August & Final Reports

Part 1 - Summary Details

REPORTS

Please use your TAB key to complete part 1 & 2.

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Cotton Research & Development Corporation

Development of trap cropping protocols for *Helicoverpa* management on cotton in central Queensland

(DAQ 97C, July 1999 - June 2002)

A final report prepared for the Cotton Research & Development Corporation

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Plain English Summary

Helicoverpa armigera (Hübner) and *H. punctigera* (Wallengren) are serious pests of cotton in Australia. These pests constitute a continually increasing production cost for most field crops, particularly cotton. At the end of the 1996-97 cotton season, cotton growers in the Emerald, Biloela and Theodore areas of CQ agreed to adopt a trap-cropping program as a first step in the development of an area-wide strategy for management of *Helicoverpa*.

The principal research objectives of this project were (i) To review the strategic framework and test the validity of ecological assumptions underlying the CQ trap-cropping program, (ii) To develop indicators for assessing the efficacy and impact of trap crops, and (iii) To determine field parameters for optimising trap crop deployment and trapping efficiency under local field conditions. These objectives have all been achieved to varying degrees.

The research outputs of the project show that the CQ trap-cropping strategy is based on sound ecological principles. The strategy seeks to exploit weaknesses in the regional population dynamics of *Helicoverpa*. The fundamental assumptions underlying the strategy are valid.

The *Helicoverpa* problem in CQ is to a great extent locally generated within the cropping system. This explains the inexorable rise in the level of insecticide resistance in the pest. Host plant bottlenecks are clearly important factors in the population dynamics and pest status of *Helicoverpa*. This project has shown a relationship between spring rainfall and the incidence of resource bottlenecks in spring, namely, the correlation between spring rainfall and the incidence of *Helicoverpa* on cotton crops. Within cropping systems, spring resource bottlenecks, if and when they occur, are important determinants of *Helicoverpa* pest status early in the spring/summer cropping season.

Field assessments have show clearly that spring trap crops have the potential to capture and destroy large numbers *Helicoverpa* larvae prior to the start of the cotton season. What is not clear is whether or not the proportion of the pest population eliminated by the trap crops is sufficient to impact negatively on the area-wide population and implicitly pest pressure on cotton during the season.

Several aspects of spring trap cropping such as the crop area required, crop management and in-field layout, are still not well understood. Research on these aspects of trap cropping has also been done in other CRDC-funded projects. One important aspect of the technique is timing of the trap crop in relation to *Helicoverpa* population dynamics in the cropping system. Based on the data and analyses presented here the optimal window for the spring trap crops in the Emerald irrigation area should stretch across September and October. This would require planting of the trap crops in late August or early September followed by destruction in early November. Spring planting of the trap crops would also facilitate the use of other crop plants such as corn and sorghum that are known to be highly attractive to *Helicoverpa*.

The efficacy of summer trap crops in cotton production systems may depend on their relative visibility and inherent attractiveness to ovipositing moths. Growth rate and eventual height differences can influence trap crop performance. The limited data presented here suggest that some trap crops such as pigeon pea may need to be substantially taller than the main crop to maximise the population sink effect. Another important factor is the ratio of the trap crop to the main crop. In the trap-cropping literature this ratio appears to vary widely with the crop and target pest. This aspect of trap cropping remains a critical issue and may be best examined by means of computer simulation studies.

Several other factors including plant species, host-plant abundance and previous moth experience may be important determinants of host plant selection by moths and implicitly the performance of trap crops. A better understanding of these factors and their influence on oviposition behaviour is fundamental to the optimal use of trap crops as IPM tools.

The spring component of the Emerald trap-cropping program is a good example of a strategically sound approach to pest management that does not appear to have any appreciable impact on the target pest, most likely due to incorrect implementation. Although the results of our research to date do not provide evidence of a demonstrable impact of trap cropping on *Helicoverpa* population dynamics in cotton crops, the technique must still be considered a promising tool for IPM of cotton within a strategic area-wide management framework.

The efficacy and impact of the summer trap crops remains largely unknown. The main reason for this is the phenotypic variability of the pigeon pea variety currently being used for summer trap cropping in cotton. Whilst pigeon pea is undoubtedly a highly attractive crop to *Helicoverpa*, its usefulness as an end-of-season trap crop is questionable because of inconsistent growth habits and phenology, and therefore attractiveness, from one year to the next.

This project was not particularly successful in assessing field parameters of traditional trap cropping protocols for various reasons, as explained in earlier sections of this report. In particular, assessments of strip and block layouts were largely inconclusive. However, an outstanding result of this research project has been the discovery of a potentially new approach to trap cropping.

This new approach based on mixing of crop plants (seed mixing) seeks to exploit previously ignored aspects of pest behaviour in mixed crop situations. From a practical perspective, growing the main crop and the trap crop in the same field, as seed mixtures, offers growers a number of advantages. Firstly, this approach does not require cultivable area to be set aside for trap cropping. Secondly, both the trap crop and the main crop can be managed as a single unit. Thirdly, this approach allows direct estimation of the benefits of the trap crop by facilitating side-by-side comparisons of plant damage and yield loss. Impact assessment is one of the problems associated with traditional trap cropping protocols. The full agronomic impacts of seed mixing need to be examined.

The seed mixing protocol for trap cropping documented in this project could potentially revolutionise pest management in cotton. The extent of aggregative egg distribution responses by *Helicoverpa* in response to seed mixing crop plant cultivars or species in other cropping systems is currently unknown. In view of the economic importance of *Helicoverpa* to agricultural crop production, demonstration of a tendency towards aggregative oviposition behaviour in other crops could have important pest management implications. Our results highlight the need for further research on the relationship between crop canopy structure and pest distribution, and the potential to manipulate these for pest management.

1.0 Background

Helicoverpa armigera (Hübner) and *H. punctigera* (Wallengren) are serious pests of cotton in Australia (Fitt 1994). *H. punctigera* is endemic to Australia and occurs throughout the continent. *H. armigera* is found largely on the east coast of Australia and is also an important pest of field crops in Asia and Africa (Fitt 1989). *Helicoverpa* constitutes a continually increasing production cost for most field crops, particularly cotton.

Grower estimates put the typical cost of insect control on cotton at roughly $30/ha in 1966 increasing rapidly to more than $800/ha in 1998 (Bligh 1998). The bulk of this cost is usually apportioned to control of *Helicoverpa* throughout the season. McGahan *et al.* (1991) estimated that in the late 1980s and early 90s *Helicoverpa* alone accounted for a yield reduction of 7% in Queensland cotton crops despite expenditure of around A$7.5 million on control. Difficulties in controlling *Helicoverpa* during the late 1990s would have seen losses grow even larger (Adamson *et al.* 1997).

1.1 The CQ trap-cropping program

At the end of the 1996-97 cotton season, cotton growers in the Emerald, Biloela and Theodore areas of CQ agreed to adopt a trap-cropping program as a first step in the development of an area-wide strategy for management of *Helicoverpa*. The development of the trap-cropping program was an ancillary outcome of the Cotton Research & Development Corporation (CRDC) project DAQ 81C (*Entomology and pest management of INGARD cotton in CQ*).

DAQ 81C was commissioned to secure the registration of INGARD cotton for CQ. The data generated by the project showed clearly that the *Helicoverpa* problem in CQ was largely cyclical in nature. The data suggested that the use of trap crops on an area-wide basis was feasible and likely to succeed. Consequently, a strategic trap-cropping program was developed and implemented across CQ, beginning in the spring of 1997.

The target of the trap-cropping program is disruption of the cyclical inter-seasonal population dynamics of *Helicoverpa* within the cropping system. In practice, this is achieved by the deployment of spring and summer trap crops. The program recommends the planting of one trap crop patch on every farm in the Emerald Irrigation Area (EIA) at the beginning and end of the spring-summer growing season (BEOS model hereafter). Patches are required to comprise the greater of 1% or two hectares of total farm area. Spring trap crops of chickpea are to be planted in autumn/winter and destroyed in spring just prior to the start of the cotton-planting window in September. The recommended procedure for crop destruction includes slashing and soil cultivation to destroy pupal chambers in the soil. The chickpea trap crops are aimed at trapping and destroying spring generations of *Helicoverpa* emerging from diapause and those coming off maturing winter crops.

Summer trap crops of pigeon pea (*Cajanus cajan* L.) are to be planted concurrently or after cotton and destroyed by slashing and soil cultivation just prior to cotton harvesting. Management guidelines for the trap crops permit use of only biological insecticides on the spring chickpea crops to keep larval numbers within manageable limits but preclude insecticidal control of larvae on the summer pigeon pea crops. The pigeon pea trap crops are aimed at trapping and destroying the final generation of *Helicoverpa* emerging from cotton crops at the end of season. The summer trap crops constitute a key component of the resistance management strategy for transgenic cotton in CQ.

The patch size of 1% was proposed for two reasons. Firstly, the value reflected growers' readiness to sacrifice potential cotton area. Secondly, given the fact that the EIA is largely fallow in winter and planted predominantly to cotton from September to March, it was felt that a mosaic pattern consisting of small patches of extremely attractive trap crops could be just as effective and more manageable than larger patches. The expectation was that if the patches were well distributed, moths flying around the area would be likely to find at least one of the patches and deposit their eggs. Although the trap crops would attract both *Helicoverpa* species, *H. armigera* was the principal target because of its dominance of the insect pest spectrum in CQ and resistance to chemical insecticides.

Widespread adoption of the program by the vast majority of irrigated cotton growers in the region was influenced primarily by two factors. Firstly, commercial production of INGARD® cotton in CQ was approved by the regulatory authorities in the spring of 1997 subject to the use of summer (end-of-season) trap crops in conjunction with the product for pre-emptive management of resistance to *Helicoverpa*. Secondly, adoption of the trap-cropping program was borne out of an emerging consensus within the cotton industry that traditional pest control using chemical insecticides was no longer adequate, given the rising levels of *Helicoverpa* resistance to most commonly used chemical insecticides and upward spiralling costs of pest control. There was an urgent need to develop alternative, non-chemical pest control tools for cotton, and trap cropping was seen as an environmentally friendly pest management option that could be used in conjunction with chemical insecticides and other pest control options.

1.2 The perceived *Helicoverpa* problem in central Queensland

Four distinct components of the production system are thought to contribute to the pest problem in the Emerald area. These components are (1) native host vegetation and cultivated volunteer host plants, (2) cotton and other spring-planted crops such as corn, sorghum and mung bean, (3) mid-summer crops such as sorghum, sunflower, grain and ley legumes, and horticultural crops, and (4) winter crops, particularly chickpea. Grower experiences, observations of professional crop consultants in the area and the general structure of the system (eg. sequence of planting times), point to a pattern of cyclical *Helicoverpa* movement among the components.

Data from other areas in Australia and overseas suggest that native vegetation and volunteer host plants are important factors in the regional population dynamics of *Helicoverpa* (Fitt 1989; Wardhaugh *et al.* 1980). The contribution of this component of the Emerald cropping system to *Helicoverpa* populations in spring has not been determined. Uncultivated host plants may be particularly important in the annual spring replenishment of *H. punctigera* populations (Fitt 1989; Wardhaugh *et al.* 1980). In contrast, spring numbers of *H. armigera* in irrigation areas are likely to be more dependent on the cropping sequence and level of diapause within these areas (Fitt 1989).

Cotton is perceived to be the largest producer of moths in the spring-summer cropping season. In late February and March oviposition pressure on maturing cotton appears to decline. At around the same time, significant infestations are often observed on young flowering rainfed crops of sunflower and sorghum planted in December and January. Such observations suggest that a large proportion of moths emerging from cotton in February and

March migrates out of the irrigation area in search of younger, more attractive flowering crops in rainfed areas, whereas the remainder may go on to infest the following late summer crops within the EIA.

The contribution of summer legume crops within the EIA to late summer and winter populations of *Helicoverpa* appears to vary considerably between years. In some years the summer crops largely escape infestation presumably due to a time lag between the commencement of flowering in these crops and maturity of cotton.

Amongst the winter crops, wheat is known to support low density populations of *H. armigera* in certain years but there is little evidence of large-scale breeding on this host plant (Wardhaugh *et al.* 1980). In central Queensland (CQ) crop consultants and grain growers do not consider *H. armigera* to be an economic pest of wheat. Both *Helicoverpa* species are, however, serious pests of chickpea in Queensland (McCosker 1999). Chickpea is observed to support significant populations of *Helicoverpa* even in the early vegetative phase of the crop. Significant larval populations observed on chickpea in August and early September indicate that chickpea crops are likely to be the principal nurseries of *H. armigera* in spring.

2.0 Project objectives and the extent to which they have been achieved

Since the initial implementation of the CQ trap-cropping program in 1997, one of the questions frequently asked by growers in CQ is "Are the trap crops working?" Adoption of new technology by growers and incorporation of that technology into routing farm practices requires demonstration of its scientific rigour, practicality and profitability. The CQ trap-cropping program differed in this respect in that it was developed and implemented in the absence of any background research.

The strategic framework of the CQ trap-cropping program was based on a largely conceptual model of *Helicoverpa* population dynamics with untested assumptions. In view of the importance of trap cropping for continued CQ access to transgenic cotton technology and as a novel tool for regional *Helicoverpa* management, research was ungently needed to validate the scientific foundations, quantify the parameters and evaluate the effectiveness of the CQ trap-cropping program.

The principal research objectives of DAQ97C were (i) To review the strategic framework and test the validity of ecological assumptions underlying the CQ trap-cropping program, (ii) To develop indicators for assessing the efficacy and impact of trap crops, and (iii) To determine field parameters for optimising trap crop deployment and trapping efficiency under local field conditions. These objectives have all been achieved to varying degrees.

Objectives (i) & (ii) were achieved partly through a theoretical assessment of the ecological constraints on and empirical analyses of *Helicoverpa* population dynamics within and between seasons. The population dynamics of *Helicoverpa* in the Emerald cropping systems from 1996-1999 was quantified and analysed. This data facilitated preliminary assessments of the efficacy and likely impact of trap cropping on the pest status of *Helicoverpa* in the region. To achieve objective (iii), a series of on-farm experiments were conducted each year, from 1999-2002, to quantify various field parameters for trap cropping, including choice of trap crop plant, and field layouts.

Research activities undertaken to achieve each of the listed objectives and the outputs are described in the following sections.

2.1 The strategic framework of the CQ trap-cropping program

2.1.1 *The Emerald cropping system*

Emerald lies just above the Tropic of Capricorn at 200 m above sea level and 275 km inland from the east coast of Australia. The EIA, comprising 26000 ha of intensively cultivated land, forms the core of the system. The Emerald cropping system may be defined as the irrigated core surrounded by a rainfed cropping area, the bulk of which lies within a radius of approximately 100 km of Emerald. The majority of rainfed crops are found within a radius of 65 km around Emerald.

Cotton has been grown commercially in the EIA since 1976. The area under cotton varies between seasons but is usually around 20,000 hectares. This makes cotton the largest and most important crop within the irrigation area. The spring-summer cropping season stretches from September to May. The cotton window stretches from late September to March. Significant areas of seedling cotton can be found in most years by the end of October. Cotton harvesting in the EIA is usually complete by the end of April. In most years the irrigation area is largely fallow between June and September.

Small areas of spring-planted corn (*Zea mays* L.), sunflower (*Helianthus annuus* L.) and legumes such as mung bean (*Phaseolus (Vigna) aureus* Roxb.) and soybean (*Glycine max* (L.)) can be found in the irrigation area in years when availability of water is limited early in the season. Under favourable rainfall conditions small areas of summer sorghum (*Sorghum bicolor* (L.)), sunflower and legume crops may also be commonly found within the irrigation area. These crops are normally planted in January and February.

Summer rainfed crops, mainly sorghum and sunflower, are planted from late-December onwards and harvested by May or June. The two main rainfed winter crops in CQ are chickpea (*Cicer arietinum* L.) and wheat (*Triticum* spp.). The optimal planting window for both crops is from late April to the end of May. Chickpea and wheat crops planted in the optimal window begin to mature and dry by early September.

2.1.2 *Ecological assumptions underlying the trap cropping strategy*

The BEOS model of trap cropping for the EIA was based partly on the theory and experience of area-wide management of heliothine moths in the USA (Stadelbacher 1981; Knipling and Stadelbacher 1983; Mueller *et al.* 1984). The objective of the spring trap crops was to destroy the offspring of the first 1-2 spring generations of *H. armigera* so as to delay the build-up of the pest and minimise damage to crops early in the growing season. The summer trap crops targeted the offspring of the last *Helicoverpa* generation emerging from cotton so that insecticide resistance developed over the season could be confined to the irrigation area and minimised.

The strategic framework underlying the BEOS model was based on three fundamental assumptions. The first of these was that population dynamics of *H. armigera* was driven substantially by recruitment within the Emerald cropping system (as defined above). This assumption is consistent with the prevailing view that in comparison to other heliothine species *H. armigera* tends to be more sedentary and prevalent in cropping areas where a continuous supply of host plant resources is available (Wardaugh *et al.* 1980; Fitt 1989). The development of high levels of insecticide resistance in *H. armigera* is also consistent with substantial local recruitment in cropping systems (Forrester *et al.* 1993). Local recruitment would increase the likelihood of successfully targeting and controlling the founding populations of the pest in spring.

