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Cotton Research and Development Corporation

Annual, Progress and Final Reports

REPORTS

Part 1 - Summary Details

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

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Project Title: Area-wide monitoring and cultural control of key cotton pests in central Queensland

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Research Program: 3 Crop Protection

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Cotton Research & Development Corporation
&
Grains Research & Development Corporation

Area-wide monitoring and cultural control of key cotton pests in central Queensland

Development of an area-wide decision support system for whitefly management in central Queensland cropping systems

DAQ 120C & DAQ 00056
(July 2002 - June 2005)

A final report prepared for the Cotton and Grains Research & Development Corporations

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Plain English Summary

Heliothine caterpillars and silverleaf whitefly (SLW) are the major pests of field crops in central Queensland (CQ). *Helicoverpa* has been the primary focus of cotton insect pest management since the inception of the CQ industry in the 70s. SLW is a recent introduction to the mixed cropping systems of CQ. Both pests are serious threats to cotton.

Although the advent of Bollgard II Bt cotton varieties has largely relegated *Helicoverpa* to minor pest status, the continuing threat to cotton from this pest stems from its ability to develop resistance to the technology. SLW is a major threat to the cotton and grains industries. The excretion of sugary 'honey dew' by nymphal and adult SLW feeding on the underside of cotton leaves can make the lint sticky and unmarketable. Large populations of SLW can totally destroy susceptible legumes (eg, soybean) and sunflower plants.

Project DAQ 120C had two objectives. The first was to further develop novel pest management tactics for *Helicoverpa* initially identified in previous projects. The second, and major objective, was to develop a comprehensive research and management framework for SLW in CQ.

Cotton crop canopy modification using intercropping with exotic varieties of cotton selected for specific phenological and growth characteristics was trialled in a field of commercial cotton. The outputs suggest that cotton canopy modification has enormous potential as a novel IPM platform on which other cultural, biological and chemical control tactics can be superimposed. The concept of canopy modification for pest management deserves further detailed investigation and trial work.

The SLW research outputs of DAQ 120C collectively make up a substantial body of ecological and field sampling data and information that will serve as a pest management framework for cotton and other crops in CQ. Salient features of SLW ecology in CQ include population cycling between cotton and weeds components, high levels of natural mortality inflicted by native beneficial insects indicating the potential for stable population dynamics, and negative impacts of pest management activities on cotton and other industries targeting other pests on SLW bionomics in the region. SLW management in cotton based on overseas protocols and parameters is of questionable long-term utility. Overseas protocols and parameters must be adapted to reflect local environmental conditions and pest ecology.

1.0 Background

1.1 Helicoverpa – A traditional cotton nemesis

The noctuid moths ***Helicoverpa armigera*** and ***H. punctigera*** have traditionally been the most dominant and economically important pests of field crops in the mixed cropping systems of central Queensland (CQ). *Helicoverpa* has been the primary focus of cotton insect pest management since the inception of the CQ industry in the 70s.

The Bt cotton era, which began in CQ with the introduction of single insecticidal transgene (INGARD®) varieties in 1997, ushered in fresh hope for a shift away from the traditional reliance on insecticides to genuine integrated pest management strategies (IPM) for in-field pest control. Subsequent research focussed on the integration of INGARD® cotton into broad-based IPM strategies and the development of pre-emptive resistance management tactics appropriate to the semi-arid subtropical environment of CQ. This line of research culminated in DAQ 97C (*Development of trap cropping protocols for Helicoverpa management on cotton in central Queensland*) that ended in June 2002. Project DAQ 97C sought to find ways and means of maximising the efficacy of the Bt resistance management strategy (RMS) developed for CQ *Helicoverpa* populations by the use of habitat manipulation tactics such as trap cropping and crop canopy modification. Further development of these novel pest management tactics was one of the objectives of DAQ 120C.

1.2 Silverleaf Whitefly – A new pest in central Queensland

Bemisia tabaci (Gennadius) B-biotype, the Silverleaf whitefly (SLW), is an agricultural pest of global importance and a relatively recent introduction to Australia (De Barro 1995). Since its introduction, SLW has rapidly spread along coastal cropping regions of Queensland and New South Wales where it is a major production constraint on a wide variety of horticultural, fibre, summer grain and oilseed crops (De Barro 1995; Gunning and Cottage 2000).

