant diapause in CQ implied that the practice of pupae busting after crop harvest, a key resistance management tactic required for growing Bt cotton, would be ineffective in CQ.

The entomological challenge for the CQ region was to get Bt cotton registered for commercial production in the shortest time frame. The principal obstacles to this end were (a) finding an alternative to pupae busting for Bt resistance management, and (b) the requirement for a comprehensive heliothis population management plan.

Meeting the Bt cotton challenge

Finding solutions to both obstacles for registration of Bt cotton in CQ required a thorough understanding of the regional population dynamics and dispersal patterns of heliothis throughout the year. With funding from the Cotton Research & Development Corporation (CRDC), a 12-month, three-year population dynamics study of heliothis pupae under various crops in the Emerald Irrigation Area (EIA) was initiated in October of 1996. Within 12 months, the study provided data on the spatial and temporal abundance pattern of heliothis that confirmed what growers, crop consultants and researchers had suspected for many years. The succession of heliothis host crops grown in the region facilitated dispersal between crops and inter-seasonal population cycling. Heliothis moths dispersed from the inner irrigated core of the EIA to surrounding rainfed crops in late summer and return to the irrigation area in spring (Sequeira 2001). Based on these data and industry experiences, a year-round, area-wide management (AWM) program for heliothis was proposed. Built into the AWM strategy was a unique CQ alternative to pupae busting that addressed the Bt cotton resistance management strategy (Bt RMS) needs of the region.

The heliothis AWM program and incorporated Bt RMS were based on strategic placement of trap crops at the beginning and end of the season, in relation to perceived dispersal patterns of heliothis (**Fig. 1**). The use of trap crops as a form of habitat manipulation was seen as the best option for the Emerald area in the initial stages of development of the area-wide management plan. Trap crops had to be positioned and attractive in August-September to soak up the incoming first generation of heliothis, and in February-March to prevent outward migration of the final generation of moths carrying Bt and conventional insecticide resistance coming off cotton within the irrigation area.

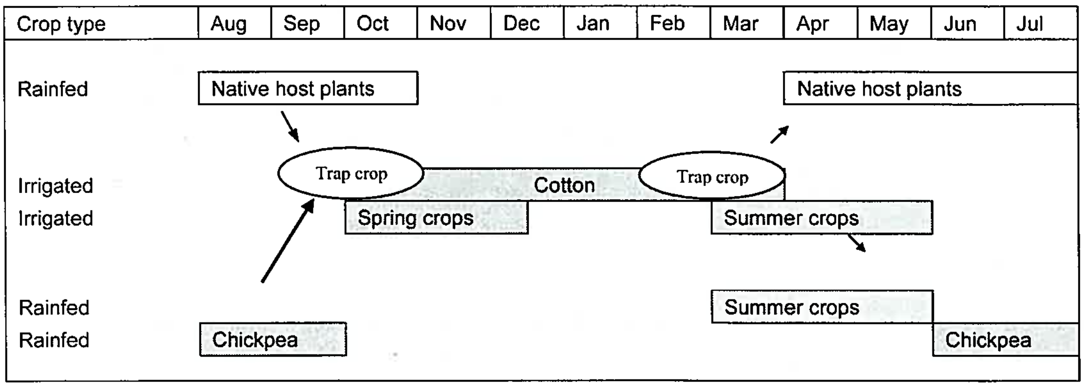

Figure 1. The positioning of the trap crops in relation to the local dispersal pattern of heliothis in the cropping system. Source: Sequeira (1998).

The spring trap crops were to serve as a general population management tool to enhance successful management of the pest during the season whereas the summer trap crops were intended to serve as substitutes for pupae busting in the Bt RMS. The principle underlying the trap-cropping program was that if fewer moths were allowed to migrate out to survive on rainfed crops then fewer would return the following spring to re-infest the irrigation area.

The heliothis AWM strategic framework for CQ, including the rationale for its development, in-field protocols and underlying assumptions, has been discussed in detail by Sequeira (2001). The background research for securing CQ access to Bt cotton including the development of a CQ Bt RMS using summer trap crops as substitutes for pupae busting has been detailed by Sequeira & Playford (2001).