The second assumption was that a bottleneck in the availability of *Helicoverpa* host plant resources within the cropping system develops every year. Chickpea crops grown in the optimal winter cropping window (April - October) normally mature in early September. Substantial areas of spring-planted crops including cotton that can sustain large larval populations of *Helicoverpa* are normally not available for oviposition until early November. This can result in a period of several weeks when there is an acute paucity of cultivated host plants and few suitable weed host plants in uncultivated areas. The presence of trap crops timed to occur during such resource (host plant) bottlenecks in spring could potentially augment the pest population bottleneck that inevitably results.

The third assumption provided the rationale for the summer component of the trap-cropping strategy. Cotton was assumed to be the largest producer of moths in mid-summer and, as the largest consumer of insecticides in the cropping system, also the vehicle of selection for resistance in *H. armigera.*

2.1.3 *Interseasonal population dynamics of Helicoverpa: pupae production in the Emerald cropping system: 1996 -1999*

Prior to the implementation of the trap-cropping program in 1997, a three-year survey of *Helicoverpa* pupal abundance and temporal distribution under crops grown in the Emerald cropping system was initiated in October 1996. The objective of the exercise was to validate the basic assumptions of the trap-cropping program against the observed dynamics of moth production and inferred pattern of movement between crops or components of the system. The data from this survey have been published in Sequeira 2001.

Table 2.1.1. Estimated areas of production for major cropping options in the Emerald cropping system.

	Production type, season and area (hectares x 10^3)							
	Irrigated*				Rainfed			
Crop	1996-97	1997-98	1998-99	1999-00	1996-97	1997-98	1998-99	1999-00
Wheat				200	150,000	140,000	180,000	90,000
Chickpea	50		100	100	15,000	12,000	13,000	7,000
Cotton	19,000	22,000	22,000	22,000	5,000	5,000	5,000	5,000
Sorghum	500				120,000	40,000	125,000	120,000
Sunflower	100	100			75,000	55,000	40,000	25,000

*Grown within the EIA.

Estimates of production area for the major crops grown in the system from 1996 to 1999 are listed in Table (2.1.1). Minor crops or those grown occasionally are not included in the table. Estimates of production area for the minor crops are indicated in context below in this section. It should be noted that all estimates of production area are approximate and intended to serve only as rough indicators of the potential for recruitment of *Helicoverpa* moths.

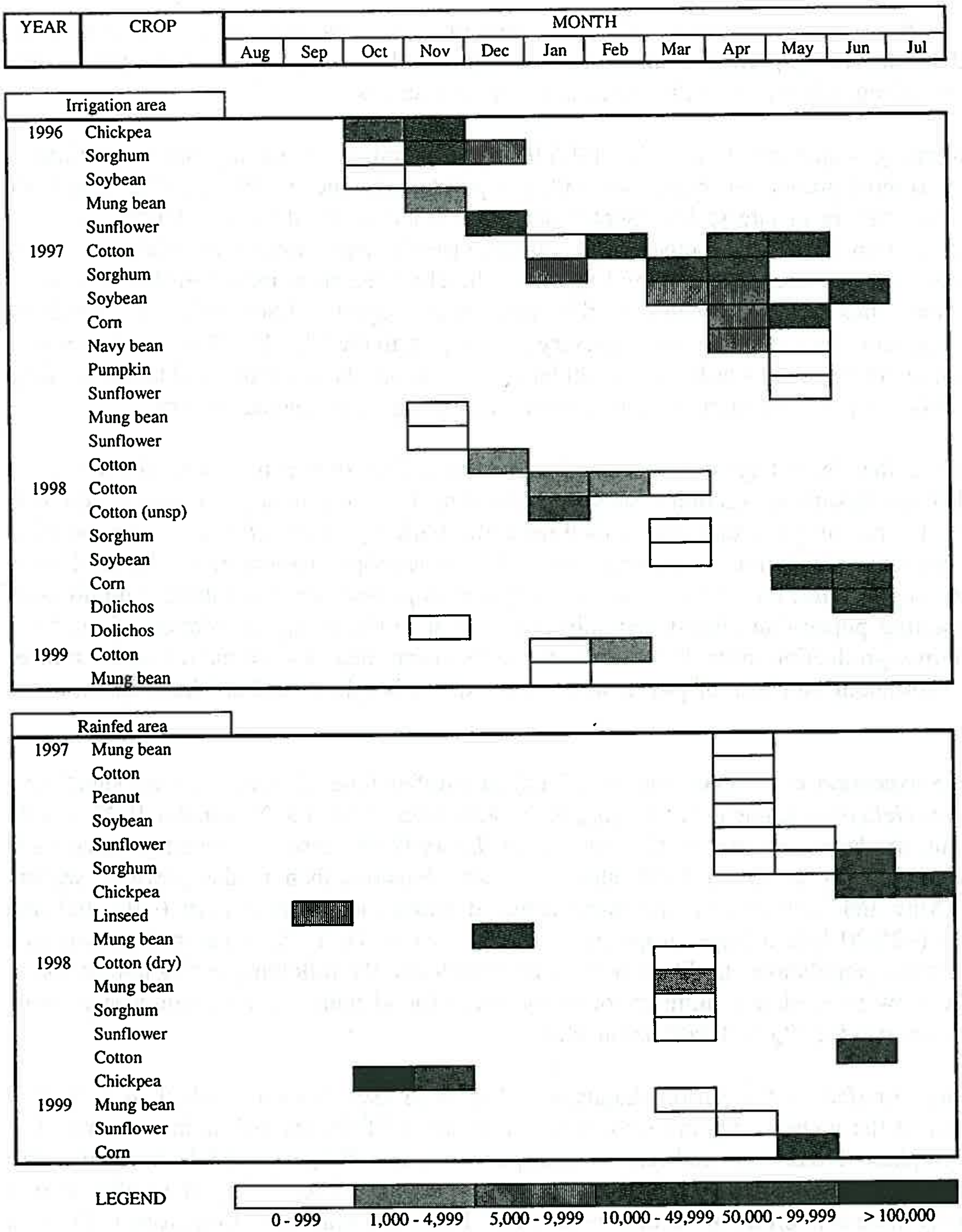

Fig. 2.1.1. Abundance (pupae per hectare) and temporal distribution of *Helicoverpa* pupae in relation to the crops grown and the cropping system in the Emerald area: 1996 - 1999. Note that three distinct types of cotton crops are recognised, namely irrigated and protected with insecticides [cotton], irrigated but completely unsprayed [cotton (unsp)], and rainfed and protected with insecticides [cotton (dry)]. Estimates of pupal abundance for each crop are based on number of pupae found in 20 1-m^2 random soil samples. The number of times each crop was sampled ranges from 1 to 6.

The abundance and distribution of pupae (and implicitly moths) under cultivated crops throughout the survey period is summarised in Figure (2.1.1). Crops under which pupae were not detected (eg. wheat) are not included in the survey results.

The cropping sequence during the 1996-97 spring-summer cropping season facilitated continuous moth production, beginning with late-planted chickpea (~ 40 ha) in October 1996. Substantial rainfall in late spring (September or October) resulted in an extended chickpea cropping season by inducing renewed vegetative growth and flowering in chickpea. Empty pupal cases encountered during sampling under the chickpea crop, indicated that a previous generation of moths had emerged from this crop during August and September. The chickpea crop presumably served as the initial nursery for the pest in the EIA. Small areas of sorghum, soybean, mung bean and sunflower (~ 100 ha of each) would have contributed to the build-up of the *Helicoverpa* population in the irrigation area during the following months.

Cotton was the single largest producer of pupae in the EIA during the 1996-97 season. An extended spring/summer cropping season resulted in detection of pupae under cotton well into April. This suggests that cotton facilitated the build-up of the *Helicoverpa* population and movement on to summer sorghum, corn and legume crops (maximum 200 ha production area for each) within the EIA. These late summer crops harboured substantial numbers of overwintering pupae that almost certainly contributed to the spring population of moths in 1997. Pupae production in the EIA was matched by complimentary production under rainfed crops. Substantial numbers of pupae were found under sorghum and chickpea in June and July.

With the exception of a small area (~ 50 ha) of rainfed linseed there were no substantial sources of *Helicoverpa* pupae in the cropping system from August to November 1997. Cotton was again the largest source of *Helicoverpa* in the 1997-98 season, producing pupae from December through to March 1998, albeit at lower densities than in the previous season. During May and June 1998 pupae were detected under late summer corn (~100 ha) and dolichos (~25-30 ha), a large proportion of which were observed to be in diapause (see below). These populations are likely to have contributed to the following spring population in the EIA. Low to moderate numbers of pupae were found under rainfed mung bean crops (production area for CQ > 10,000 ha) in March.

Substantial rainfall in the period August-October 1998 (see below) resulted in a marked extension of the winter cropping season well into the 1998-99 spring/summer season. The large area planted to commercial rainfed chickpea crops in 1998 (Table 2.1.1) combined with very high densities of pupae in October and November (Fig. 2.1.1) translated into a potentially large pest problem for cultivated crops during the season. Cotton crops in the EIA were subjected to high *Helicoverpa* pressure from October to the middle of December. The EIA was largely free of non-cotton crops between October 1998 and September 1999. Cotton was the only significant source of pupae in the irrigation area in February 1999. A small area of mung bean (~50 ha) with negligible density of pupae was the only other source of *Helicoverpa* encountered within the EIA.

Low rainfall after February 1999 prevented planting of late summer crops in the EIA. Few crops were grown in the rainfed area. Corn (max. 1000 ha) was the only substantial source of pupae in May 1999 (Fig. 2.1.1). Lack of moisture in the soil profile resulted in dramatically reduced acreages of chickpea crops during the winter of 1999 (Table 2.1.1). There were no chickpea crops within about 50 km from the irrigation area.

Over the survey period, a total of 4171 pupae were collected of which 86% were *H. armigera*. Pupae collected in late summer in the EIA and rainfed areas tended to be almost all *H. armigera*. A total of 429 pupae were collected from May-July over the survey period. Of these winter-collected pupae, 76% were observed to be in diapause.

The pattern of pupae production under cotton described above and egg/larval densities on the crop (R. Sequeira, unpublished observations) indicates that under environmental conditions experienced in the EIA the final or penultimate generation of *Helicoverpa* moths from cotton emerges in February. The overall pattern of pupae production under various crops by itself does not constitute evidence of moth movement between crops and seasons as suggested in Fig. (2.1.1). However, the temporal distribution of pupae within the irrigation area together with complimentary pupae production in rainfed areas is strongly suggestive of a cyclical pattern of moth movement.

The data on pupal abundance and their temporal distribution strongly support the validity of the first and third assumptions underlying the strategic framework of the trap-cropping program. The magnitude and pattern of pupae production in the Emerald cropping system over the entire survey period clearly indicate substantial 'local' recruitments within the cropping system. The data show clearly that cotton is the largest and most important source of *Helicoverpa* pupae, and implicitly the vehicle for development of resistance to insecticides in H. armigera. The second assumption, that a host plant resource bottleneck occurs in spring each year, is only partially valid.

The continuous pattern of pupae production in the cropping system in the 12-month period to August 1997 (Fig. 2.1.1) suggests the absence of a resource bottleneck in the spring of 1996. Similarly, an extended winter cropping season in the spring of 1998 appears to have prevented the development of a resource bottleneck in that year. The absence of substantial cropping and sources of pupae in the period August-September of 1997 and 1999 does not prove but is consistent with the development of a resource bottleneck in these two years.

2.2. Efficacy and impact of trap crops

2.2.1. *Trap crop performance*

The trap crop plants, chickpea and pigeon pea, were selected on the basis of differing criteria. Chickpea was the ideal candidate for a spring trap crop, being a substantive cultivated winter host of *Helicoverpa* in the region. The choice of pigeon pea as the summer trap crop was based on literature reports of its attractiveness to *Helicoverpa* (eg. Abate 1988). The first spring trap crops were planted in May/June 1997 and destroyed in late August. The summer trap crops were planted for the first time in October 1997 and destroyed in March 1998, just prior to cotton harvesting.

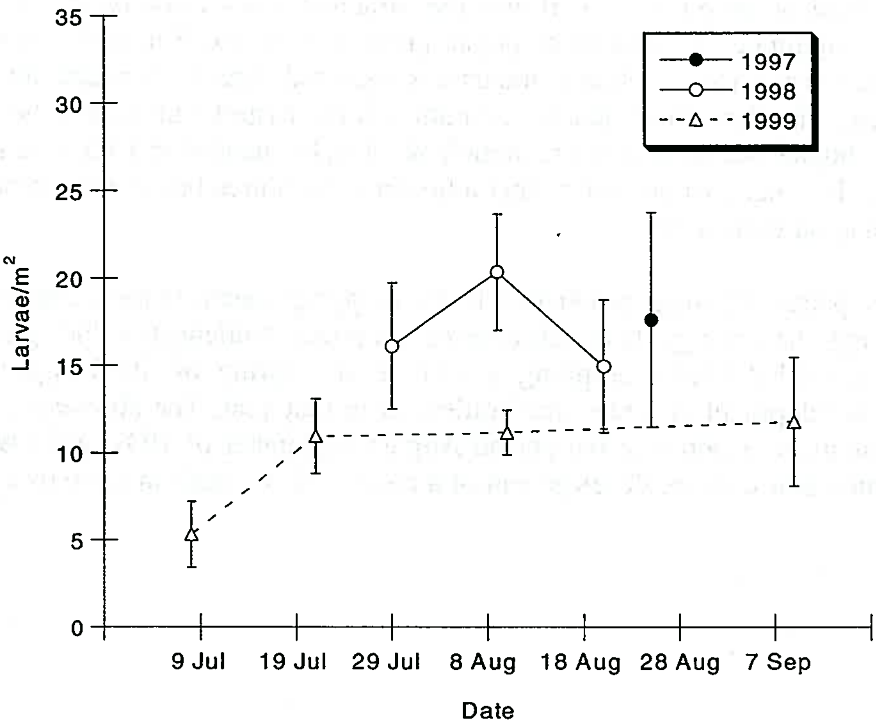

Fig. 2.2.1. Mean *Helicoverpa* larval counts on chickpea trap crops in the winter and spring of 1997 (•), 1998 (o) and 1999 (Δ). Error bars show S.E.M.

Of some 63 individual farms or farming units in the EIA, at least 55 (87%) planted a total of between 120 and 140 hectares of chickpea trap crops over the three-year period. Random drop-sheet sampling under the trap crops (10 x 1m^2 areas of n=2 crops in 1997, n=6 crops in 1998 and n=4 crops in 1999) between July and September indicated population densities ranging from 5 to 30 larvae/m^2 (Fig. 2.2.1). *H. armigera* constituted 86% and around 90% of the larval population on the trap crops in 1997 and 1999, respectively. Species identification of larvae was not done in 1998 but pupae collections from chickpea contained over 90% *H. armigera*. Using a conservative mean of 10 larvae/m^2 over all three years, destruction of the trap crops in late August/early September potentially eliminated more than 12 million larvae each year prior to spring planting of cotton and other crops.

Approximately 120 ha of unsprayed pigeon pea trap crop (var 'Quest') were planted adjacent to sprayed cotton in the 1997-98 and 1998-99 seasons. Compliance with the summer trap cropping recommendation was estimated at over 90% of individual farms or farming units in the EIA. Oviposition activity on the trap crops commenced only after the onset of flowering in early December, approximately 65 days after planting.

Table 2.2.1. Temporal distribution of *Helicoverpa* pupae (mean density/ha) under cotton and pigeon pea trap crops in the Emerald Irrigation Area over two summer cropping seasons.

Season	Crop	Month				
		Dec	Jan	Feb	Mar	Apr
1997-98	Cotton	3,000	3,250	2,500	0	
	Pigeon pea	41,000	26,750	121,129	239,667	
1998-99	Cotton	0	217	2100	0	
	Pigeon pea	0	0	4,875	0	

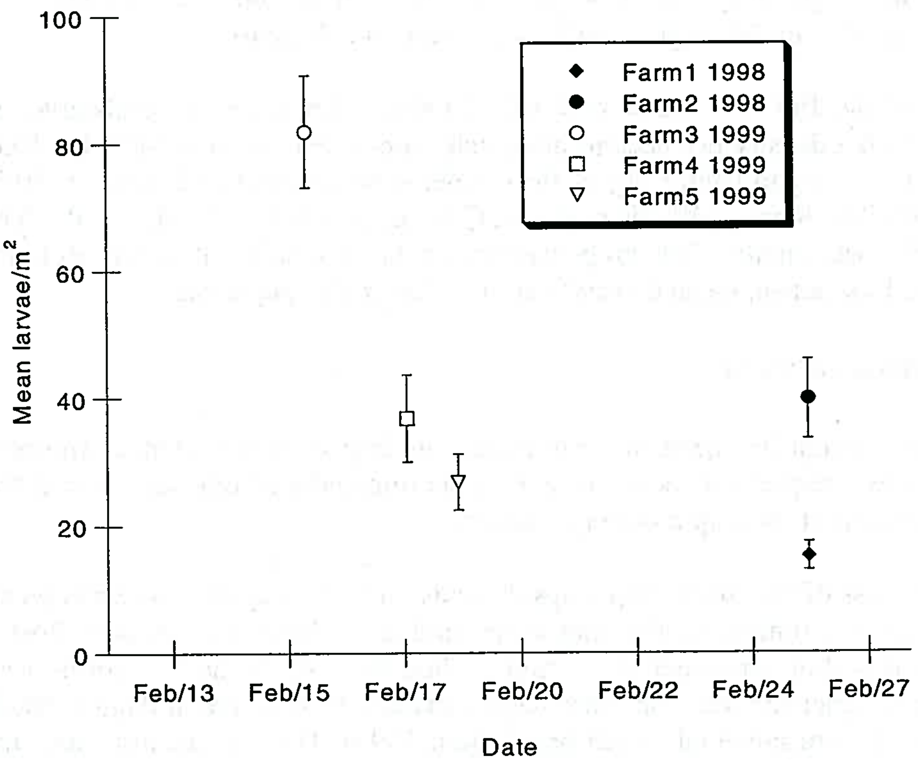

Fig. 2.2.2. Mean *Helicoverpa* larval densities on pigeon pea trap crops in the Emerald irrigation area. Error bars show S.E.M.