SLW was first detected in the Emerald irrigation area in 1998 mainly on ornamental plants in parks and gardens (Franzmann *et al.* 1998). However, the pest did not constitute a problem until the winter of 2001 when it reached outbreak proportions on a few cucurbit crops including pumpkin, melon and squash. In the following summer months (December 2001-March 2002) the pest spread rapidly and the central Queensland region experienced its first large-scale outbreak of SLW on cotton, summer grain, horticultural crops, nursery plants and feral host plants (Moore et al. 2004).

Cotton pest activity in the Emerald irrigation area (EIA) during the 2001-02 season was overwhelmingly dominated by the silverleaf whitefly (SLW). Monitoring by Dr. Paul De Barro of CSIRO showed that in the second half of the season SLW activity was detected in all cotton crops, most non-crop host plants such as weeds, ornamentals and other crops in the EIA, as well as isolated crops outside the irrigation area. Outbreak densities of SLW were detected on more than 50% of cotton crops in the area with (ineffective) control action taken on a considerable number of these crops. SLW activity was also detected in crops in Clermont, north of Emerald, and in the Dawson valley (Theodore), thereby inflating the threat posed by this pest to one of regional significance.

Several local soybean crops developed massive infestations with some having to be destroyed and others being useful only for hay. Yields of crops taken to harvest were generally at non-profitable levels. Irrigated and dryland sunflower crops in the region were inundated with large populations of SLW during January and February. This resulted in large reductions in yield. Autumn rock melon crops were severely damaged by SLW. The earliest planted crops suffered lower sugar (brix) levels in the fruit (affecting sweetness), caused by the removal of sugars from the plant by the insect. Despite being a non-preferred host, local peanut crops developed high populations throughout January and February. Peanut yields were substantially lower in areas that harboured high SLW numbers.

Local Nurseries were also badly affected by the SLW outbreak. Some nurseries had to destroy large quantities of plants. Furry leafed plants were worst affected especially, scented gums, hibiscus, geraniums, durantra, tomatoes, pumpkins, and eggplant seedlings.

The threat posed by SLW to the cotton industry resulted principally from the high likelihood of honeydew contamination of lint which in turn made the regional cotton industry vulnerable to a sticky cotton stigma, negative commercial sentiment and crippling price penalties. In addition, the feeding activity of the pest can result in substantial yield loss and the spread of plant diseases.

Cotton and grain growers in CQ were deeply concerned about the lack of short and long-term management options for SLW and called for urgent research support from the Cotton and Grains Research & Development Corporations to provide a better understanding of the pest's ecology, future pest status and annual threat to CQ field crops. SLW research and management in the central Highlands became the second and major focus of DAQ 120C.

Being a new pest in the region, there was no ecological or pest management knowledge on SLW relevant to the CQ region prior to the start of DAQ 120C. Over the three-year duration of the project, an enormous dataset on the field ecology and management potential of SLW has been collected. This report summarises some aspects of that SLW dataset where preliminary data analysis have been completed. Other sections of the dataset are currently being analysed. A comprehensive document (monograph) detailing SLW field ecology and management potential will be published by December 2005.

2.0 PART A: Helicoverpa Research

2.1 Objectives

1. Identify pigeon pea varieties or alternative crops suitable for end-of-season trap cropping.

2. Quantify impact of crop canopy manipulation through seed/cultivar mixing and companion/strip cropping on population dynamics of major cotton pests.

3. Foster development and on-farm implementation of new and existing IPM tools in the region.

2.2 Outcomes

2002-03 Season

Pigeon pea cultivar screening

Initial screening of pigeon pea varieties suitable for end-of-season trap cropping commenced in DAQ 97C was continued. Local and overseas accessions of pigeon pea (Table 1) were planted and evaluated on the basis of agronomic characteristics and attractiveness to *Helicoverpa* for use as potential end-of-season trap crops with INGARD/BOLLGARD II technology. The assessment was done at the QDPI Research Station in Emerald.

Table 1. Cultivars of Cajanus cajan (Pigeon pea) evaluated for agronomic characteristics including height and days to flower for use as potential end-of-season trap crops.