Commencement of the Bt cotton era in CQ

The advent of INGARD®

The CQ heliothis AWM and Bt RMS proposal, along with a plan for their rapid implementation, was accepted by the federal regulatory body, the Australian Pesticides and Veterinary Medicines Authority (formerly National Registration Authority) as a basis for the release of INGARD® into CQ in September 1997. Release of the product into CQ, just prior to the start of the 1997-98 cotton season, was made contingent upon universal compliance with the AWM program and Bt RMS amongst cotton growers, and subject to validation under actual field conditions. With the release of INGARD® into CQ, the region was brought into the Bt cotton biotechnology fold on a theoretical platform, albeit a completely untested one.

As a first step in achieving these outcomes, compliance with the summer trap-cropping component of the program (Bt RMS) was made mandatory for users of Bt cotton technology by inclusion of the trap crop requirement in the product label specification by Monsanto Australia Ltd. Whilst this regulatory process effectively dealt with the issue of compliance, a number of "difficult" practical issues remained. With funding from the CRDC, a new three-year research program aimed at validation of the AWM program and Bt RMS and collection of data to address key functional issues associated with the use of area-wide trap cropping in CQ was initiated in 1999. The principal objectives of this research program were to field test the key assumptions and field parameters of the AWM program.

Are we using the right trap crops?

The success of a trap cropping strategy is critically dependent upon the characteristics and efficiency of the trap crop used, among other factors. The use of chickpea and pigeon pea as spring and summer trap crop options, respectively, had been advocated largely on observations and anecdotal evidence of larval infestation levels in local crops and research results from other areas. Thus, the issue of whether or not chickpea and pigeon pea were the best choices had to be addressed before other issues related to outcomes of the AWM program could be addressed.

Field evaluations were conducted in the winter of 1999 to determine which winter cropping options were most attractive to heliothis. The attractiveness of six alternative trap crops to heliothis moths for egg laying was compared to that of chickpea in a large split plot design. The crops included in the field evaluation were *Brassica juncea* (L.) (**indian mustard**), *Brassica napus* L. var. *napus* (**canola**), *Vicia faba* L. var. *faba* (**faba bean**), *Pisum sativum* L. var. *arvense* (**field pea**), *Linum usitatissumum* L. (**linseed**) and *Lupinus albus* L. (**lupin**). Full details of the study and its results can be found in Sequeira *et al.* (2001); a brief summary is given below.

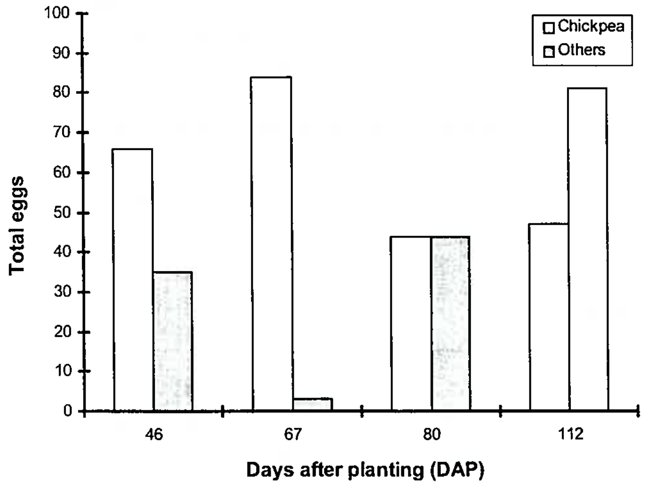

Figure 2. Mean density per metre of heliothis eggs on chickpea and other crops in a field evaluation of winter cropping options in 1999. The 'other' crops become attractive to heliothis moths for egg laying only after the onset of flowering (112 days). Chickpea remains attractive for egg laying in all its developmental stages. Source: Sequeira *et al.* (2001).

The results of the field evaluation showed that chickpea was attractive to ovipositing heliothis moths from as early as 14 days after planting and throughout the evaluation period (**Fig. 2**). The alternative crop species varied in relative attractiveness to ovipositing moths but none was able to effectively divert heliothis egg pressure away from chickpea during the pre-flowering stages. After the onset of flowering, the alternative species became substantially more attractive than chickpea. However, this reversal in attractiveness post flowering did not diminish the tendency of moths to lay on chickpea (**Fig. 3**). Of all heliothis larvae recorded from all samples and crop combinations, 98.3% were found on chickpea. These results supported the recommendation of chickpea as the preferred spring trap crop in the AWM strategy.

Is the CQ AWM program working?

The uptake and useful life of new agricultural technology, products or practices depend largely on perceived benefits to the end users, the primary producers. This is where strategic area-wide initiatives can often come unstuck. Area-wide initiatives, by definition, do not include "control" areas where the action or treatment is not applied, thereby precluding a comparison between "treated" and "untreated" areas. Comparisons of pest dynamics involving large cropping systems that are geographically isolated are also invalid because of inherent differences that result from the uniqueness of each area or region.