The temporal pattern of pupae production under cotton and pigeon pea in the 1997-98 season was used to determine the level of synchrony between the two crops in attractiveness to *Helicoverpa*. Detection of substantial numbers of pupae under pigeon pea in December 1997 (Table 2.2.1) indicated that the trap crops were becoming attractive for oviposition by early December, very early in the cotton season. The trap crops therefore posed the risk of exacerbating the pest problem by becoming sources of moths during the season. Later planting of the trap crops (late November - early December) recommended for the 1998-99 cropping season to ensure flowering in February resulted in better synchrony of pigeon pea attractiveness and maturity of cotton, as indicated by the detection of pupae under both in February (Table 2.2.1).

Fig. 2.2.2 shows mean *Helicoverpa* larval density (n = 10 x $1m^2$ drop-sheet samples per crop) on unsprayed pigeon pea trap crops in the vicinity of sprayed cotton on five farms in February over the two-year period. These estimates of larval densities are indicative of the trapping potential of the crop. Samples of larvae collected for species identification were 100% *armigera* in both seasons. Using a conservative estimate of 20 larvae/m^2 and a trap-crop area of 120 hectares, destruction of the trap crops would have potentially eliminated 24 million individuals, most of which would have been highly resistant to a number of chemical insecticides, at the end of the 1997-98 season.

Despite the trapping potential of pigeon pea evident the previous year, implementation of the summer trap cropping component in the 1998-99 season was fraught with agronomic and crop management problems. In addition to low seed and availability issues, pigeon pea crops appeared to vary considerably in plant height (and implicitly trapping potential) within and between years, and between farms. Although specific height measurements were not recorded for individual crops, they could be grouped into tall (≥ 180 cm) and short (≤ 140 cm) phenotypes relative to the height of adjacent cotton (140-160cm).

At the end of the 1997-98 season both tall and short phenotypes were observed under field conditions. Pupal density per hectare under tall crops [n=6, mean = 245.15 x 103 ± 96.28 x 103 (SEM)], was significantly higher than under short crops [n=12, mean = 30.58 x 103 ± 6.75 x 103 (SEM); Kruskal-Wallis rank test, Chi-square = 8.25, df = (1,22), P < 0.01]. During the 1998-99 season, none of the crops were taller than the adjacent cotton. In four crops that were sampled for pupae, mean density was only 4.88 x 103 pupae/ha.

2.2.2. *Impact Assessment*

Currently no attempt has been made to assess the impact of the summer (pigeon pea) trap crops for reasons explained above. Therefore the remainder of this section will focus on the spring component of the trap-cropping program.

The effectiveness of the spring trap crops depends on the timing of moth emergence in spring in relation to the timing of the trap crops and availability of alternate host plants for oviposition. Based on computer simulation studies, the bulk of the first spring generation of *Helicoverpa* (diapausing and non-diapusing) is expected to emerge in August and September under Emerald environmental conditions (Dillon 1998). These predictions are supported by data on termination of diapause in over-wintering pupae and pheromone trap catches showing a spike in mid-August (R. Sequeira, unpublished data).

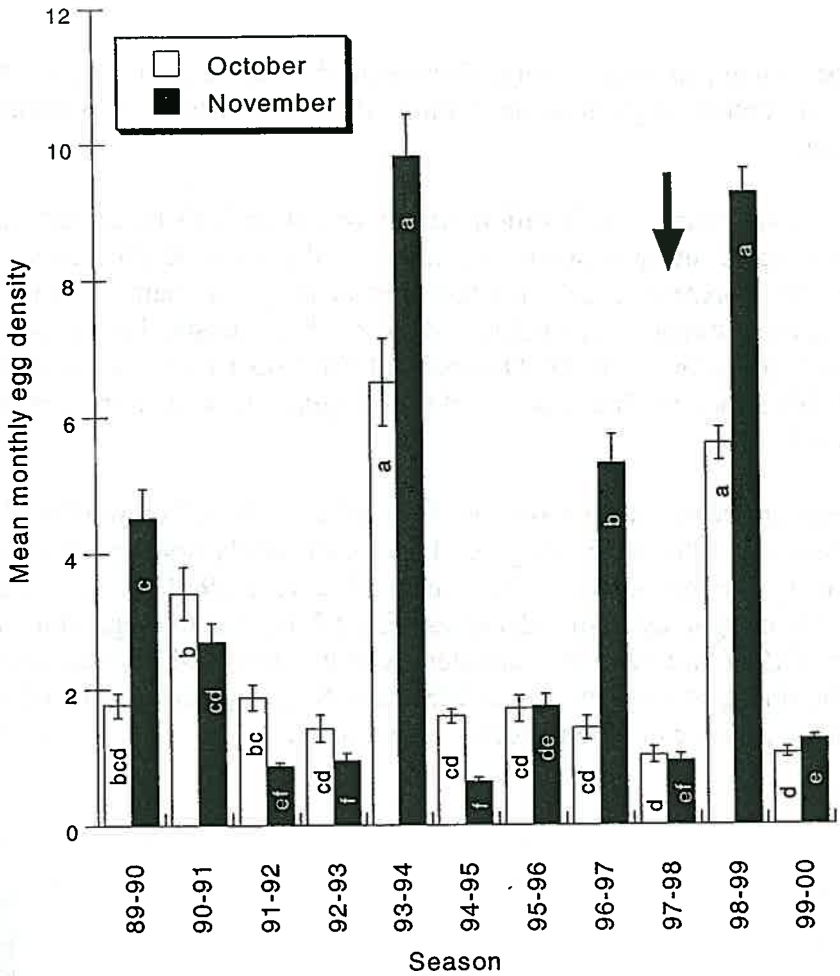

Fig. 2.2.3. Changes in mean monthly egg density per metre of cotton for the months of October and November over a period of 11 seasons. The arrow marks the beginning of the trap cropping program in the winter of 1997. Error bars show SEM. Means represented by same species of bars that share the same letters are not statistically different ((Kruskal-Wallis rank test, Comparison of mean ranks, $\alpha = 0.05$). **Data provided courtesy of A. J. Noone Pty Ltd, Emerald, and Duane Evans Pty Ltd, Emerald.**

The density of pupae under chickpea (Fig. 2.2.1) clearly indicates that the area under commercial chickpea crops is a major determinant of the *Helicoverpa* moth population in spring. A trap crop area of 120 hectares equates to < 1% of the commercial chickpea cropping area in most years (Table 2.1.1). In the absence of a host plant resource bottleneck, the spring trap crops would have little or no impact on *Helicoverpa* abundance later in the season because a minuscule area of trap crops would be competing with a much larger resource area of commercial chickpea and other host plants. Similarly, if the spring trap crops were not timed to occur within the resource bottleneck window, their impact would also be minimal. However, because host plant resource bottlenecks are inevitably followed by pest population bottlenecks, even a relatively small area of well-dispersed trap crops timed to occur within the former could potentially augment the latter.

The cropping sequence and pattern of moth recruitment in the Emerald cropping system (Fig. 2.1.1) together suggest that spring populations of *Helicoverpa* experienced a resource bottleneck in 1997 and 1999. The resulting *Helicoverpa* population bottleneck in these two years would be evident as substantially decreased abundance as measured by oviposition pressure on young cotton crops in comparison to 1996 and 1998 when a resource bottleneck was not apparent.

Fig. 2.2.3 shows a summary of oviposition activity on cotton in October and November based on commercial crop scouting data for five farms in the Emerald area over a period of 11 seasons. Each bar represents mean monthly egg density per metre of row calculated by averaging the daily estimates over fields and farms. For statistical purposes, between-year differences in density recorded during October and November were analysed separately using the Kruskal-Wallis rank test. The arrow marks the beginning of the trap-cropping program in the winter of 1997.

The lowest mean egg density for October was recorded in 1997, followed by 1999. The years 1991, 1992, 1994 and 1997 were categorised as a statistically homogeneous group with the lowest egg density for the month of November. The year 1999 was assigned to the next higher group with marginally higher densities (Fig 2.2.3). The low egg densities in October and November of 1997 and 1999 are consistent with the proposed development of a resource bottleneck in the spring of these two years. Similarly, high egg densities in 1996 and 1998 are consistent with the absence of a bottleneck in these years.

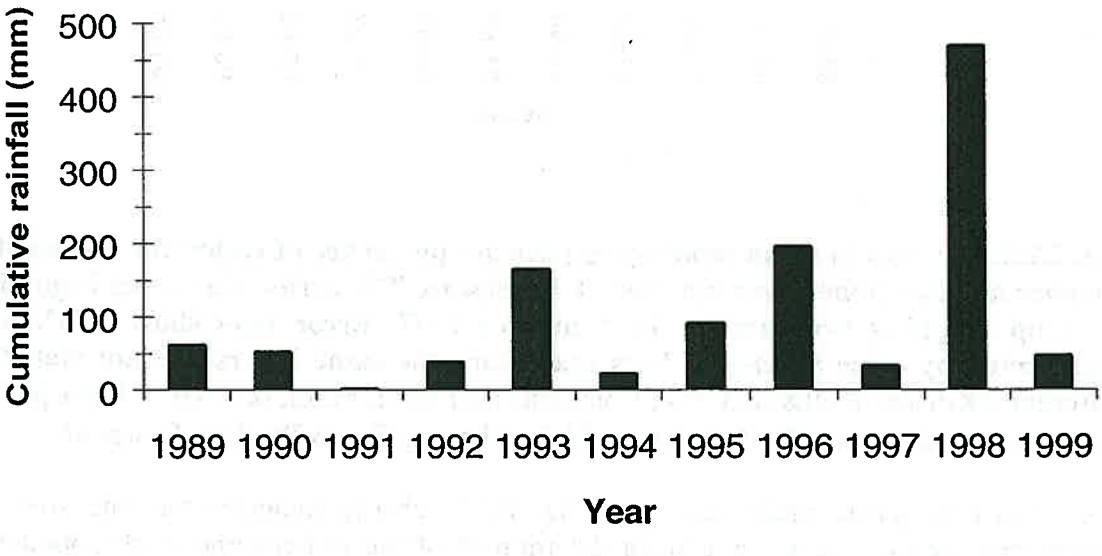

Fig. 2.2.4. Cumulative rainfall for the months of August, September and October recorded within the Emerald irrigation area each year from 1989 to 1999.

The lack of cropping and pupal dynamics data for the period 1989-1995 precludes any definitive conclusions about the availability of spring host plant resources in these years. However, the amount of spring rainfall is indicative of resource availability during that period in any year. Substantial spring rainfall results in greater availability of host plant resources for *Helicoverpa* through renewed vegetative growth and flowering in chickpea (and probably other host plants), and often a longer winter cropping season. Fig. 2.2.4 shows cumulative rainfall over the period August-October from 1989 to 1999. The striking similarity between the pattern of winter rainfall and average monthly *Helicoverpa* egg density on cotton over the 11-year period (Fig. 2.2.3) clearly points to a high correlation between wet springs and *Helicoverpa* abundance.

In years when spring rainfall exceeded 50 mm (Fig. 2.2.4) *Helicoverpa* abundance on cotton in November, measured as egg density on cotton, was also markedly higher (Pearson correlation, R = 0.81). Similarly, there is also good agreement between rainfall and egg density in October but less so than for November (Pearson correlation, R = 0.66). The majority of cotton crops in the EIA are normally in the very early seedling stage in October with the result that *Helicoverpa* egg density in November more accurately reflects pest pressure on cotton early in the season. Close correspondence between substantial spring rainfall and increased *Helicoverpa* abundance in cotton suggests that a resource bottleneck did not develop in 1989, 1990 and 1993.
A marked reduction in *Helicoverpa* egg density on cotton in 1997 and 1999 relative to other 'bottleneck' years (1991, 1992, 1994 and 1995) would be a qualitative indication of the impact of spring trap crops. It is evident from Fig (2.2.4) that the impact, if any, of the trap crops on the population dynamics of *Helicoverpa* cannot be distinguished from the expected consequences of a spring resource bottleneck. The most likely explanation for this result is inopportune destruction of the trap crops in August, prior to the development of the resource bottleneck expected in September and October. It must also be recognised that, based on the current data set (three plantings), only a preliminary assessment of the spring trap cropping technique is possible.

2.3. Quantification of field parameters for trap cropping

At the time of initial implementation, several aspects of trap cropping were poorly understood. Among the most significant issues related to trap crops was the actual field deployment. How big should the area of the trap crop be in relation to the main crop it is meant to be protecting? What is the pulling power of a given area of trap crop? What is the best trapping option (choice of trap crop) for cotton in CQ? How should the trap crops be laid out? Are blocks of trap crop better than strips? These were some of the questions being asked by growers. The long-term adoption of trap cropping by the grower community and a positive outcome of the technology required answers to the above questions.

A series of farm experiments and assessments were conducted between 1999 and 2002 to answer some of the above questions. These research activities can be grouped into three categories, namely (i) Evaluation of spring trap crop options, (ii) Evaluation of summer trap crop options, and (iii) Evaluation of trap crop layouts. The outputs of these activities are described below.

2.3.1. Evaluation of spring trap crop options

Cultural control by way of habitat diversification has received considerable attention as an alternative pest management strategy (Bohlen & Barrett 1990; Abate 1991; Tonhasca & Stinner 1991; Emeasor & Ezueh 1997; Balasubramanian *et al.* 1998; Wang & Yue 1998; Banks & Ekbom 1999; Ekesi *et al.* 1999; Mensah 1999; Parajulee & Slosser 1999). Habitat diversification by way of companion or strip cropping aims to reduce the pest population on the target crop by diverting pressure away from the main crop or increasing the abundance of beneficial insects.

The objective of this assessment was to identify crop species that could serve as diversionary hosts for ovipositing *Helicoverpa* moths when grown as companion crops. Patterns of host selection by *Helicoverpa* in chickpea-companion crop combinations were determined. A serendipitous and little known pattern of host selection in weedy chickpea was documented.

Experimental design and field layout

The field assessment was done on cracking black clay soil under furrow irrigation in Emerald (23°34' S, 148°10' E), Queensland. The field layout followed a split-plot design (Cochran & Cox 1957; Steel & Torrie 1980) with 4 blocks, 6 plots within blocks and 2 subplots within plots. Plots were randomised within blocks. Each plot was assigned to one of six, paired crop combinations. Within each plot, one of the paired subplots was randomly assigned to chickpea (cv 'Amethyst'), the other to one of six companion crops.

Winter tolerant crop species suited to the semi-arid subtropical environment of central Queensland were chosen for companion planting. The paired crop combinations with chickpea were as follows: (1) *Brassica juncea* (L.) (indian mustard, cv 'CSIRO 997-1-1'); (2) *Brassica napus* L. var. *napus* (canola, cv 'Hylite 200 IT'); (3) *Vicia faba* L. var. *faba* (faba bean, cv 'Fiesta'); (4) *Pisum sativum* L. var. *arvense* (field pea, cv 'Dunn'); (5) *Linum usitatissumum* L. (linseed, cv local); (6) *Lupinus albus* L. (lupin, cv 'Mutant Kiev').

All crop species were planted on 7 May 1999 on raised beds at recommended commercial planting rates. Subplots measuring 15-m x 5.4-m (12 rows x 45-cm spacing) within plots were adjacent to each other within plots. Blocks and plots within blocks were separated by 5.4-m wide (12 rows x 45-cm spacing) strips of *Triticum aestivum* L. (wheat) as a buffer crop to isolate the crop combinations. *H. armigera* is occasionally found on wheat but at very low densities and is not considered to be an economic pest of this crop in central Queensland. *H. punctigera* is restricted to dicotyledonous hosts.

Sampling protocols

Paired crop combinations. Sampling was done at key phenological stages of the plants, *viz.*, vegetative, early flowering, peak flowering and grain filling. Accordingly, plant samples were collected within a 6-hour period at 46, 67, 80 and 112 days after planting (DAP) respectively. At each of the four sampling dates, egg and larvae counts were obtained by using the following procedure. Within plots, two 1-m row of crops were selected at random from each subplot and the plants cut at ground level. These plants were enclosed individually in large brown paper bags and transferred to the laboratory where the number of *Helicoverpa* eggs and larvae on each plant was recorded.

In-crop weeds and wheat buffer. As part of the routine maintenance of the trial area, the plots were hand-weeded on 11 August 1999. During this operation, *Helicoverpa* eggs were observed on weeds growing within chickpea rows but not on weeds in the companion crops. Of the 24 chickpea subplots, 14 had been weeded before this phenomenon was observed. Therefore, quantification of *Helicoverpa* eggs and larvae was done on the remaining 10 chickpea subplots. The height of each weed plant and its surrounding chickpea canopy was recorded. Canopy height was determined by recording the average height of five chickpea plants within a radius of 30-cm around each weed. The total number of *Helicoverpa* eggs and larvae on each weed plant in the subplot and 10 chickpea plants surrounding each weed plant was quantified.

For each of the 10 chickpea subplots in which oviposition on weeds had been quantified, eggs and larval counts were obtained for 10 randomly selected wheat plants from buffer rows closest to and third away from chickpea. The objective of this assessment was to determine whether or not moths had discriminated between wheat plants growing in the buffer strips and as weeds in chickpea.