Type	Cultivar/Name	Source/Country
Cajanus cajan	QPL 968	UQ
Cajanus cajan	QPL 941	UQ
Cajanus cajan	QPL 875	UQ
Cajanus cajan	ICPL 1	ICRISAT
Cajanus cajan	ICPL 4	ICRISAT
Cajanus cajan	PANT A3	ICRISAT
Cajanus cajan	PUSA AGETI	ICRISAT
Cajanus cajan	ASHAI T21	ICRISAT
Cajanus cajan	RKJ 2	COLOMBIA
Cajanus cajan	RWS 930	BRAZIL
Cajanus cajan	431W	NEPAL
Cajanus cajan	021W (269W)	NEPAL
Cajanus cajan	ROYES	UQ
Cajanus cajan	ICP 6927 / CODE 15	TRINIDAD & TOBAGO
Cajanus cajan	ICPL 87091	
Cajanus cajan	ICP 13256 / PRN 171	KENYA
Cajanus cajan	ICPL 83024	

None of the varieties in the assessment were found to meet the requirements in terms of plant height and phenology of flowering. These results suggest that pigeon pea may not be the ideal candidate for end-of-season trap cropping (a mandatory requirement for INGARD/BOLLGARD II technology). The feasibility of sorghum or exotic cotton varieties as end-of-season trap cropping alternatives was examined. Accordingly, a field trial to examine the feasibility of sorghum was planned and carried out on three commercial farms. However, the trial was not successful and had to be abandoned due to lack of pest pressure.

Exotic cotton cultivar screening

Screening of cotton varieties with desirable characteristics (attractiveness to insects, height, etc) that may be suitable for seed mixing with commercial cultivars or as alternative trap crops for end-of-season trap cropping, commenced in DAQ 97C, was continued. A number of exotic cotton varieties were evaluated in terms of phenology and suitability for trap cropping at the QDPI Research Station in Emerald. Initial seed material was obtained from the Australian Tropical Crops & Forages (AusTCF) Germplasm collection in Biloela (Qld). Several of the varieties evaluated were found to be suitable for this purpose. The most promising cultivars are listed in Table 2.

Table 2. Cotton cultivars evaluated for agronomic characteristics including height and days to flower for use as trap crops.

Cultivar	AusTCF[1]	Species	Origin	Habit	Leaf Type	DTM[2]	Height (cm)
Tanguis	300654	*Gossypium barbadense*	Peru	erect + branches	pubescent	na	230
Naked seed	300841	*Gossypium hirsutum*	na	compact	normal	144	230
Mata	300884	*Gossypium hirsutum*	na	compact	normal	161	220
H 11014	300839	*Gossypium hirsutum*	na	erect + branches	smooth	na	180
AC 134	57996	*Gossypium hirsutum*	Pakistan	erect + branches	normal	134	180
UK 63	57399	*Gossypium hirsutum*	Tanzania	erect + branches	normal	160	180
IAC 13	300647	*Gossypium hirsutum*	na	erect + branches	normal	162	170
CZA (70) 33	57043	*Gossypium hirsutum*	Zambia	erect + branches	normal	149	170
MCU 5	57272	*Gossypium hirsutum*	India	compact	normal	162	140
Albar G501	123737	*Gossypium hirsutum*	Zimbabwe	na	normal	na	147

Notes: [1] Australian Tropical Crops & Forages Collection number; [2] Days to maturity

The results of the evaluation were inconclusive because the desired canopy modification effect failed to materialise, suggesting that seed mixing may not be the best way of utilising the exotic cotton for pest management purposes. An alternative strip layout may be a more viable option for deployment of the exotic cotton varieties in amongst commercial cotton.

2003-04 Season

A large-scale field trial of the cotton crop canopy manipulation technique for pest management using exotic cottons was conducted on .Mr Michael McCosker's farm ("Marathon") in Emerald. The canopy structure of a field of unsprayed conventional cotton (cv. Sicot 71) was modified by inter-planting twin rows of exotic cotton varieties. The expectation was that distortion of the normally uniform canopy structure would alter the distribution of insects in the field by making the twin rows of exotic cottons more attractive than the surrounding commercial cotton cultivar.