The next logical step in the validation of the CQ heliothis AWM strategy was to determine the impact of its implementation on the pest problem. For reasons given above, the CQ heliothis AWM program did not lend itself easily to a cost benefit analysis. Sequeira (2001) attempted a limited qualitative assessment of the program from 1997 to 2001. His results showed that whilst a change in the seasonal abundance pattern of heliothis populations on cotton was evident after the commencement of the AWM program in 1997, this change could not be unequivocally attributed to the impact of the AWM program on abundance of heliothis. The altered population dynamics of heliothis could also have resulted in part from changes in weather patterns, particularly abnormally low rainfall since the late 90s, and ensuing impacts on host plant availability. The introduction of Bt cottons to the region in 1997 may also have impacted on the

Deleted: . The winter-planted trap crops were effective population sinks in spring. Similarly, spring-planted trap crops were effective sinks in late summer. However, despite their effectiveness as population sinks,

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regional population dynamics of heliothis, most likely in combination with other factors. Importantly, a significant impact of the CQ AWM program on heliothis population dynamics could NOT be discounted.

The results and conclusions of Sequeira's (2001) study suggested that the impacts of the CQ AWM program would not become apparent until the program had gone through several additional cycles of implementation. The study also suggested that the program was not working as well as it could be. There were several weaknesses and inefficiencies in the structure and implementation of the AWM program at the field level that needed to be addressed in order to maximise the expected benefits. Key among these were (1) temporal placement (when to plant and destroy) and trapping efficiency of chickpea trap crops, (2) management of larval populations in chickpea trap crops, and (3) temporal placement and efficiency of summer pigeon pea trap crops.

Are the summer pigeon pea trap crops working?

The functionality and effectiveness of summer pigeon pea trap crops is an issue of on-going concern for the cotton industry in CQ. The key role that pigeon pea trap crops play in underpinning the Bt RMS and access to the technology has not been fully recognised by cotton growers in the CQ region. Visual surveys of pigeon pea trap crops in February since 1997 have revealed enormous differences between farms in terms of trap crop care and maintenance. These differences largely reflect a commitment to fulfilling the letter rather than the spirit of the law. Pigeon pea trap crops range in quality from lush, well maintained stands that are highly attractive to heliothis moths, to poor, water-deprived stands where the weeds outnumber the trap crop plants. Recent attempts to address this issue have focussed on assessing suitable alternative trap crop plants such as sorghum that are less management intensive and more stress tolerant. However, to date pigeon pea remains the option with the most desirable characteristics when given the necessary agronomic care and resources.

Are the spring chickpea trap crops working?

The expected outcomes of the CQ AWM program, for example, reduced heliothis infestation early in the cotton season, were underwritten in large part by the spring chickpea trap crops. Although the trap crops were instrumental in the capture and elimination of large numbers of individuals (Sequeira 2001), their impact on the population dynamics of heliothis could not be fully gauged for reasons explained above. From another perspective, accumulation of large larval populations on these crops increased the risk of creating heliothis nurseries from which moths could escape. Increasing the trapping efficiency and management of larval populations in these crops were therefore fundamental to maximising the effectiveness of the AWM program. Accordingly, one key research objective was to enhance the mortality of heliothis juvenile stages in the spring chickpea trap crops thereby enhancing their effectiveness. Another key research objective was to minimise the contribution of commercial winter chickpea crops, previously identified as key contributors, to the spring pre-cotton season heliothis population.

How can we enhance the effectiveness of the spring trap crops?

A common solution to both key research objectives came from an unexpected quarter. During the field evaluation of winter cropping options described above it was observed that the pattern of heliothis egg distribution in clean (weed free) chickpea plots was dramatically different from that in contaminated (weedy) plots. Contamination of chickpea plots by other plant species altered moth egg laying behaviour, making the contaminants more attractive than the chickpea plants. Moths were found to be laying most of their eggs on the contaminants, resulting in a