Data analysis

Data from the paired crop combinations were log transformed (count + 1) and analysed as a split-plot design across space and time (Steel & Torrie, 1980) with Sample-date (or DAP) as the time factor. Egg and larval data were analysed separately. The error term for plots was used to examine the significance of overall differences in egg distribution among crop combinations. The significance of differences in the distribution of eggs between chickpea and the paired companion crop were tested at the subplot level. Inclusion of Sample-date in the design facilitated the detection of temporal changes in the pattern of egg distribution.

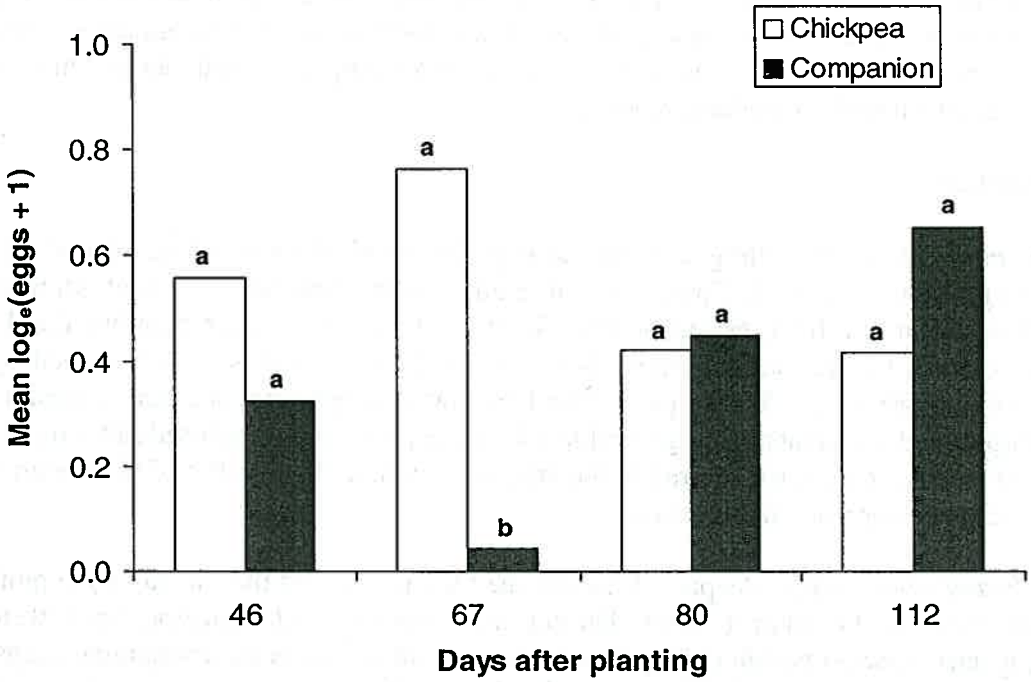

Figure 2.3.1. Distribution of total egg counts on chickpea and companion crop across paired crop combinations, pooled over Sample dates and blocks. Paired crop combinations with chickpea: (1) *Brassica juncea* (2) *Brassica napus* (3) *Vicia faba* (4) *Pisum sativum* (5) *Linum usitatissumum* (6) *Lupinus albus*.

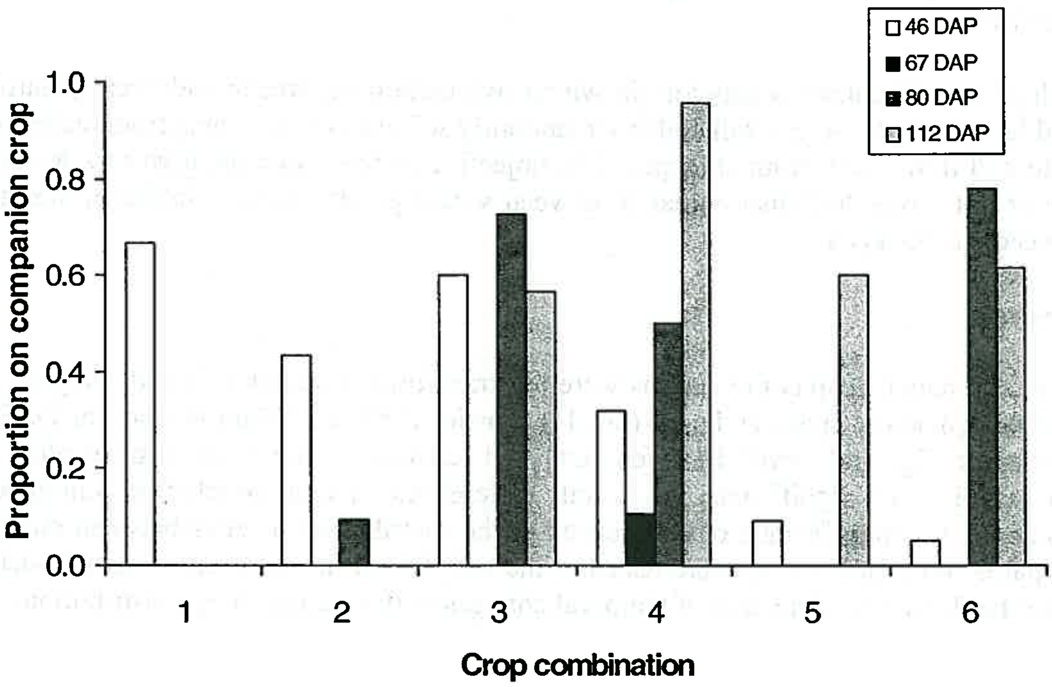

Figure 2.3.2. Mean egg density per metre on chickpea and companion crop across Sample dates, pooled over blocks and crop combinations.

Results

Crop phenology. Of the six companion crops, mustard followed by canola and faba bean, exhibited the most vigorous seedling growth. Only the *Brassica* species were flowering at the time of the first sample (46 DAP). *Helicoverpa* eggs and neonate larvae were found on chickpea plants within 7 days of seedling emergence (14 DAP) but not until much later on the other species. At the time of the second sample (67 DAP), all plant species were flowering, and at 80 DAP, all companion crop plants except lupin were taller than chickpea.

Analysis of egg counts - Paired crop combinations. A total of 404 eggs were recorded over all Sample-dates, Blocks and Plots. Of this total, 59.7% were found on chickpea. Egg distribution (pooled across all Sample-dates and Blocks) varied between and within crop combinations (Figure 2.3.1). Within combinations 3 (*V. faba*) and 4 (*P. sativum*), chickpea and the paired companion crop received similar numbers of eggs whereas in all the other combinations the majority of eggs was laid on chickpea. Combination 4 received the largest proportion of eggs (31%) whereas 1 (*B. juncea*) and 5 (*L. usitatissumum*) received the least.

The results of the split-plot analysis on eggs are given in Table 2.3.1. There were significant differences in overall mean egg density among crop combinations. Combinations 3, 4 and 6 (*L. albus*) were not significantly different from each other in mean egg density but as a group differed significantly from the others [LSD, $P < 0.05$]. The effect of Sample-date is insignificant, indicative of parity in egg distribution over time. The borderline significance level ($P = 0.06$) of the Subplot main effect, together with significant two- and three-way interaction with the other factors indicate changes in the distribution of eggs within and among crop combinations over time. The Subplot.Sample-date interaction results from the marked preference for chickpea subplots at 67 DAP. The Plot.Subplot.Sample-date interaction is shown in Figure 2.3.2. The companion crops *B. juncea* and *B. napus* received few or no eggs after the first Sample-date (46 DAP). In contrast, *V. faba, P. sativum, L. usitatissumum* and *L. albus* received more than 50% of the eggs laid at 80 and 112 DAP.

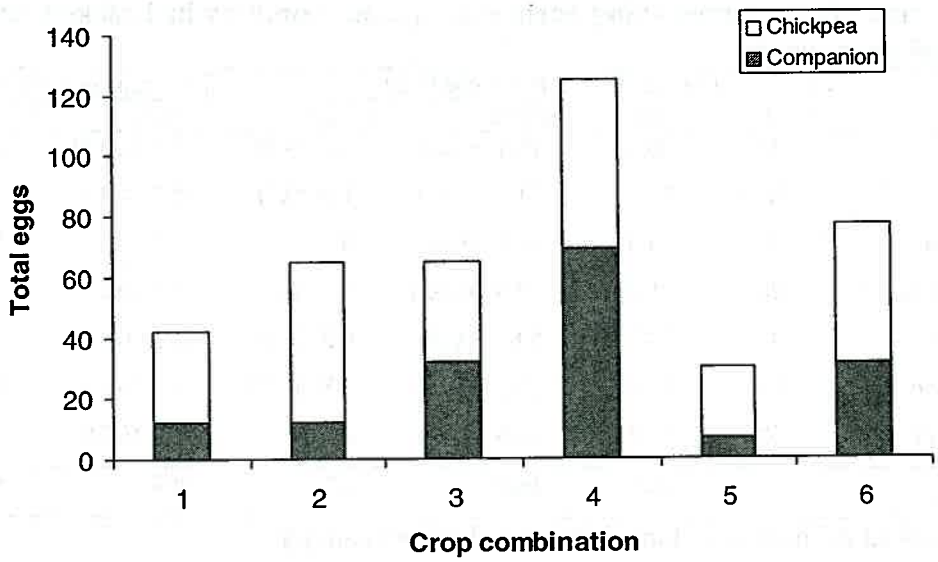

Figure 2.3.3. Distribution of total egg counts on chickpea and companion crop across paired crop combinations and Sample date, pooled over blocks. See Figure 2.3.1 legend for crop combination labels.

Table 2.3.1. Analysis of variance table for the split-plot design across space and time on log transformed (count + 1) data for eggs

Source of variation	d.f.	s.s.	m.s.	v.r.	P
Block level					
Block	3	1.5	0.5	0.8	
Plot level					
Plot	5	11.531	2.306	4.17	0.014
Residual	15	8.294	0.553	0.79	
Subplot level					
Subplot	1	2.851	2.851	4.1	0.058
Plot.Subplot	5	3.282	0.656	0.94	0.477
Residual	18	12.523	0.696	4.37	
Sample-date level					
Sample-date	3	0.921	0.307	1.0	0.394
Plot.Sample-date	15	7.454	0.497	1.62	0.07
Subplot.Sample-date	3	12.304	4.101	13.34	<0.001
Plot.Subplot.Sample-date	15	14.941	0.996	3.24	<0.001
Residual	252	77.483	0.308		
Total	383	160.716			

Table 2.3.2. Mean number of eggs and larvae observed on individual weed plants and 10 chickpea plants surrounding each weed plant. Numbers in brackets are minimum and maximum counts

Weed species	N	Height* (cms)	Per Weed Plant Eggs	Per Weed Plant Larvae	Per ten chickpea plants Eggs	Per ten chickpea plants Larvae
B. napus	11	16.4	10.1 (0,29)	0.3 (0,1)	1.7 (0,15)	0.8 (0,3)
V. faba	8	7.4	21.3 (0,47)	1.0 (0,3)	0.3 (0,1)	1.4 (0,4)
P. sativum	3	23.0	28.7 (3,61)	0	0.3 (0,1)	0.3 (0,1)
L. usitatissumum	28	11.0	13.9 (0, 55)	0.7 (0,4)	1.2 (0,5)	1.2 (0,3)
B. juncea	8	24.3	5.8 (0,29)	0.3 (0,1)	0.3 (0,1)	0.8 (0,2)
S. oleraceus	12	14.2	23.2 (0,128)	2.8 (0,29)	1.3 (0,9)	0.5 (0,4)
T. aestivum.	32	21.0	24.6 (0,64)	0.5 (0,4)	0.5 (0,7)	1.2 (0,5)
MEAN		**16.7**	**18.2**	**0.8**	**0.8**	**0.9**

*Mean height of the weed plant above the chickpea canopy

Paired crop combinations - Larval counts. Of 2749 larvae enumerated across all Sample-dates, Blocks and crop combinations, 2703 (98.3%) were found on chickpea in comparison to 46 (1.7%) on all companion crops. Mean larval density per m^2 (± s.e.m) on chickpea increased from 15.6 (1.3) at 46 DAP to 45.8 (0.4) at 67 DAP before decreasing to 20.8 (5.3) at 112 DAP. By comparison, the corresponding estimates on the companion crops did not exceed 1.7/ m^2. In view of the highly asymmetric distribution of larvae (98.3% on chickpea), tests of differences in mean density among groups could not be assigned any biological significance and hence are not presented here.

Oviposition on in-crop weeds and wheat buffer. Deposition of eggs on the weeds in chickpea subplots became apparent only after the weed plants grew noticeably above the height of the chickpea canopy. Although weeds were found in companion-crop subplots, none were taller than the surrounding crop canopy or had *Helicoverpa* eggs on them. The weed population in chickpea comprised *T. aestivum*, *Sonchus oleraceus* L. (common sowthistle) and all companion-crop plants except *L. albus*.

A total of 1866 eggs were recorded on 102 weed plants. The mean number of eggs per plant on the weed species ranged from 5.8 (*B. juncea)* to 28.7 (*P. sativum*), whereas the corresponding mean of eggs found on 10 chickpea plants surrounding each weed plant (nearest neighbour) ranged from 0.3 to 1.7 (Table 2.3.2). A total of 90 eggs were recorded on all the nearest-neighbour chickpea plants from all plots. In contrast to egg density, mean larval density was similar on both groups of plants, ranging from 0 (*P. sativum*) to 2.8 (*S. oleraceus*) on individual weed plants and 0.3 to 1.4 on 10 nearest neighbour chickpea plants (Table 2.3.2).

Within weed species for which sample size was adequate, namely *L. usitatissumum* and *T. aestivum*, a positive, albeit weak, correlation between egg density and height of weed plants above the canopy was detected. For both species the regression of egg density on height above chickpea was significant (*L. usitatissumum*: N = 28, $R^2 = 0.244$, Student's $t = 2.89$, P = 0.008; *T. aestivum*: N = 32, $R^2 = 0.187$, Student's $t = 2.62$, P = 0.014).

Few eggs were found on *T. aestivum* plants in the buffer strips. Mean egg density per *T. aestivum* plant in buffer row 1 (closest to chickpea) ranged from 0 to 0.9 and in buffer row 3 (third away from chickpea) from 0 to 0.5. *Helicoverpa* larvae were not found on the 100 *T. aestivum* plants sampled in the buffer strips.

Discussion

The results presented here show that some crop combinations were more attractive to *Helicoverpa* moths than others. Crop combination 4 received the largest proportion of eggs over all Sample-dates (Figure 2.3.3), but within that combination a clear preference for P. sativum (96% of eggs) did not become evident until 112 DAP (Figure 2.3.2). The Brassica crops (combinations 1 and 2) flowered earliest and enjoyed a height advantage over the other crops which could account for some oviposition activity on these crops at 46 DAP. However, the paucity of eggs on these species at later Sample-dates (Figure 2.3.3) suggests that they were not preferred hosts relative to the other crops evaluated in our study. Vicia faba, P. sativum, L. usitatissumum and L. albus were able to divert 50% or more of eggs away from chickpea only in the later flowering stages (80, 112 DAP; Figure 2.3.2) and after a clear height differential with chickpea had become apparent.

Chickpea elicits oviposition by *Helicoverpa* in all its phenological stages (Reed *et al.* 1987) but is particularly attractive at 67 DAP in our study (Figure 2.3.1) which corresponds to the peak flowering stage. At 67 DAP 96.5% of all eggs recorded (pooled across blocks and plots) were found on chickpea whereas the remainder were found on P. sativum (combination 4, Figure 2.3.2). It is noteworthy that with the exception of P. sativum at 112 DAP, oviposition on chickpea was never reduced to insignificant levels throughout the field assessment.

From a practical pest management viewpoint, an effective diversionary crop must be markedly more attractive than the main crop for a significant duration of the crop cycle. This differential attractiveness can then be exploited by using a relatively small area of the former to draw pest pressure away from a much larger area of the latter. None of the companion crops tested in this study was sufficiently more attractive than chickpea throughout all of its phenological stages to be useful as a diversionary or trap crop.

The highly aggregative oviposition pattern on weeds within chickpea is a behavioural response possibly triggered by the vertically differentiated canopy structure made up of tall plants sparsely dispersed within a population of shorter plants. Another possible trigger for the observed oviposition response is the chickpea foliar secretions containing high concentrations of malic acid (Rembold 1981). The amount of foliar exudate and the concentration of malic acid depend on temperature and growth stage, and have been shown to increase during the reproductive stages of the plant (Koundal & Sinha 1981). Whilst moths are drawn to chickpea in all growth stages, there is relatively less oviposition activity and damage in resistant cultivars that secrete high concentrations of malic acid (Rembold 1981; Rembold & Winter 1982; Lateef 1985; Reed *et al.* 1987). Moths could therefore be assessing weeds in post-flowering chickpea as oases in an increasingly hostile oviposition environment.

Subsequent to this study, the aggregative oviposition response of *Helicoverpa* in weedy chickpea has been documented in experimental as well as commercial crops with results similar to those reported here (R. Sequeira, unpubl.). However, much work needs to be done to fully understand the processes underlying observed patterns of host plant selection in the field and their relevance to insect pest management.