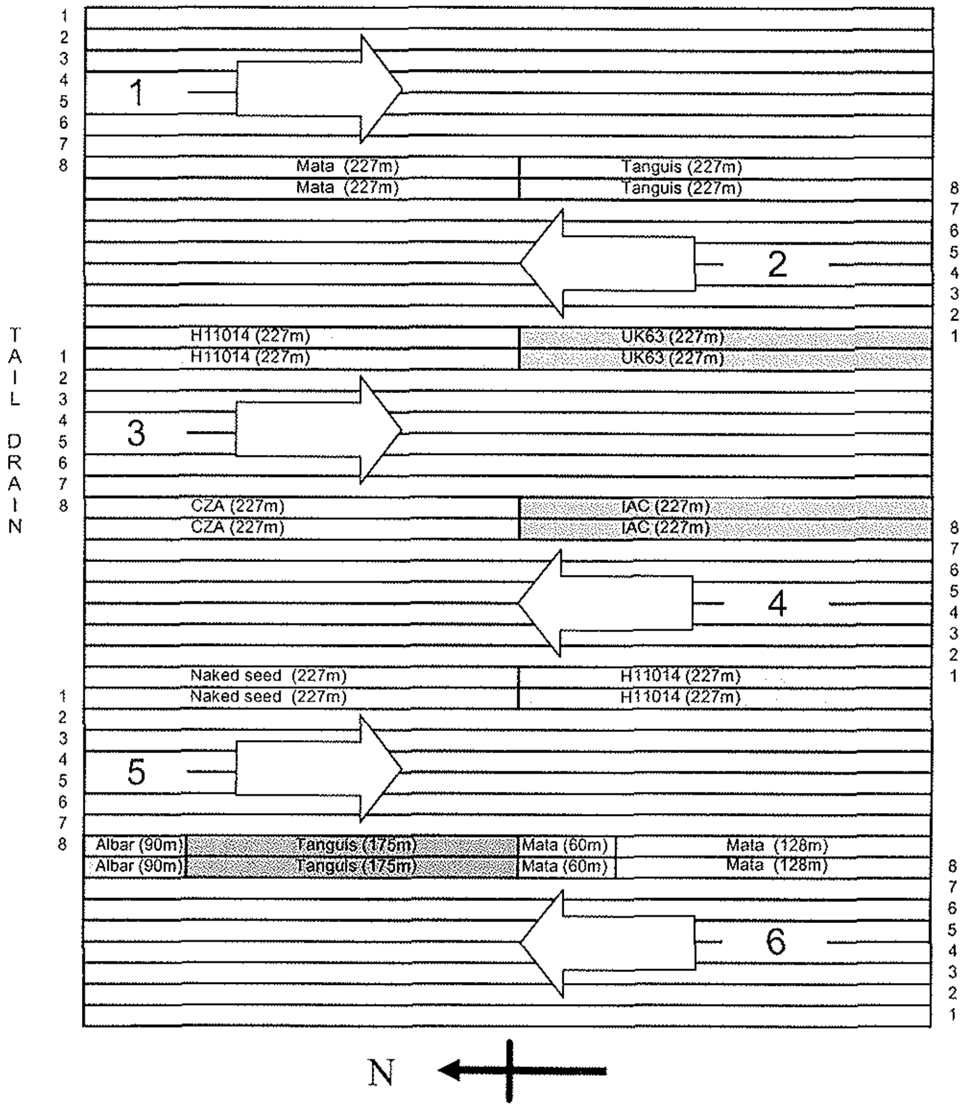


Fig. 1. Field layout of cotton canopy manipulation technique trial at Michael McCosker's farm ("Marathon") in Emerald showing exotic cultivars and areas planted. Each row and corresponding number along the vertical margins represents a single row (1-m row spacing). The large numbers represent runs of an eight-row planter in the direction shown.

<u>Trial design & Layout:</u>

The unsprayed cotton field was bounded on the right (south) by a field of BOLLGARD II® and on the left (north) by fallow area. The exotics were cultivars or experimental lines selected for higher growth rates, flowering and other phenological characteristics. The canopy distortion experiment was done in the middle section (40 rows) of the field. The inter-planting design was achieved by planting five runs of an eight-row planter to a mix of Sicot 71 and exotic cottons. The two end rows of each group of eight were planted to one or more of the exotic varieties and the intervening six rows planted to Sicot 71. The design thus created was six rows of Sicot 71 alternating with two rows of exotic cotton (Fig. 1). The remaining areas of the field on either side of the middle inter-planted strip of 40 rows were planted fully to Sicot 71. The twin rows of exotics were expected to modify the crop canopy by growing considerably taller than the conventional cultivar, or in other words, by the creation of a hedge effect.

Results:

The impact of this field layout on the distribution of insect was assessed during the course of the season. Boll count estimates on the conventional and exotic cotton varieties were obtained at the end of the season and compared to the adjacent BOLLGARD II® crop (Fig. 2).