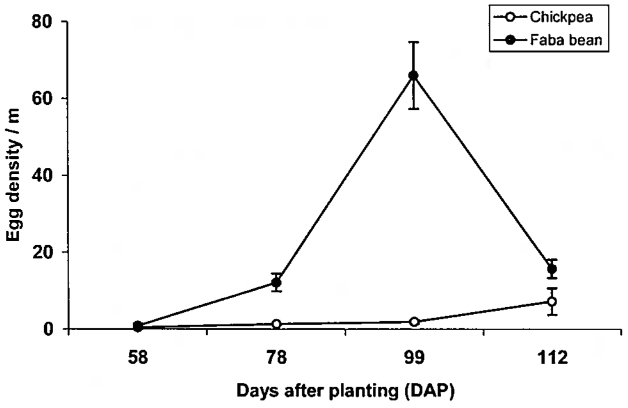

Figure 3. Mean heliothis egg density on contaminants (faba bean) and on chickpea surrounding each contaminant plant, in relation to crop age. Egg density on the contaminants increases dramatically before falling at the onset of crop maturity. Source: Sequeira & Moore (2003).

highly clumped (aggregated) distribution of eggs. The contaminants were effectively working as mini traps dispersed throughout the crop, diverting egg pressure away from the chickpea plants.

Research done over two winter seasons to characterise the aggregative egg-laying behaviour showed firstly that the phenomenon could be manipulated by deliberate contamination of chickpea plots with faba bean, wheat and other crop plants. In such seed mixed situations, moths preferentially lay eggs on the contaminants during the growth and development of the crop (**Fig. 3**). Secondly, the research showed that >80% of eggs laid on the contaminants did not survive through to the adult stage (**Fig. 4**). These results collectively established the potential of deliberate crop contamination as a solution to the heliothis problem in commercial and trap crops of chickpea. Comprehensive accounts of this research and its outcomes can be found in Sequeira *et al.* (2001), Sequeira & Moore (2003) and Sequeira (2004).

The aggregative egg-laying response of heliothis moths to contaminated chickpea crops is an example of environment or habitat manipulation for pest management. This area of research has attracted an enormous amount of attention in recent years, as evidenced by the large number of publications on the subject (See Landis *et al.* (2000) for a recent review).

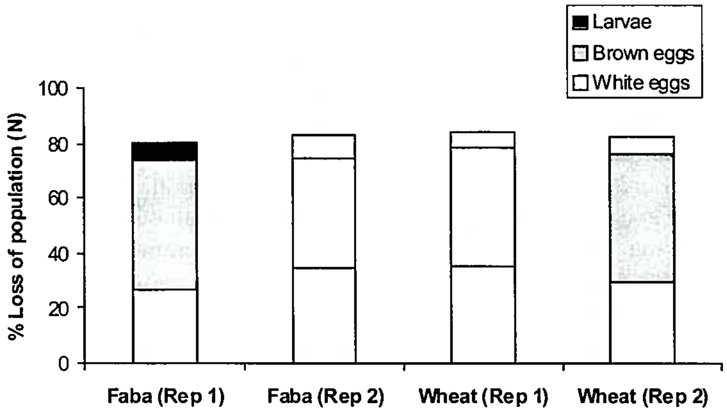

Figure 4. Mortality of heliothis white eggs, brown eggs and larvae on faba bean and wheat contaminants growing amongst chickpea plants, expressed as % loss of the total observed population. Source: Sequeira (2004).

Although the concept of habitat manipulation for pest management is not new, the potential of tactics based on this concept has yet to be fully utilised or even assessed in modern agricultural production systems.

Cotton pest Management in The BOLLGARD II® Era

The imminent release of second-generation Bt cottons in the 2004-05 growing season raises at least a couple of important questions the answers to which could profoundly influence the future of cotton production in Australia. Will heliothis cease to be a pest of cotton in the BOLLGARD II® era? Is there a future for conventional cotton in this new era? Whilst there is little doubt that heliothis will be supplanted by sucking insects as the key pest management challenge in Bt cottons, the former will undoubtedly remain a key player in the pest spectrum of the regional mixed cropping system as a whole. It is unlikely that cotton production systems will ever be 100% transgenic (Bt) based, as the overseas (US) experience seems to indicate. A likely scenario is that production systems will in time reflect a locally adapted split between conventional and Bt cottons. In this eventuality, development of IPM systems for conventional and Bt cottons that dramatically reduce the current reliance on synthetic insecticide usage will be crucial for the profitability and environmental accountability of cotton production in Australia.