2.3.2 *Evaluation of summer trap crop options*

A replicated field experiment on the relative attractiveness of a number of summer trap crop options to *Helicoverpa* was conducted in the summer of 1999. The primary objective of this assessment was to confirm literature reports that pigeon pea was preferred for oviposition by *Helicoverpa* species when compared to cotton and other summer crop plants. The evaluation was conducted at the QDPI Emerald Research Station. The trial was planted in the middle of January 2000. The crops evaluated included Cotton, Dolichos lab lab (variety Koala), Mung bean, Niger, Pigeon pea and Sesame. Assessment of *Helicoverpa* egg densities on the various crops was done at regular intervals.

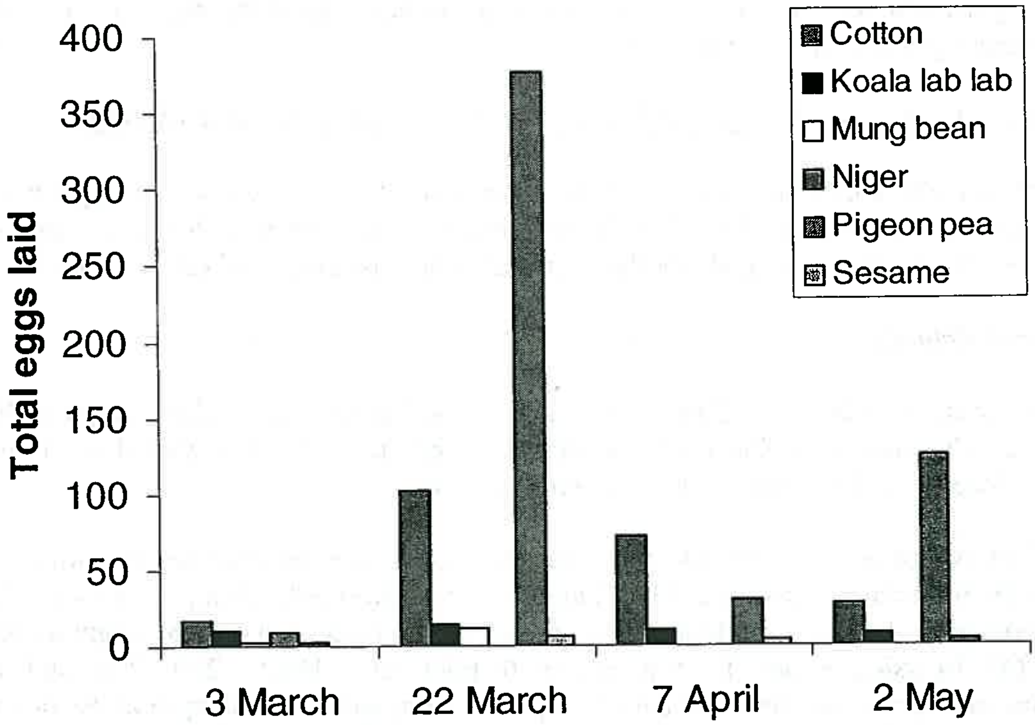

Fig. 2.3.4. Distribution of total *Helicoverpa* egg counts on summer cropping options.

The resulting data, shown in Figure 2.3.4, confirm the attractiveness of flowering pigeon pea to ovipositing *Helicoverpa* moths. Pigeon pea started flowering in mid-March, at which time egg pressure shifted dramatically from cotton to pigeon pea. However, within one week of flowering pigeon pea lost its attractiveness to ovipositing moths. Interestingly, cotton remained relatively attractive to the moths throughout the evaluation period compared to other host plants. Of the other host plants, niger was moderately attractive but only upon the commencement of flowering in early May.

These data show that cotton is a highly attractive host plant for *Helicoverpa* species. Whilst it is easy to demonstrate that several (non-cotton) crop plants in their flowering stage are much more attractive than cotton, no other plant (with the exception of chickpea) can compete effectively with cotton for *Helicoverpa* eggs throught the different growth stages; most host plants are attractive to the pest only in the flowering stage.

2.3.3 *Evaluation of trap crop layouts*

The comparison of spring trap crop options reported in section 2.3.1 resulted in the discovery of a novel behavioural mechanism in *Helicoverpa* with potentially profound implications for trap cropping and pest management. Essentially the results suggested that the novel behavioural mechanism of aggregative (clumped) egg distribution is triggered by alteration of the crop canopy by growing different crop plants together as a result of seed mixing. This outcome suggested a novel method of deploying trap crops, that is, dispersal of the trap crop species within the main commercial crop by seed mixing.

A series of experiments were conducted over the period 1999-2002 to assess conventional trap cropping layouts such as strips and blocks, and the novel seed mixing approach. The results of these experiments are outlined below.

Experiment 1 – Evaluation of the seed mixing technique for trap cropping in chickpea

This experiment was conducted to try to better understand the phenomenon of aggregative egg distribution (see section 2.3.1) and its implications for a novel approach to trap cropping using seed mixing. It was envisaged that this approach would be evaluated later in cotton.

Materials and Methods

In the winter seasons of 2000 and 2001, the pattern of egg distribution by *Helicoverpa* within experimental field plots of chickpea (cv. 'Amethyst') contaminated with plants of other crop species was documented at different stages of crop growth.

The first field assessment in 2000 had five treatments consisting of chickpea contaminated with one of the following crop species (1) *Vicia faba* L. var. *faba* (faba bean, cv. 'Fiesta'); (2) *Triticum aestivum* L. (wheat, cv. 'Batavia 2'); (3) *Sorghum bicolor* (L.) (forage sorghum, var. 'Jumbo'); (4) *Brassica napus* L. var. *napus* (canola, cv. 'Hylite 200 IT'), and an uncontaminated control. The contaminant crop species were added to chickpea at the rate of 1.5% by number and mixed thoroughly before planting. Each treatment was randomly assigned to one plot of dimensions 150 m x 7.2 m (8 rows x 90-cm spacing). Within plots every row was planted to the seed mix. The plots were separated by 1.8 m strips of bare earth buffer. All plots were planted on 16 May 2000.

Replication of the treatments (seed-mix combinations) was impractical because the data collection protocol involved destructive sampling of large areas of crop several times during the season. The need for destructive sampling favoured the use of large plots. Replication of several treatments with large plot sizes was also constrained by limited land, irrigation and management resources. In lieu of replication, selected chickpea-contaminant combinations were planted again in the following growing season to validate the observed pattern of aggregative oviposition behaviour at different stages of plant growth.

The second assessment was incorporated into a field of commercial chickpea planted on 6 June 2001. This assessment included chickpea-faba and chickpea-wheat seed mixtures at the rate of 1.5% contaminant seed by number, planted to paddock scale plots with dimensions 10.8 m x 100 m (18 rows x 60-cm row spacing). Within plots, every third row was planted to the seed mix. Treatment plots were separated by 90 rows of commercial chickpea and flanked on both sides by the rest of the commercial chickpea crop, which served as the control.

In both assessments, sampling times were within key phenological stages of the plants, *viz.*, vegetative, early flowering, peak flowering and grain filling. Sampling was at 58, 78, 99 and 112 days after planting (DAP) in the first assessment, and 41, 70, 96, and 110 DAP in the second. Plant samples were collected within a 6-hour period at each of the four sampling times. No attempt was made to distinguish between *H. armigera* and *H. punctigera* because eggs and hatchlings of the two species are morphologically indistinguishable, and both are commonly found in varying proportions in any given crop in central Queensland.

Within seed-mixed treatments at each of the four sampling times, individual contaminant plants were selected at random and the height of each was recorded. The average height of the chickpea canopy near each contaminant plant (0.5 m of row on either side) was also recorded. The selected contaminants and associated 1 m row of chickpea plants were cut at ground level and transferred to the laboratory where the number of *Helicoverpa* eggs and larvae on each plant was recorded.

In the control treatments, 1 m row lengths of chickpea were selected at random and transferred to the laboratory for enumeration of eggs and larvae. Sample size was initially 30 individual contaminant plants and associated 1 m row of chickpea plants at the first sampling time in all treatments but this was reduced to 15 at all other sampling times because of increasing difficulty associated with sampling progressively larger chickpea plants.

Analysis of the data was restricted to paired-sample t tests within treatments. Data collected at each sampling time were analysed separately. Linear regression was used to examine the relationship between variables within treatments, wherever necessary.

Results

Assessment 1 – Winter 2000. The density of chickpea plants was similar among the seed-mix treatments but higher in the control treatment. The density of contaminant plants was lowest in the canola treatment and highest in the wheat treatment.

Among the four seed-mix treatments, canola exhibited the most vigorous seedling growth followed by wheat (Fig. 2.3.5A). Sampling of the canola treatment was discontinued at 78 DAP because the canola plants had grown above 70 cm in height, with a substantial load of seed pods, and were infested with aphids, all of which resulted in plant lodging. Sampling of the sorghum treatment was also discontinued at 78 DAP because most of the sorghum plants were no longer visible, having been outgrown by the more vigorous chickpea plants.

Canola was significantly taller than chickpea from the same treatment (Fig. 2.3.5B). In the faba and sorghum treatments, there were no significant height differences between the contaminant plants and chickpea at 58 and 78 DAP (Paired sample t test, $P \geq 0.118$). In the wheat treatment, the contaminants were marginally taller than the surrounding chickpea at 58 DAP (Paired sample t test, $P = 0.026$) but there was no significant difference in height between the two groups at 78 DAP (Paired sample t test, $P = 0.052$). A clear difference in height between chickpea and contaminant plants became apparent in the faba and wheat treatments at 99 and 112 DAP (Fig. 2.3.5B).

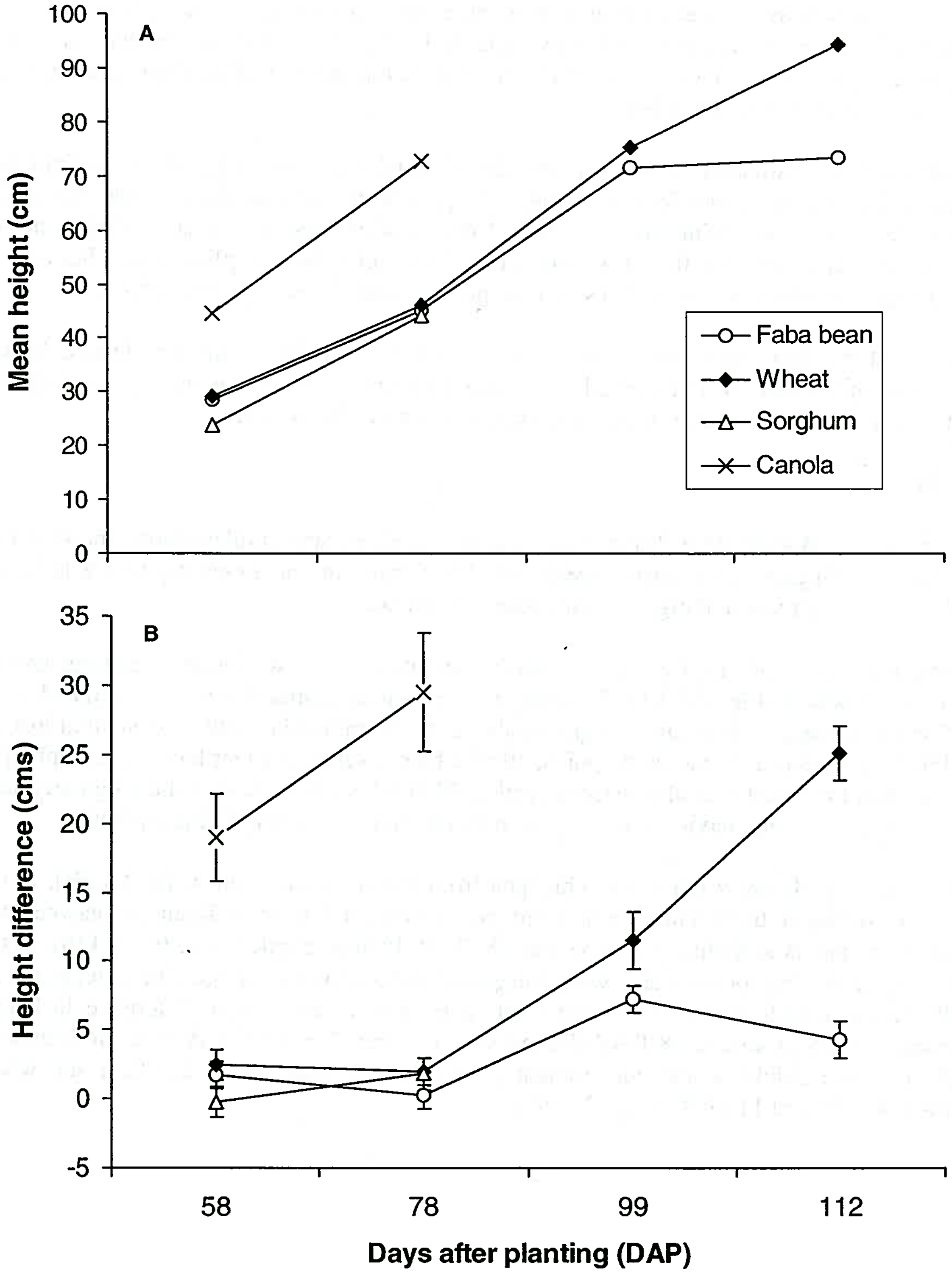

Fig. 2.3.5. Assessment 1 (2000). A. Mean height of contaminant species growing amongst chickpea in relation to crop age. B. Mean height difference between contaminants and the chickpea canopy surrounding each contaminant plant in relation to crop age. Negative values for height difference represent contaminants shorter than chickpea plants. Error bars represent ± 1 s.e.m.

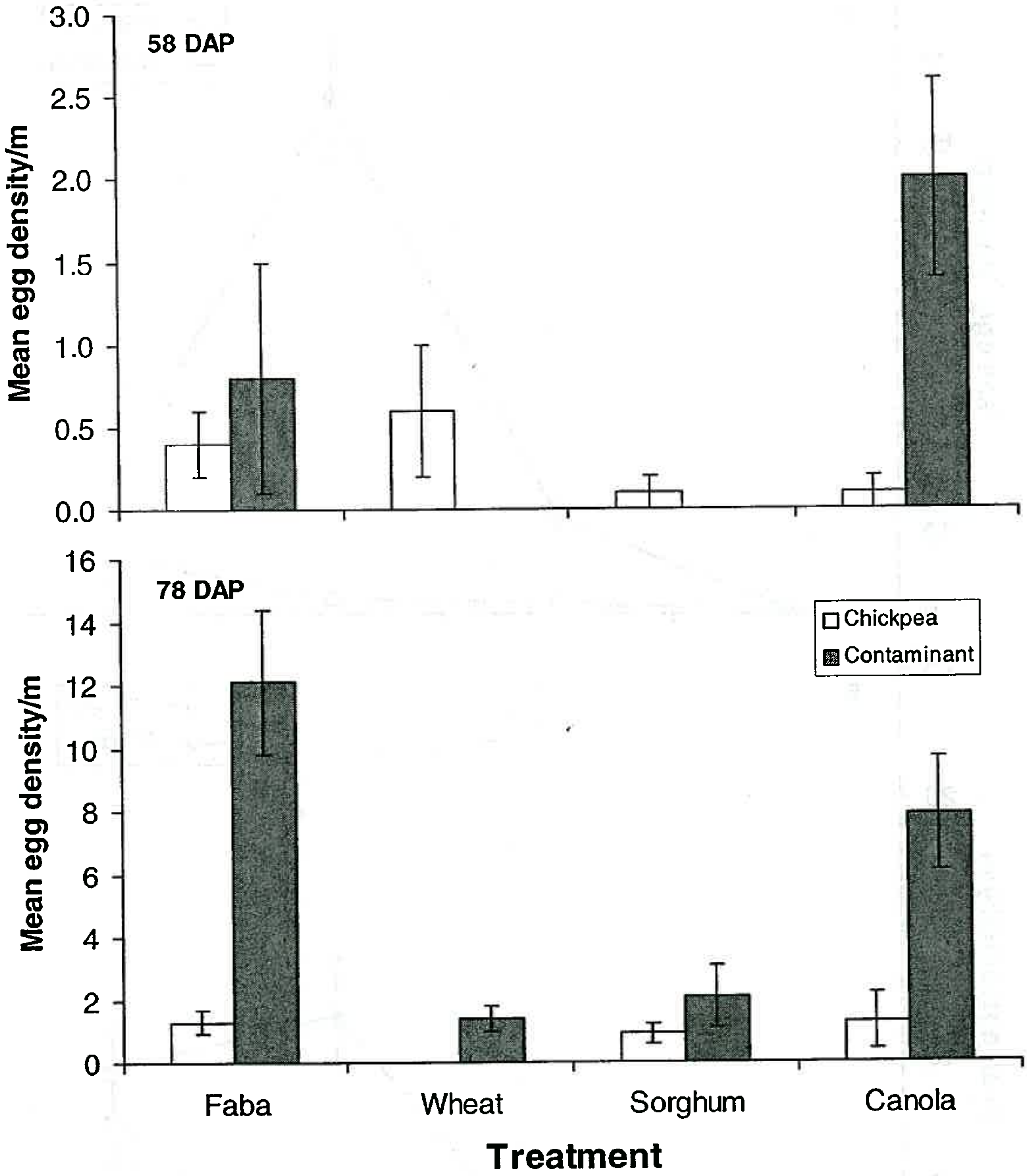

Fig. 2.3.6. Assessment 1 (2000). Mean *Helicoverpa* egg density on contaminants in the faba, wheat, sorghum and canola seed-mix treatments at 58 and 78 days after planting (DAP). Error bars represent ± 1 s.e.m.