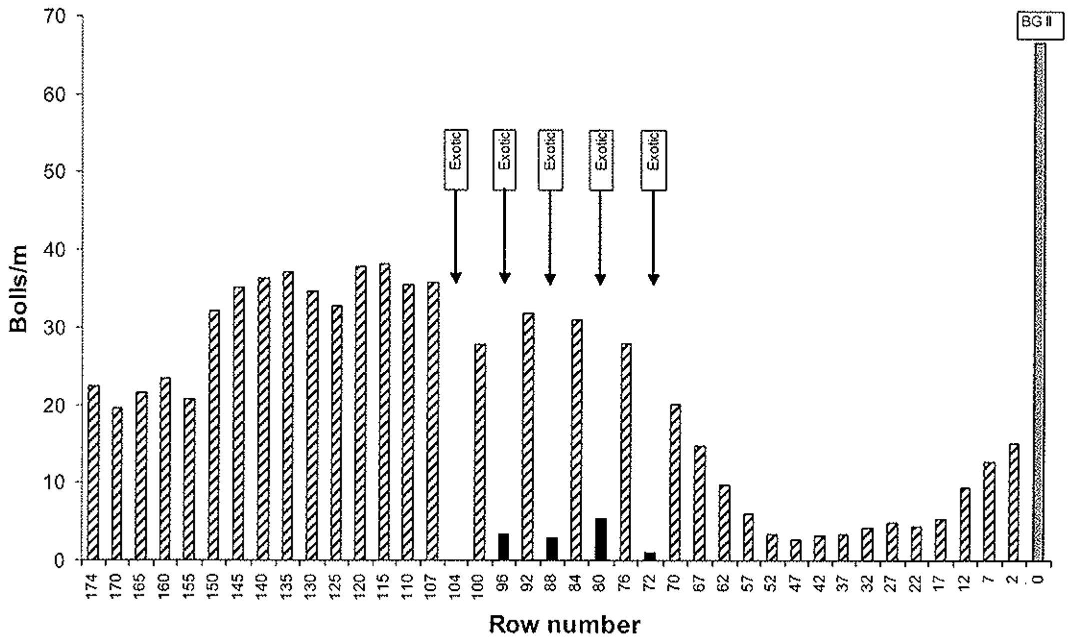


Figure 2. Mean fruit load profile for unsprayed Sicot 71 (hatched bars), exotic cottons (black bars) and BOLLGARD II® (solid grey bar) in the canopy manipulation experiment. The profile is based on 6 transects 50 m apart, from head ditch to tail drain. See text for description of field layout.

The average fruit load profile showed a number of interesting features. The boll count fell sharply from the edge of the last twin row of exotics, towards the BOLLGARD II® field. On the other edge of the twin row of exotics, towards the fallow area, the boll count profile stayed high for about 50m before declining. The exotics hedges appear to have provided some "protection" to certain rows of unsprayed Sicot 71, specifically those bounded on both sides by the exotics and those on the left hand side of the graph (Fig. 2).

Observations in the field suggest that the hedge effect demonstrated in this experiment may influence the distribution and activity of other insects such as *Creontiades* (mirids). Interestingly, SLW was not a problem in the canopy-modified paddock but required expensive insecticidal control (insect growth regulator spray) on adjacent Bollgard II paddocks. These and other aspects of the hedge effect and canopy manipulation need to be investigated further.

The results indicate that canopy manipulation has potential to become the basis of IPM in conventional cotton production systems. Other pest management tactics including chemical insecticides, biological insecticides and releases of beneficial insects such as *Trichogramma* could be used in conjunction with canopy manipulation for the development of sustainable IPM strategies for conventional cotton production systems.

The mechanism underlying this apparent protection is still not clear. The conventional cotton fruit load in amongst and to the left of the exotics was only about half that of the nearby BOLLGARD II® crop. However, the conventional field was not sprayed whereas the BOLLGARD II® field was sprayed twice for mirids and once for whitefly.

The fruit load profile for unsprayed cotton in Fig. 2 does not represent a commercially viable outcome in comparison to the adjacent BOLLGARD II® crop. However, in view of the fact that 2003-04 was considered by most cotton growers and consultants to be a relatively heavy pest pressure season, the top end estimates of fruit load on the unsprayed cotton rows shielded by the exotic cottons are not insignificant. These yield estimates demarcate a baseline performance that could only be improved with the assistance of other IPM tactics (biological insecticides, soft insecticides, natural enemies, to name a few).