The discussion on the CQ heliothis AWM program in preceding sections reveals clearly that whilst it remains a key component of the transgenic platform in warm climate production areas, it is not sufficient to prevent in-season heliothis infestation of cotton crops. The AWM program needs to be supplemented with effective in-season IPM strategies for both conventional and Bt cottons. The search for new in-season IPM tactics for cotton led again to the area of habitat manipulation. The impact of contaminant plants in chickpea crops on the behavioural responses of heliothis moths begged the questions: **If habitat manipulation can alter moth behaviour so dramatically in chickpea, why not in cotton? Can habitat manipulation be used to alter the behaviour of pests other than heliothis?**

Clear evidence of moth behaviour modification triggered by deliberate crop contamination in chickpea (see above) suggested that moth behaviour modification in cotton and other crops was possible if suitable triggers could be found. Over the last five years (1999-2004) a number of habitat manipulation experiments in cotton were conducted. A wide variety of crop combinations and layouts were evaluated over this period. Successful manipulation of heliothis oviposition behaviour was observed in two instances, namely, cotton-chickpea seed mixtures for early season management, and more recently canopy height manipulation using inter-plantings of exotic cotton varieties in amongst commercial cotton.

Cotton-chickpea seed mixtures

Chickpea is highly attractive to heliothis moths in virtually all its phenological stages. Research shows that moths begin ovipositing on chickpea seedling plants virtually as soon as they emerge from the soil. Seed mixtures of cotton and chickpea planted in one of every eight rows can effectively concentrate heliothis eggs in the seed mixed rows early in the season. Moths appear capable of locating individual chickpea plants in the seed mixed rows and preferentially laying on them (**Fig. 5**). This seed-mixing tactic was evaluated over two cotton seasons on commercial farms. For approximately 6 weeks after emergence, heliothis eggs are largely concentrated in the seed mixed rows, thereby minimising damage to plants in the remaining cotton-only rows. For a full discussion of the trial layout, results and usefulness of this tactic in cotton IPM, see Sequeira & Moore (2002).

Inter-plantings with exotic cotton varieties

The most interesting pest habitat manipulation tactic to date involves modification of the cotton canopy structure. Modern crop production practices enshrine the virtues of monocultures, clean (weed free) and uniform crops for a number of practical reasons including yield maximisation,

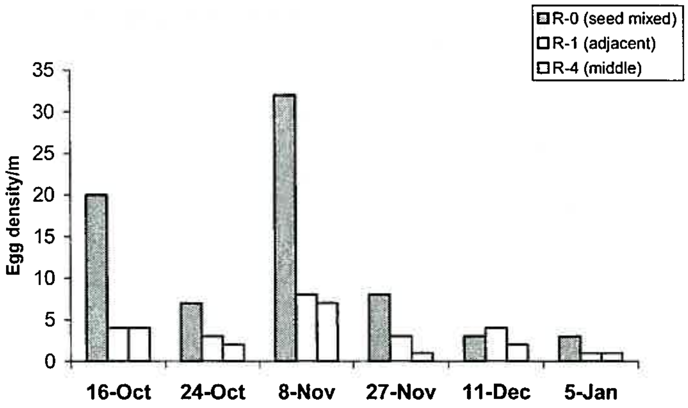

Figure 5. Comparison of mean heliothis egg density per metre in cotton+chickpea seed-mixed rows (R-0), adjacent cotton only rows (R-1) and cotton only rows 4 m away (R-4). Source: Sequeira & Moore (2002).

ease of management and harvesting. However, monocultures and uniform crop canopies are highly artificial environments that encourage insect pests such as heliothis (and others) to distribute themselves more or less uniformly throughout the field (Sequeira 2004). These largely uniform distributions make partial treatment of fields or cropping units impractical. If insect populations within a crop could be concentrated in particular rows, strips or sections, control would be easier and more effective.

At the start of the 2003-04 season, an experimental field layout designed to modify heliothis egg laying behaviour by modification of the crop canopy was evaluated. The canopy structure of a field of unsprayed conventional cotton (Sicot 71) was modified by inter-planting twin rows of exotic cotton varieties. The expectation was that distortion of the normally uniform canopy structure would alter the distribution of insects in the field by making the twin rows of exotic cottons more attractive than the surrounding commercial cotton variety.

The unsprayed cotton field was bounded on the right by a field of BOLLGARD II® and on the left by fallow area. The exotics were cultivars or experimental lines selected for higher growth rates, flowering and other phenological characteristics. The canopy distortion experiment was done in the middle section (40 rows) of the field. The inter-planting design was achieved by planting five runs of an eight-row planter to a mix of Sicot 71 and exotic cottons. The first six rows of each group of eight was planted to Sicot 71 and the two end rows to one or more of the exotic varieties. The design thus created was six rows of Sicot 71 alternating with two rows of exotic cotton. The remaining areas of the field on either side of the middle inter-planted strip of 40 rows were planted fully to Sicot 71. The twin rows of exotics were expected to modify the crop canopy by growing considerably taller than the conventional variety, or in other words, by the creation of a hedge effect.