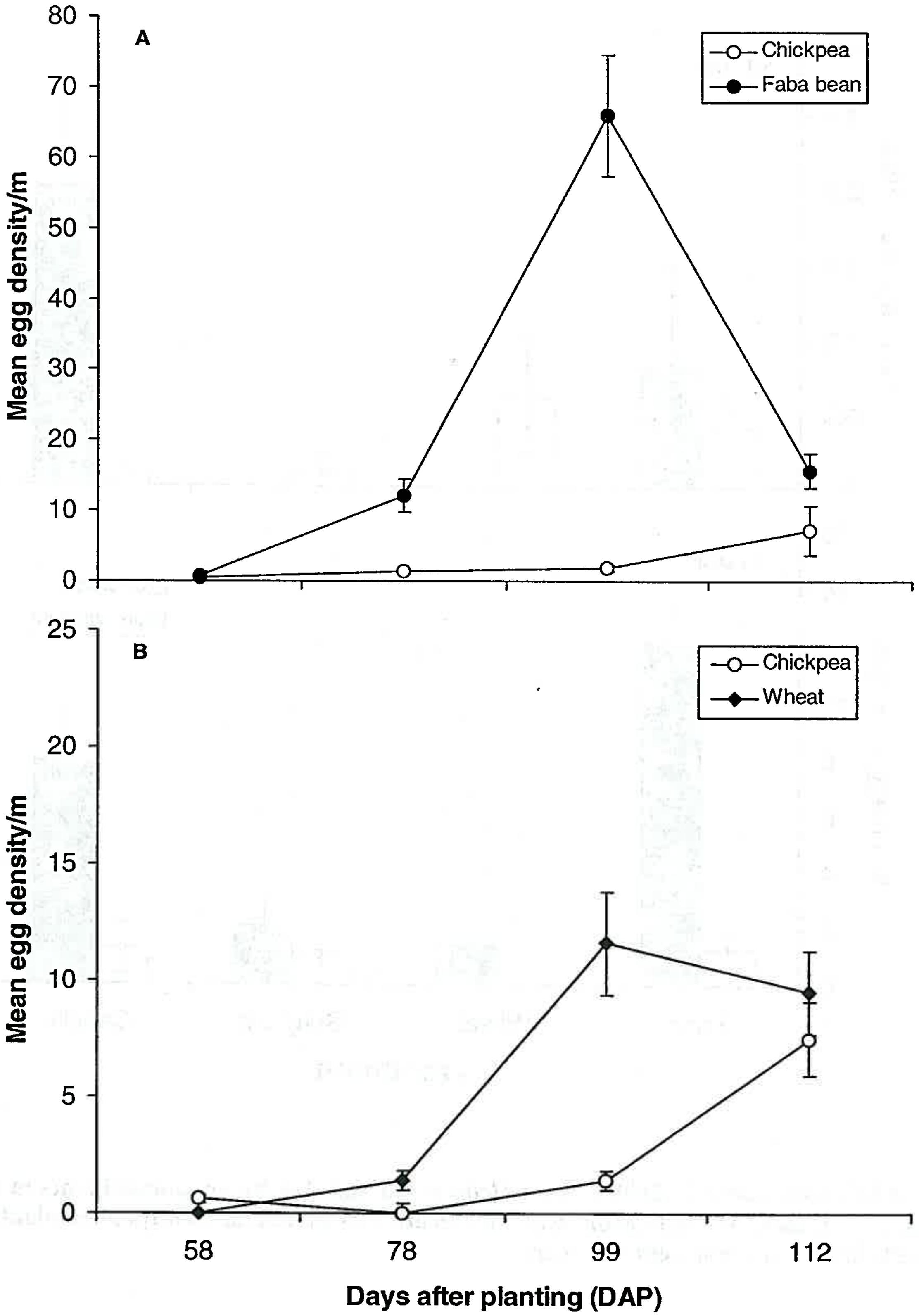

Fig. 2.3.7. Assessment 1 (2000). A. Mean *Helicoverpa* egg density on contaminants and on chickpea surrounding each contaminant in the faba seed-mix treatment in relation to crop age. Error bars represent ± 1 s.e.m. B. Mean *Helicoverpa* egg density on contaminants and on chickpea surrounding each contaminant in the wheat seed-mix treatment in relation to crop age. Error bars represent ± 1 s.e.m.

Fig. 2.3.6 shows the comparative distribution of eggs on chickpea and the contaminants in all seed-mix treatments at 58 and 78 DAP. At both sampling times, canola plants attracted substantially greater oviposition activity than the surrounding chickpea (Paired sample ***t*** test, $P \leq 0.007$) whereas oviposition on wheat and sorghum plants was not evident until 78 DAP. In the faba treatment, a trend towards preferential oviposition on the contaminants was evident at 58 DAP but strong preference for the contaminants became evident at 78 DAP.

Mean *Helicoverpa* egg density on the faba contaminants increased rapidly from less than 1 egg/plant at 58 DAP to 66 eggs/plant at 99 DAP before decreasing sharply at 112 DAP (Fig. 2.3.7A). The drop in egg density at 112 DAP was coincident with partial desiccation of the faba plants resulting from water stress and maturation of the surrounding chickpea. The corresponding mean egg density on chickpea plants remained at less than 2 eggs/m in the first three samples before increasing slightly in the final sample. A similar pattern of egg distribution was found in the wheat treatment (Fig. 2.3.7B) though fewer eggs were laid on wheat than on faba contaminants.

Oviposition activity on chickpea plants was similar across treatments, as evidenced by the broadly overlapping 95% confidence intervals for the means (Fig. 2.3.8). This result must be interpreted cautiously because the absence of treatment replication limits the validity of comparisons between treatments. Rigorous estimation of the between-treatment effect was beyond the scope of this study.

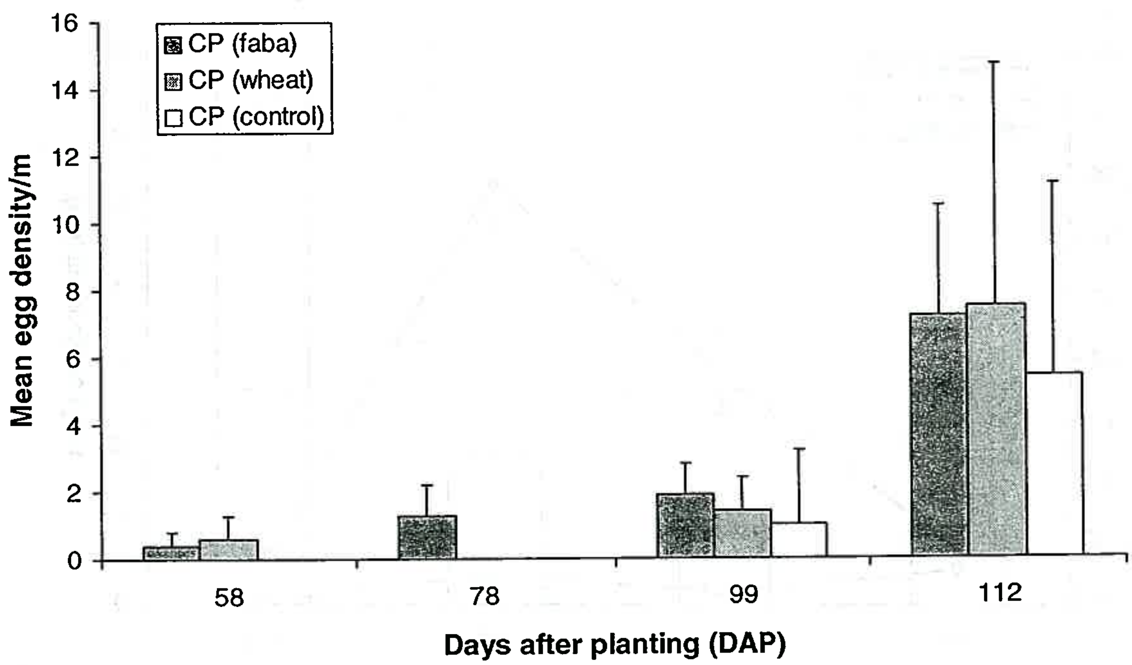

Fig. 2.3.8. Assessment 1 (2000). Mean and 95% confidence interval for *Helicoverpa* egg density on chickpea plants in the control, and the faba and wheat seed-mix treatments in relation to crop age.

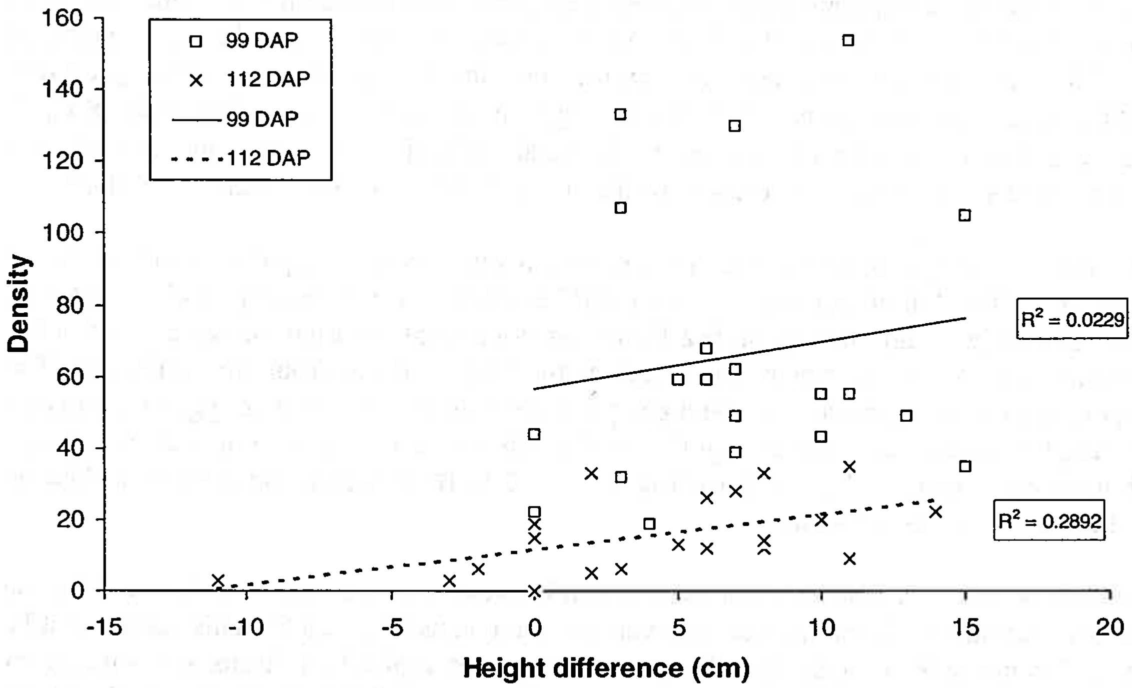

Fig. 2.3.9. Assessment 1 (2000). *Helicoverpa* egg density (total number of eggs recorded) in relation to height above chickpea (height difference) on individual contaminants in the faba treatment at 99 and 112 days after planting (DAP). Negative values for height difference represent contaminants shorter than chickpea plants.

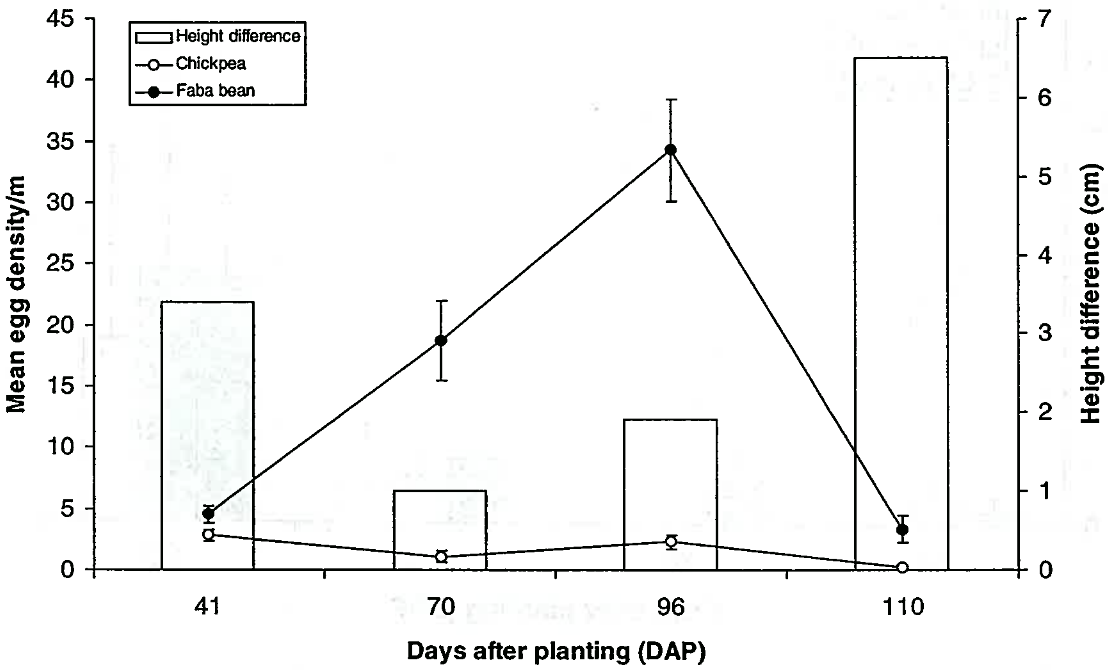

Fig. 2.3.10. Assessment 2 (2001). Mean *Helicoverpa* egg density on faba contaminants and on chickpea surrounding each contaminant, in relation to mean height of the contaminants above the chickpea canopy (height difference). Error bars represent ± 1 s.e.m.

The relationship of mean egg density to height of contaminant plants above the chickpea canopy was examined for the faba and wheat treatments at 99 and 112 DAP. Mean egg density on the wheat was not correlated with height above chickpea at 99 or 112 DAP (Pearson correlation, $R^2 < 0.04$; and Pearson correlation, $R^2 < 0.01$).
In the faba treatment there was no correlation between mean egg density on the contaminant plant and height above chickpea at 99 DAP and a weak positive relationship at 112 DAP (Fig. 2.3.9; Regression, $P < 0.013$).

Assessment 2 – Winter 2001. The wheat treatment suffered from poor germination and slow growth of seedlings that were quickly outgrown by chickpea. Consequently, the wheat treatment was not sampled and data are presented only for the faba treatment.

The change in mean *Helicoverpa* egg density in the faba treatment and height difference between chickpea and faba contaminants over time are shown in Fig. 2.3.10. The change in mean egg density on the faba plants followed the pattern recorded in the previous assessment, increasing linearly over the first three samples, followed by a sharp decline at 110 DAP. The decline in egg density on faba plants recorded at 110 DAP occurred despite irrigation at 100 DAP to minimise water stress on the treatment. Mean egg density on faba plants was not correlated with height above the chickpea canopy at 96 or 110 DAP (Pearson correlation, $R^2 < 0.04$).

Mean egg density on chickpea plants in the faba treatment did not rise above 2/m row throughout the assessment (Fig. 2.3.10). By comparison, on chickpea plants in the control treatment, mean egg density decreased from around 6/m-row at 41 DAP to less than 1/m-row in subsequent samples.

Discussion

Chickpea elicits oviposition by *Helicoverpa* in all its phenological stages (Reed *et al.* 1987; Sequeira *et al.* 2001). Field choice assessments involving a range of winter crops (Sequeira *et al.* 2001) show that in the vegetative stage chickpea is highly preferred for oviposition by *Helicoverpa* whereas faba becomes increasingly attractive after the onset of flowering; wheat and canola are among the least preferred hosts. In view of this hierarchy of preferences, the seemingly atypical pattern of aggregative oviposition on contaminants in chickpea is best explained in terms of differential host plant apparency (*sensu* Feeny 1976).

Some plants may be more 'apparent' and hence more attractive than others as a result of differences in relative growth rate (height), morphological distinctness, isolation from other plants, physiological differences or a combination of these and other factors (Courtney 1982; Soberón *et al.* 1988). Differences among host plants are likely to become increasingly evident to ovipositing moths as the plants grow and mature. Thus, the degree of host plant apparency will be greater in the flowering and fruiting stages, as evidenced by the higher level of egg aggregation on older plants in our study (Fig. 2.3.7).

Canola is presumably more apparent to ovipositing moths by virtue of its rapid growth rate and resulting height differential with chickpea (Figs. 2.3.5A, B), thereby attracting greater oviposition activity than chickpea in the early seedling stage (Fig. 2.3.6). This conclusion is further supported by the findings of Sequeira *et al.* (2001). They found that in field choice tests, canola attracted greater *Helicoverpa* oviposition activity than several other host plant species in the early seedling stage, presumably as a result of its rapid growth rate.

In contrast to canola, significant aggregation of eggs on faba and wheat contaminants occurs before differences in growth rates between the different plant species become evident. This suggests that in addition to growth rate (height), morphological and possibly other differences may serve to enhance the apparency of faba and wheat contaminants in chickpea. This conclusion is supported by the absence of a significant correlation between height above chickpea and total egg load for wheat and faba contaminant (Fig. 2.3.9). Substantial aggregation of eggs occurs on individual contaminants exhibiting little or no height differential with chickpea.

Chickpea physiology may also play an important role in enhancing the apparency of contaminants. Acid secretion by chickpea foliage increases with growth stage and increasing temperature (Koundal & Sinha 1981; Rembold 1981; Reed *et al.* 1987). This makes the crop environment increasing hostile for most insects (Romeis *et al.* 1999), thereby possibly exaggerating the natural tendency of *Helicoverpa* to oviposit on contaminant plants.