A planned second, more comprehensive evaluation of the canopy modification protocol in the 2004-05 season aimed at validating the results of the McCosker trial in the 03-04 season was attempted but could not be managed adequately primarily due to a lack of irrigation water resources stemming from on-going drought conditions during the season.

3.0 PART B: Silverleaf Whitefly Research

3.1 Objectives

1. Quantify spatial and temporal population growth profiles of SLW, natural mortality factors and pattern of movement on all crops within and between seasons on an area-wide basis.

2. Characterise the SLW threat to field crops industries in CQ in terms of crop susceptibilities and the level of risk to cotton, grains and oilseed crops.

3. Use the population dynamics data to develop an analytical framework with short-term control tactics and a long term management strategy

4. Foster development and on-farm implementation of new and existing IPM tools in the region.

3.2 Outcomes

3.2.1 Spatial and temporal population dynamics of SLW 2002-2005

The outbreak experience and data collected by CSIRO (Dr. Paul De Barro) during the 2001-02 growing season in Emerald highlighted the challenges as well as knowledge gaps that needed to be addressed if the SLW threat was to be successfully contained or alleviated. Given the sheer size of the CQ cropping system and the diversity of crops grown throughout the year, it was physically impossible to distribute the research effort across all SLW susceptible crops in view of the limited resources available. From an ecological and cropping system perspective, the logical approach to targeting the research effort was to focus on characterising linkages between cropping system components in terms of SLW dynamics and the key factor(s) driving the regional population dynamics of the pest.

With only one season of SLW activity to rely on for local baseline ecological and pest management data, development of a research framework had to be based on overseas experiences, particularly from parts of the United States (Arizona, Texas and southern California), where SLW is an endemic problem. Characterising the temporal and spatial abundance, distribution and dispersal patterns was an essential first step in identifying potential management strategies. Whilst general principles of the bionomics and autecology of SLW in other parts of the world were generally applicable, local environmental factors and cropping practices would ultimately determine the parameters underling the pest problem in CQ.

Materials & Methods

Over a three-year period (September 2002 - June 2005), sampling was conducted on the broad leaved cropping system components that were known to be susceptible to SLW infestation *viz*, field crops, weeds and horticultural crops. Cultivated field crop plants, including cotton, sunflower, pulses (soybean, mungbean, navy bean, adzucki bean), horticultural crops (primarily cucurbits), peanut and lucerne were sampled. The importance of broad leaved weeds to SLW dynamics was gauged by sampling an 'indicator' weed that is widespread and prolific in the CQ cropping system – *Sonchus* spp. (sowthistles).

A total of 164 fixed sampling sites representing cotton, horticultural and other crop host plants within seven area sectors were identified and tagged using GPS coordinates for year-round sampling (Fig 3). Cotton and weed sites were represented in all area sectors. Whilst the North West and Foley Road sectors accounted for the bulk of the cotton production area and consequently the majority of cotton sampling sites, the South East sector accounted for the least. Horticultural sites were primarily small (< 5 acres) cucurbit crops, restricted to the South East sector, with the exception of one rockmelon grower (max. 60 ha) in the North East sector. Sampling was done at fortnightly intervals.

All the sites were sampled in the first year. The sampling effort was progressively reduced in the second (69 sites) and third year (50 sites), reflecting a shift in the research focus from area-wide population dynamics to within field and crop aspects of bionomics, and development of management tactics.