The impact of this field layout on the distribution of insect was assessed during the course of the season. Boll count estimates on the conventional and exotic cotton varieties were obtained at the end of the season and compared to the adjacent BOLLGARD II® crop (**Fig. 6**). The average fruit load profile showed a number of interesting features. The boll count fell sharply from the edge of the last twin row of exotics, towards the BOLLGARD II® field. On the other edge of the twin row of exotics, towards the fallow area, the boll count profile stayed high for about 50m before declining. The exotics hedges appear to have provided some "protection" to certain rows of unsprayed Sicot 71, specifically those bounded on both sides by the exotics and those on the left hand side of the graph (**Fig. 6**).

The mechanism underlying this apparent protection is still not clear. The conventional cotton fruit load in amongst and to the left of the exotics was only about half that of the nearby BOLLGARD II® crop. However, the conventional field received no sprays whereas the BOLLGARD II® field was sprayed twice for mirids and once for whitefly.

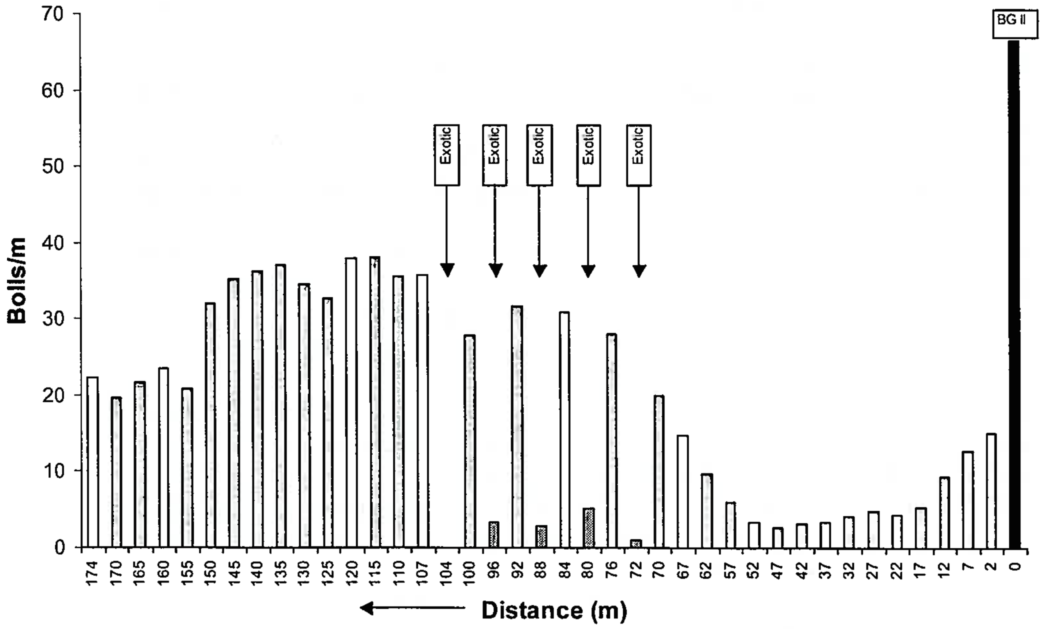

Figure 6. Mean fruit load profile for unsprayed Sicot 71 (hatched bars), exotic cottons (grey bars) and BOLLGARD II® (solid black bar) in the canopy manipulation experiment. The profile is based on 6 transects 50 m apart, from head ditch to tail drain.

The fruit load profile for unsprayed cotton in **Figure 6** does not represent a commercially viable outcome in comparison to the adjacent BOLLGARD II® crop. However, in view of the fact that 2003-04 was considered by most cotton growers and consultants to be a relatively heavy pest pressure season, the top end estimates of fruit load on the unsprayed cotton rows shielded by the exotic cottons are not insignificant. These yield estimates demarcate a baseline performance that could only be improved with the assistance of other IPM tactics (biological insecticides, soft insecticides, natural enemies, to name a few). Observations in the field suggest that the hedge effect demonstrated in this experiment may influence the distribution and activity of other insects besides heliothis. This and other aspects of the hedge effect and canopy manipulation need to be investigated further.

Acknowledgements

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