Clumped distribution of eggs resulting from differential host plant apparency has been documented in several butterfly species, eg., *Sandia xami* (Soberón *et al.* 1988), *Antocharis cardamines* (Courtney 1982), *Cactoblastis cactorum* (Myers *et al.* 1981), Euphydryas editha (Rausher *et al.* 1981), and more recently in a moth species, *Ochrogaster lunifer* (Floater & Zalucki 2000). Given the results of these other studies, the finding that oviposition behaviour of *Helicoverpa* is strongly influenced by host plant apparency should not be surprising.

In cotton crops *Helicoverpa* lay eggs either singly or in small clusters of 2-3 at each oviposition (Mabett & Nachapong 1983; Zalucki *et al.* 1986; Fitt 1991). Eggs are generally well distributed among plants in a uniform crop canopy. However, to the best of our knowledge, a highly clumped egg distribution pattern of the type described here, resulting in >100 eggs being deposited on some individual plants, has not been documented before under field conditions.

Further field studies of the phenomenon indicate high rates of egg and larval mortality on the contaminants plants in chickpea crops (R. Sequeira, unpublished data), raising the possibility of using contaminants or varietal seed mixtures for natural control of *Helicoverpa* in commercial chickpea crops.

The extent of aggregative egg distribution responses by these species in other crops is currently unknown. In view of the economic importance of *Helicoverpa* to agricultural crop production, demonstration of a tendency towards aggregative oviposition behaviour in other crops could have important pest management implications. This study highlights the need for further research on the relationship between crop canopy structure and pest distribution, and the potential to manipulate these for pest management.

Experiment 2 – Evaluation of the seed mixing technique for trap cropping in cotton

Here we report on trials during the 2000/01 and 2001/02 seasons on commercial farms to evaluate the seed mixing protocol for trap cropping. We used chickpea to manipulate the pattern of *Helicoverpa* oviposition activity within early-season cotton crops. Mixtures of cotton and chickpea seed were planted to determine if a) *Helicoverpa* egg pressure could be diverted away from cotton and onto chickpea, and b) egg laying activity could be concentrated into particular rows, thereby taking the pressure off adjacent rows.

Trial set-up and results

2000-01 season

On one 45-ha paddock, a mixture of cotton and chickpea seed (5 kg cotton + 5 kg chickpea /ha) was planted in 1 of every 8 rows by placing the seed mix in the 4th box of an 8-row planter. Cotton only at the normal rate (10-12 kg/ha) was planted in all the other rows.

The trial was planted on 24 September. Sampling for *Helicoverpa* eggs and larvae was done at regular intervals in the first half of the season. At every sampling, 30 plants each of cotton and chickpea from the seed-mixed row (R-0), 30 cotton plants from the adjacent row (R-1) and 30 cotton plants from the 4th row (R-4) were selected at random and examined for eggs and larvae. The height of chickpea and cotton plants was also recorded.

Fig. 2.3.11 shows mean *Helicoverpa* egg densities per plant during the first half of the season. The attractiveness of chickpea to the moths was apparent as early as 1 week after plant emergence. A strong preference for chickpea plants in the seed-mixed rows was evident at the first sample roughly 3 weeks after planting. One week later at the time of the second sample (24 October), the chickpea plants were largely defoliated and partially or completely eaten out by *Helicoverpa* larvae, which might explain the lower egg densities recorded at this sampling. The chickpea plants subsequently recovered somewhat, thereby facilitating further oviposition in early November. A clear preference for chickpea plants within the seed-mixed rows was again evident at the 3rd sample (8 November).

Helicoverpa oviposition activity was clearly concentrated in the seed-mixed rows for approximately the first 8 weeks after planting (Fig. 2.3.12). During this period, egg density in the seed-mixed rows was generally 2-3 times greater than in the cotton-only rows. The higher attractiveness of the seed-mixed rows compared to cotton-only rows is still evident in late November. After November the chickpea plants were no longer attractive to *Helicoverpa*, partly because of excessive acid production in response to increasing temperatures, and partly as a result of being shaded out by cotton that was by then substantially taller (Fig. 2.3.13).

In the first 4 samples, larval densities ranged from 0.5 to 1.5 larvae/plant on chickpea and negligible numbers on cotton. The majority of larvae were first and second instars. Over the whole sampling period (October – January) 78% of all larvae enumerated were found on chickpea plants, 14% on cotton plants in the seed-mixed rows and the remainder on the cotton-only rows. Some larvae migrated from chickpea to cotton within the seed-mixed rows but only after the chickpea plants had been largely defoliated or destroyed by feeding.

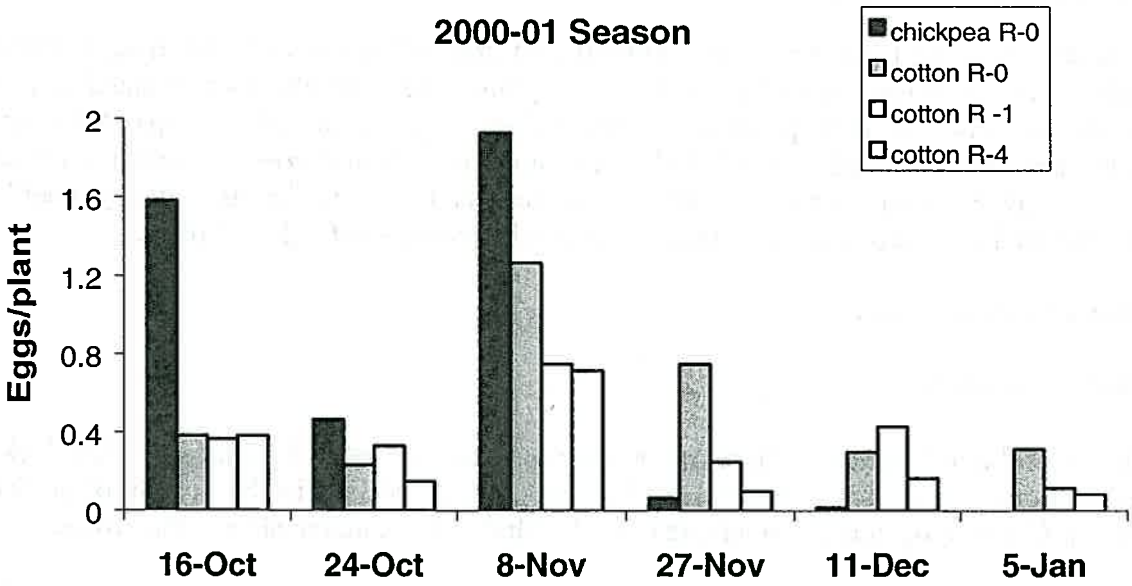

Fig. 2.3.11. Mean *Helicoverpa* egg density /plant on chickpea and cotton in the seed-mixed rows (R-0), adjacent (R-1) and 4th (R-4) cotton-only rows. The trial was planted on 24 September.

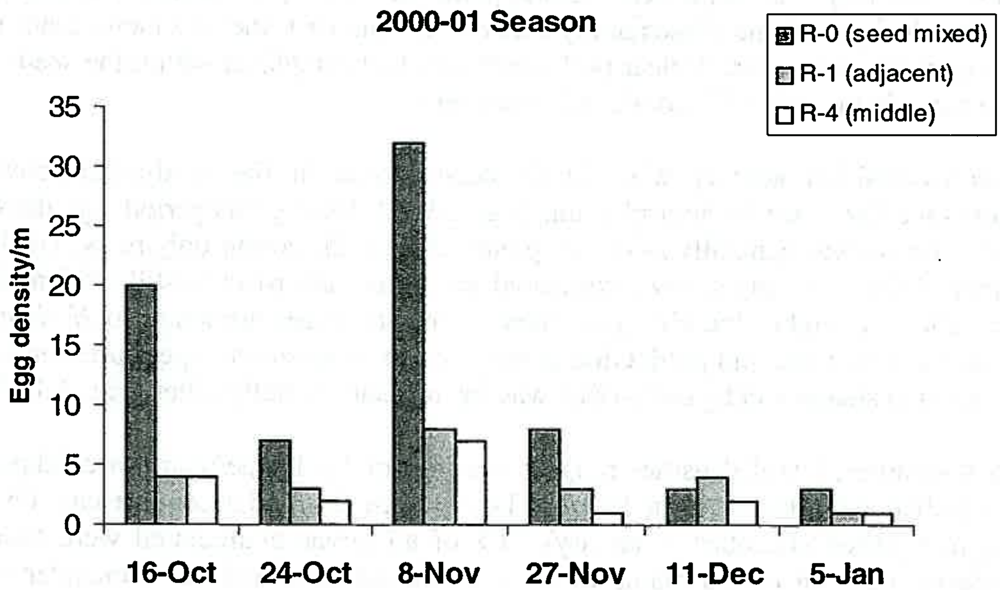

Fig. 2.3.12. Comparison of mean *Helicoverpa* egg density /m in seed-mixed (R-0) and cotton-only rows (R-1 and R-4).

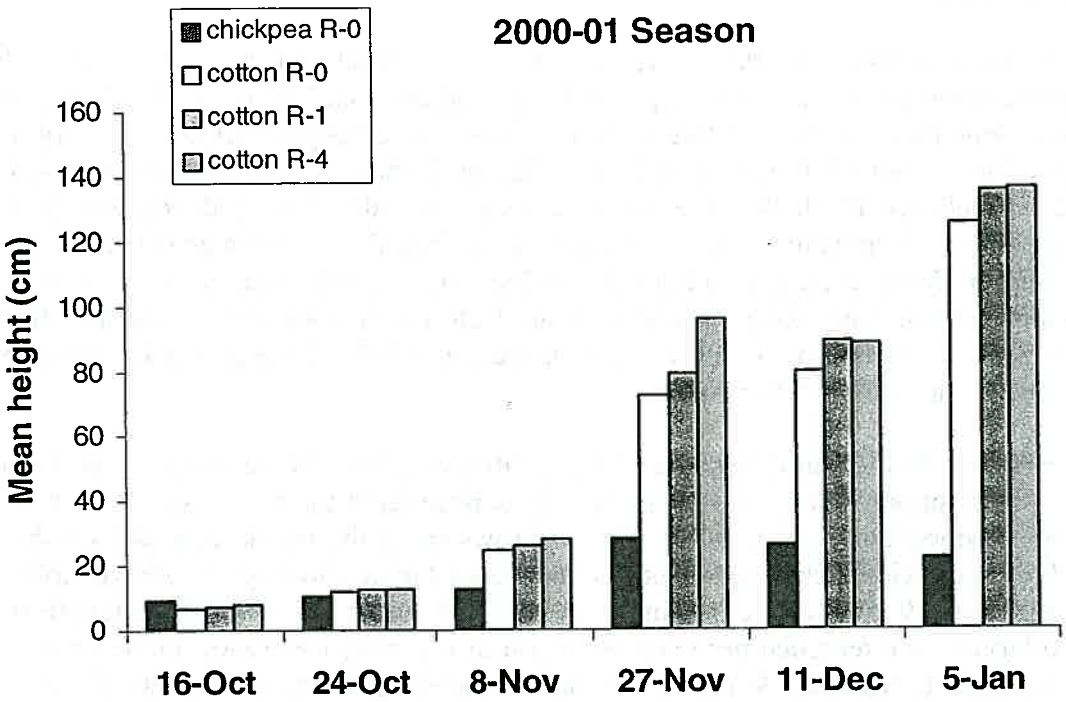

Fig. 2.3.13. Mean height of chickpea and cotton in the seed-mixed rows (R-0), adjacent cotton-only rows (R-1) and 4th cotton-only rows (R-4).

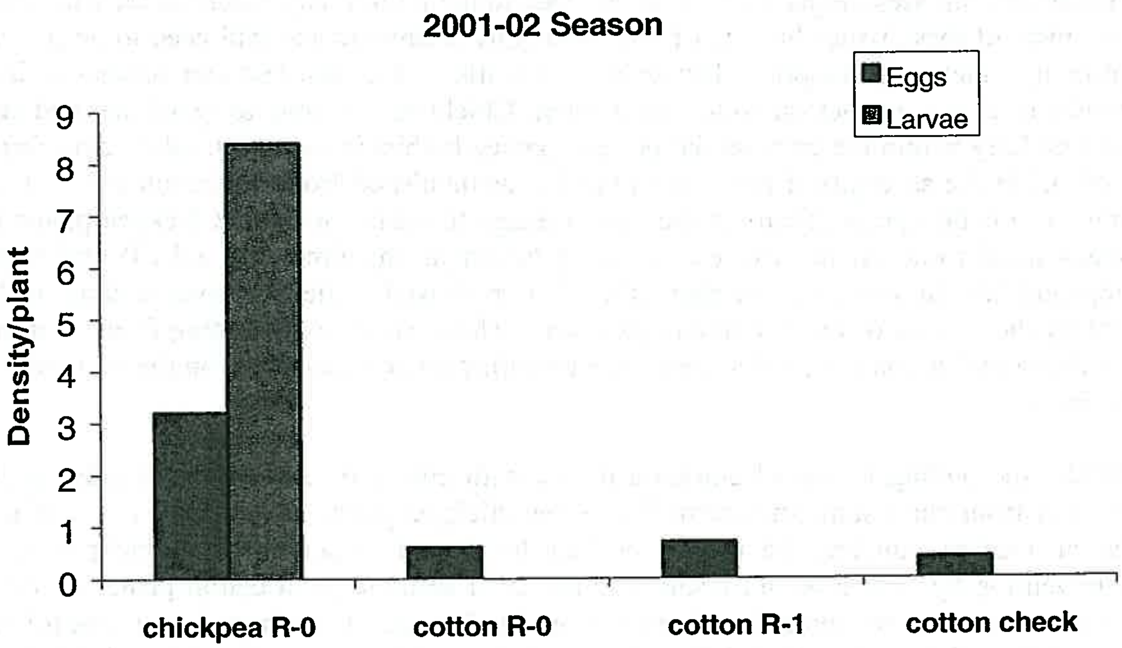

Fig. 2.3.14. Mean *Helicoverpa* egg and larval density /plant on chickpea and cotton in seed-mixed rows (R-0), adjacent cotton-only rows (R-1) and in the cotton-only check area.

2001-02 season

The protocol adopted in the previous season was modified to accommodate higher oviposition pressure and larval damage to chickpea plants. One half of a paddock was planted to the cotton-chickpea seed mixture (5 kg cotton + 5 kg chickpea /ha) in 2 of every 8 rows, through the 3rd and 6th boxes of an 8-row planter. Cotton only at the normal rate (10-12 kg/ha) was planted in all the other rows. The second half of the paddock was planted to cotton only as a commercial check. The trial was planted on 18 September. Random plant sampling for *Helicoverpa* egg and larval was done on 30 plants each of cotton and chickpea from the seed-mix row (R-0), 30 cotton plants from the adjacent row (R-1), and 30 cotton plants from the middle of the check area in the other half of the paddock, approximately 100m away from the seed-mix treatment.

The results of the first sampling event 23 days after planting (10 October) are shown in Fig. 2.3.14. Oviposition activity was again heavily concentrated in the seed-mixed rows. There was little oviposition activity in the adjacent rows or in the check area. Within the seed-mixed rows, individual chickpea plants were estimated to be carrying on average more than 3 eggs and around 9 mostly first and some second-instar larvae. By comparison, less than 1 egg and no larvae were recorded per plant on cotton in the same row (R-0), in the adjacent row (R-1) or in the check area. At the time of the second sample three weeks later (October 30), the chickpea plants were found to have been completely destroyed by larval feeding, thus precluding further sampling.

Agronomic and management issues

Mixing another plant species with cotton raises issues related to agronomy, management, weediness, diseases, impacts on yield, etc. Due to the preliminary nature of the trials done so far, most of these issues have not been thoroughly addressed and will need to be researched prior to widespread adoption. However, observations over the last two seasons point to a minimal, if any, impact on cotton production. Chickpea was able to germinate and emerge successfully within the commercial pre-emergence herbicide regimes used on both farms. In both trials the seed-mixed rows could not be distinguished from the cotton-only rows with regard to cotton plant density at the end of Stage II (early January). Chickpea plants in the seed-mixed rows did not exceed 30 cm in height at any time (Fig 2.3.13) and were not apparent later in the season, having either been destroyed earlier by larval feeding or shaded out by the closure of the cotton canopy above. Thus, weediness resulting from seed mixing chickpea and cotton does not appear to be a significant concern based on the trial work done to date.

Whilst the pulling power of chickpea mixed with cotton on *Helicoverpa* moths is clearly evident from our results, the useful life of the chickpea plants is short as a result of intense larval feeding damage. Failure to control the larval population on chickpea or non-intervention by choice would result in some level of damage to cotton plants in the seed-mixed rows due to some larval migration. In the scenario where larval control is not undertaken, the damage would be restricted to the seed-mixed rows as larval migration to adjacent or more distant rows has not been observed and is not very likely. In the alternative scenario, band application of biopesticides (virus and Bt formulations) to the seed-mixed rows for larval control may be a viable option. Band application of ovicidal products such as Amitraz to seed-mixed rows in heavy oviposition pressure situations may be another option. Whilst the need for insecticide application for *Helicoverpa* larval control may be viewed as a drawback of the tactic, concentration of the pest in 1 or 2 of every 8 rows immediately cuts down the spray area by more than 75%.

Further testing of the technique is planned in forthcoming trials. Future research will address larval management and other issues related to cotton-chickpea mixtures. The scope for integrating this tactic with other cultural control measures for *Helicoverpa* and sucking pest control will also be examined.

Experiment 3 – Evaluation of the seed mixing technique for trap cropping in cotton

1999- 2000 season

The results of Experiment 1 above showed clearly that the technique of seed mixing had great potential for *Helicoverpa* control in chickpea. Experiment 2 showed that *Helicoverpa* could be managed effectively in early-season cotton. For the technique to be used successfully in cotton during the second half of the season when protection from *Helicoverpa* damage was difficult, the right combination of contaminant or trap crop species had to be found. Preliminary evaluations were conducted with commonly used non-cotton crop plants to determine which of these could be used successfully for trap cropping using the seed mixing protocol in commercial cotton crops.

A preliminary appraisal of seed mixing trap crops and cotton was evaluated in September/October 1999. The trial involving seed mixing of cotton with small amounts of pigeon pea and Okra seed were conducted on two commercial farms. These trials proved to be inconclusive. Okra was found to be ineffective as a trap crop and unable to compete successfully with cotton in terms of growth rate. The currently used pigeon pea cultivar (Quest) was found to be unsuitable for trap cropping because of variable phenology. Okra was not considered further as a candidate trap crop.

2001-2002 season

A paddock-scale randomised bock experiment was conducted at the Emerald Research Station in October 2001 to assess the oviposition response of *Helicoverpa* to textural and structural manipulation of the crop canopy. Crop canopy characteristics were manipulated by planting mixtures of cotton cultivars with different phenotypic characteristics such as leaf type and plant height. The assessment included a number of experimental treatments consisting of commercial cotton cultivars either singly or as mixtures with other commercial and exotic cotton cultivars. The treatments were grouped into **(a)** manipulation of the crop canopy texture, and **(b)** manipulation of texture and structure. The treatments in the first category included: (1) Siokra 1-4 by itself as a commercial check; (2) Sicot 189 by itself as a commercial check; (3) Siokra 1-4 + Sicot 189 (mixture of normal and okra leaf type cottons). The treatments in the second category included: (4) Siokra 1-4 + MCU 5 (mixture of okra leaf and tall normal leaf variety from India); (5) Siokra 1-4 + 6249V (mixture of commercial okra leaf type with tall *Gossypium barbadense* variety).

The results of this trial were inconclusive because of agronomic and non-target pest problems. The combinations of cotton varieties chosen were unsuitable for trap cropping using the seed mixing protocol because the expected segregation of growth rates and other phenotypic factors expected between the cultivars did not materialise. *Helicoverpa* pest pressure remained low throughout the season at the experimental site and the trial had to be destroyed prematurely because of uncontrollable infestations of aphids in the second half of the season. Further research is required to find the right combinations of varieties suitable for seed mixing.

Experiment 4 - Evaluation of traditional trap cropping layouts in cotton

In October 2000, an experiment was conducted on the Emerald Agricultural College farm to evaluate the impact of strip cropping. On one paddock, a strip (8 rows) of chickpea and corn seed mix was planted along one side of the paddock. Sampling for *Helicoverpa* eggs and larvae was done throughout the season. The results of this trial indicated that initially corn attracted significant egg laying but this effect soon declined. The strip of corn and chickpea seed mix did not compete well with cotton for *Helicoverpa* eggs.

In September and October 2000, several activities related to evaluation of trap crop designs and candidate crop species for seed mixing were conducted at the QDPI Research station in Emerald. These are outlined below.

Several long-season, indeterminate lines of pigeon pea were obtained in September 2000 from the QDPI Genetic Resources Centre (GRC) in Biloela and planted for preliminary evaluation of phenological characteristics to identify candidate varieties for trap cropping. Several cotton cultivars were also obtained from the GRC and planted for the same purpose. Seed of other promising cotton cultivars was sourced from the collection of Dr. Greg Constable at ACRI in Narrabri, NSW, and planted in September 2001. Assessments of these cotton cultivars for future use in trap cropping using the seed mixing approach are continuing.

Two evaluations of trap cropping designs were conducted on the QDPI Research Station in September and October 2000. Treatments (designs) in the evaluations included 8-row strips of corn and chickpea mix, cotton-chickpea seed mix in every 8th row, 8-row strip of sorghum, chickpea in-furrow, 8-row strip of Niger for mirid management, 8-row strip of corn, 1 in 8 rows of corn, 1 in 8 rows of sunflower. All treatments were monitored and sampled throughout the trial period. However, the results of the trials conducted at the QDPI Research Station were inconclusive because of extremely low *Helicoverpa* and mirid pest pressure for most of the season. In addition, the trials had to be terminated early because of a failure to control heavy aphid infestations.

3.0 How the research has addressed the Corporations three outputs: Sustainability, profitability and international competitiveness, and/or people and community

The cost of insect control on cotton has risen from roughly $30/ha in 1966 to $800-1000/ha in 1998. The bulk of this cost arises from the need to control *Helicoverpa* species throughout the season. During most of the 1997-98 season, cotton growers on the Darling Downs had to contend with *Helicoverpa* pressure exceeding 15 eggs/metre coupled with high levels of insecticide resistant *H. armigera* comprising around 80% of the population in mid November. By comparison, *Helicoverpa* pressure in the Dawson and Callide irrigation areas was much higher, resulting in many crops sustaining extensive damage and yield loss.

The current dependence on insecticides for *Helicoverpa* management in the cotton industries poses significant risks in terms of sustainability and profitability. The research conducted during this project aimed to better understand trap cropping on a commercial scale and develop new approaches for the implementation of this technology that would complement traditional insecticide-based pest management in cotton. This project was an integral part of QDPI's new initiative for fostering cleaner and greener industries through the development of more environmentally sound *Helicoverpa* management practices.

The CQ model of trap cropping has generated considerable interest in IPM-based area-wide management of *Helicoverpa* in cotton. Since the implementation of the CQ program, there has been interest in developing area-wide management programs is several other parts of the cotton belt. Spring trap crops are now planted each year on the Darling Downs and other cotton growing areas.

The registration of INGARD cotton for commercial production in Australia promised new hope that biotechnology would finally pave the way for reduced dependence on chemical insecticides. By and large, the new technology has delivered on its promise. The INGARD technology and its successors are vital to the sustainability and viability of cotton production in warmer areas such as CQ where insect management has traditionally been one of the most limiting factors for production and of concern to environmental health. The viability of INGARD cotton in areas such as CQ hinges on an effective resistance management strategy, a corner stone of which is the end-of-season trap crop of pigeon pea for *Helicoverpa* management.

The effectiveness of end-of-season trap crops in soaking up the last generation of moths, thereby slowing resistance development, will determine the future viability of INGARD and its successors in the region. The research on trap crops done through this project addressed issues that are vital to the long-term survival of cotton production in CQ.

4.0 General Discussion

4.1 The strategic framework of the CQ trap-cropping program

In Australia, Titmarsh (1992) first advocated control of the spring generations of *Helicoverpa* as a means of minimising subsequent population growth and infestation of crops on the Darling Downs. The CQ trap-cropping program constitutes the first large-scale test of Titmarsh's proposal. When implemented correctly, trap cropping for management of *Helicoverpa* may be a valuable addition to IPM-based area-wide management strategies. However, the use and proper implementation of trap crops necessarily requires a thorough understanding of the pest's ecology within the whole cropping system.

The data and analysis presented in section 2.1 show that the CQ trap-cropping strategy is based on sound ecological principles. The strategy seeks to exploit weaknesses in the regional population dynamics of *Helicoverpa*. The fundamental assumptions underlying the strategy are valid.

The data on population dynamics show clearly that the *Helicoverpa* problem in the Emerald area is locally generated within the cropping system. This explains the inexorable rise in the level of insecticide resistance in the pest. Host plant bottlenecks are clearly important factors in the population dynamics and pest status of *Helicoverpa* (Gregg *et al.* 1995). Wilson *et al.* (1979) first alluded to the importance of spring resource bottlenecks and *H. armigera* abundance within cropping systems. More recently, Oertel *et al.* (1999) demonstrated a dependency between winter rainfall in central Australia and the abundance of *H. punctigera* in spring. This project has similarly shown a relationship between spring rainfall and the incidence of resource bottlenecks in spring. This relationship is evident in the correlation between spring rainfall and the incidence of *Helicoverpa* on cotton crops. We propose that within cropping systems spring resource bottlenecks, if and when they occur, are important determinants of *H. armigera* pest status early in the spring/summer cropping season.

4.2 Efficacy and impact of trap crops

From a practical pest management viewpoint, an effective diversionary crop must be markedly more attractive than the main crop for a significant duration of the crop cycle. This differential attractiveness can then be exploited by using a relatively small area of the former to draw pest pressure away from a much larger area of the latter. In relation to the CQ trap-cropping program, the data presented here show that chickpea is by far the best choice for spring trap cropping.

The data presented in section 2.2 show clearly that spring trap crops have the potential to capture and destroy large numbers *Helicoverpa* larvae prior to the start of the cotton season. What is not clear is whether or not the proportion of the pest population eliminated by the trap crops is sufficient to impact negatively on the area-wide population and implicitly pest pressure on cotton during the season.

Several aspects of spring trap cropping such as the size of trap crop area required, crop management and in-field layout, are still not well understood. Research on these aspects of trap cropping is also being done in other CRDC-funded projects. One important aspect of the technique is timing of the trap crop in relation to *Helicoverpa* population dynamics in the cropping system. Based on the data and analyses presented here the optimal window for the spring trap crops in the EIA should stretch across September and October. This would require planting of the trap crops in late August or early September followed by destruction in early November. Spring planting of the trap crops would also facilitate the use of other crop plants such as corn and sorghum that are known to be highly attractive to *H. armigera*.

Another important factor influencing trap crop performance is the relationship between height of the summer trap crop relative to adjacent cotton and its effectiveness as a population sink at the end of the season. The limited data presented here suggest that the trap crop needs to be substantially taller than the main crop to maximise the population sink effect. Yet another important factor is the ratio of the trap crop to the main crop. In the trap-cropping literature this ratio appears to vary widely with the crop and target pest. This aspect of trap cropping remains a critical issue and may be best examined by means of computer simulation studies.

Several other factors including plant species, host-plant abundance and previous moth experience may be important determinants of host plant selection by moths and implicitly the performance of trap crops. A better understanding of these factors and their influence on oviposition behaviour is fundamental to the optimal use of trap crops as IPM tools.

The spring component of the Emerald trap-cropping program is a good example of a strategically sound approach to pest management that does not appear to have any appreciable impact on the target pest, most likely due to incorrect implementation. Although the results of our research to date do not provide evidence of a demonstrable impact of trap cropping on *Helicoverpa* population dynamics in cotton crops, the technique must still be considered a promising tool for IPM of cotton within a strategic area-wide management framework.

A dynamic planting window strategy for cotton in the EIA has the potential to significantly enhance the effectiveness of cultural and insecticide-based pest management options. Substantial spring rainfall potentially enhances availability of host plant resources not only for *Helicoverpa* but also for important sucking pests of cotton such as aphids and mirids (*Creontiades* spp.). In years characterised by substantial spring rainfall, a cotton-planting window that places seedling cotton crops out of the spring flush could be of significant benefit in ameliorating the pest management challenge on commercial cotton being experienced under the status quo.

The efficacy and impact of the summer trap crops remains largely unknown. The main reason for this is the phenotypic variability of the pigeon pea variety currently being used for summer trap cropping in cotton. Whilst pigeon pea is undoubtedly a highly attractive crop to *Helicoverpa*, its usefulness as an end-of-season trap crop is questionable because of inconsistent performance from one year to the next.

4.3 Quantification of field parameters for trap cropping

Cultural control tools such as trap cropping seek to exploit specific biological or ecological traits of the target organism. For example, companion or strip cropping is aimed at exploiting pest preferences for certain stages, cultivars or species of host plants. This form of trap cropping involves planting a block or strip of the trap crop adjacent to the main crops to serve as a 'sink' for the pest population (Abate 1988; Hokkanen 1991). Pre-season trap cropping which assumes substantial 'local' recruitment of the pest been used successfully for bollweevil control on cotton in the USA (Burris *et al.* 1983; Isley 1950; Scott *et al.* 1974) and Nicaragua (FAO 1981; Holl *et al.* 1990).

Whilst it has been known for a very long time that trap crops can potentially play a useful role in pest management, there has been limited commercial application of the technology in modern (conventional) agricultural production systems. One important reason for this lack of adoption has been the cost of the technology to the grower in terms of resource allocation.

The traditional approach to trap copping requires a substantial proportion of cultivated area to be set aside for the trap crop. In cases where the trap crop is of a sacrificial nature (i.e., it is not grown to maturity but is destroyed before the main crop is harvested) the area set aside for trap cropping does not produce any financial returns for the grower. Other resources such as water, fertilizer, use of machinery and fuel required for producing the trap crop constitute additional costs to the grower.

This project was not particularly successful in assessing field parameters of traditional trap cropping protocols for various reasons, as explained in earlier sections of this report. In particular, assessments of strip and block layouts were largely inconclusive. However, an outstanding result of this research project has been the discovery of a potentially new approach to trap cropping.

This new approach based on mixing of crop plants (seed mixing) seeks to exploit previously ignored aspects of pest behaviour in mixed crop situations. From a practical perspective, growing the main crop and the trap crop in the same field, as seed mixtures, offers growers a number of advantages. Firstly, this approach does not require cultivable area to be set aside for trap cropping. Secondly, both the trap crop and the main crop can be managed as a single unit. Thirdly, this approach allows direct estimation of the benefits of the trap crop by facilitating side-by-side comparisons of plant damage and yield loss. Impact assessment is one of the problems associated with traditional trap cropping protocols.

The seed mixing protocol for trap cropping documented in this project could potentially revolutionise pest management in cotton. The extent of aggregative egg distribution responses by *Helicoverpa* in response to seed mixing crop plant cultivars or species in other cropping systems is currently unknown. In view of the economic importance of *Helicoverpa* to agricultural crop production, demonstration of a tendency towards aggregative oviposition behaviour in other crops could have important pest management implications. Our results highlight the need for further research on the relationship between crop canopy structure and pest distribution, and the potential to manipulate these for pest management.

5.0 Likely impact of the results and conclusions of the research project for the cotton industry

The trap-cropping research outcomes of the project could potentially revolutionise management of *Helicoverpa* and sucking pests such as mirids. In a canopy where certain plants that are attractive to the pest are dispersed in amongst the bulk of the crop that is relatively less attractive, the attractive plants serve as beacons not only to the pest but also to beneficial insects, thereby increasing the efficiency of the latter. Thus, the research proposed here promises to provide a unifying framework for a number of other pest management approaches funded by CRDC, including the use of beneficial insects and use of biological insecticides.

Trap cropping works on the basic principle that pests have distinct host plant preferences. Some plant species are more attractive to certain insect pests than other plants. One plant species that stands out for attractiveness to *Helicoverpa* is chickpea (*Cicer arietinum*). This feature has resulted in the growing use of chickpea to trap and destroy early spring populations of *Helicoverpa* in several cotton producing areas in Australia.

There is already evidence of adoption of research coming out of DAQ 97C. Some growers are mixing wheat and other plants in their trap crops to manage *Helicoverpa* populations on these crops. The chickpea/cotton seed mixing tactic for *Helicoverpa* management has been evaluated in Kunnunnurra (Dr. Amanda Annells, personal communication) and Biloela (Dr. Paul Grundy, personal communication) with further evaluation planned in the coming season. Seed mixing for trap crops is soon likely to become a standard recommendation for spring chickpea trap crops.

In the current harsh economic climate, growers cannot afford to allocate large proportions of their resources to pest management but in most cases have little or no choice when faced with crippling losses due to insect damage. Substantial areas of the farm planted to trap crops equate directly to lost income. By using 'smart' trap cropping tactics that involve using the insects' own weaknesses (preference for certain plants) against it, the successful achievement of research objectives outlined here could eliminate the need for dedicated trap crop areas by growing the trap and main crop as a single entity. This would have significant and far-reaching implications for pest management.

The Emerald trap-cropping program has generated considerable interest in alternative (non-chemical based) population management tactics throughout the Australian cotton industry and renewed awareness of the need for integrated pest management in an environment characterised by high levels of insecticide resistance in pest populations. The program has fostered increased communication and exchange of ideas between groups of growers. These are perhaps the most significant benefits of the program to date.

6.0 Follow-up research requirements

(a) to further develop or to exploit the project technology.

The level of adoption of the CQ trap-cropping program remains high, at well over 90%. This high level of adoption is still driven by the perceived need for urgent control measures against *Helicoverpa* and the legal requirements for access to transgenic cotton tehnology, rather than the benefits of the program. In order to maintain the current level of adoption, on-going research on ways to maximise the efficiency and impact of trap crops is required. The program needs to be defined and developed within the context of area-wide pest management. The novel approach to the deployment of trap crops identified in this project, namely canopy manipulations through seed mixing of crops, warrants further research.

Cotton has unique features that distinguish it from other field crops. The successful deployment of trap cropping and other cultural tactics for pest control in cotton will require the development of new and 'smart' approaches. The ideal pest management strategy is to manipulate the environment in such a way that even if the pest is present in the crop, its activity is not causing economic loss. Some of these new ideas have begun to materialise through the research done in DAQ 97C and need to be further developed in future research.

(b) for the future presentation and dissemination of the project outcomes.

The majority of project outcomes have already been disseminated to industry. As much of the research reported here is continuing in new and other projects, further outcomes will be reported in due course.

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8.0 List the publications arising from the research project

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