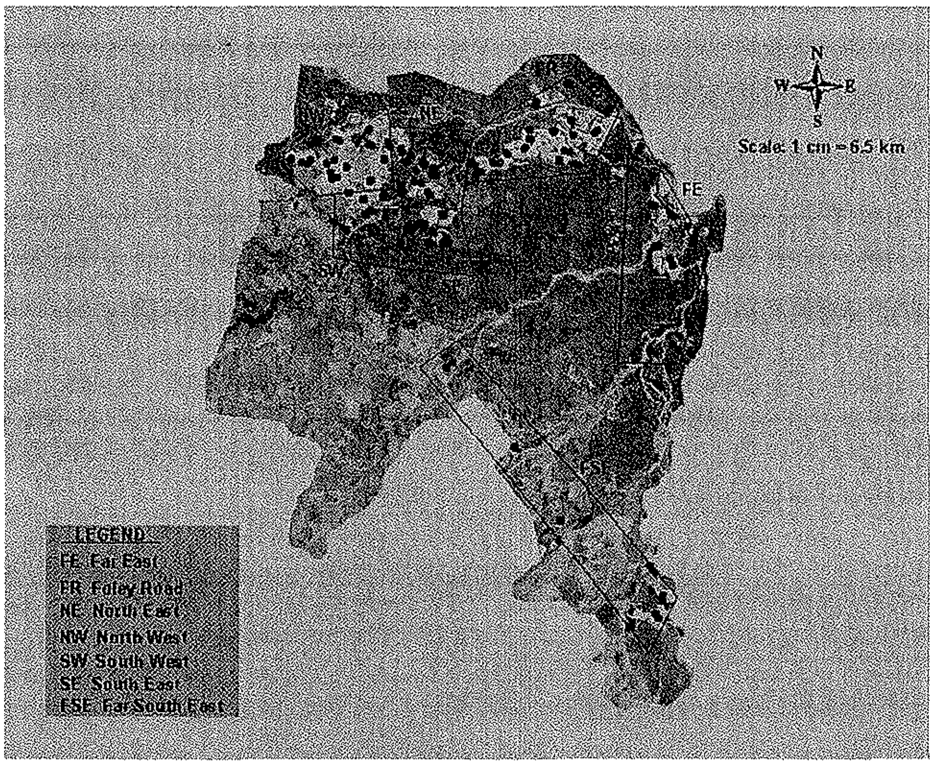


Fig. 3. Distribution of sampling sites and area sectors across the Emerald cropping system. The confluence of the North-West, North-East, South-West and South-East sectors marks the township of Emerald.

Sampling was based on protocols for SLW monitoring in field crops developed in Arizona, USA. Commercial crop sites were sampled in a zigzag or U-shaped pattern after walking approximately 20 m into the crop so as to avoid edge effects, and allowing 5 m between individual samples. Avoidance of edge effects was not practicable for horticultural crops because of small plot sizes and for weeds due to the variable size of plant stands. At each site, 15 plants were randomly selected for assessment of SLW nymph and adult density

<u>Sampling cotton crops</u>

Adult SLW density on selected plants was estimated by gently turning over one leaf and counting the total number of insects on the underside. In the early stages of plant growth (7-8 nodes) the sampling leaf was selected from the middle of the plant (4^{th} or 5^{th} node). In older plants the sampling leaf was selected from the upper half of the plant excluding the top three (youngest) nodes.

Nymph density was estimated using the same leaf selected for assessment of adult SLW density. All large nymphs (3^{rd} and 4^{th} instar (red-eye)) within a 3.88 cm^2 disk placed in the leaf sector formed by the left and middle major veins on the underside were counted, following the protocol developed for SLW sampling in Arizona (Naranjo et al. 1997; Ellsworth & Martinez-Carrillo 2001).

Sampling weeds

Sampling for SLW adults on weed plants was done by visually scanning the underside of one randomly selected fully unfurled leaf from the top half of the plant (excluding the youngest leaves). The density of large nymphs was estimated from a 3.88 cm^2 disk placed on a randomly selected leaf from the bottom half of the plant.

Sampling horticultural & other crops

In horticultural crops (cucurbits) adult density was estimated by visually scanning the underside of one leaf from the top third of each plant/vine whereas large nymph numbers were estimated from one leaf from the bottom half using a leaf disc.

In lucerne and peanut crops, terminal leaves were scanned for SLW adults and lower leaves scanned for the large nymphs. The 3.88 cm^2 disc was not suitable for plants with tri-foliate leaves; hence large nymph density was recorded for the entire trifoliate leaf.

Results & Discussion

The data on SLW nymphal and adult densities were used firstly to generate fortnightly GIS spatial and temporal SLW distribution maps (in Acrview® 8.x) in the hope that the development of 'hotspots' and profiles of density changes across the sampling area could be identified and targeted by crop consultants and growers. The SLW distribution maps proved to be useful visual aids in grower updates and workshops but of little analytical value primarily because the expected SLW spatial and temporal density mosaics either did not materialise over the sampling period or were beyond the sensitivity of the technique and the sampling scale permitted by the available resources.

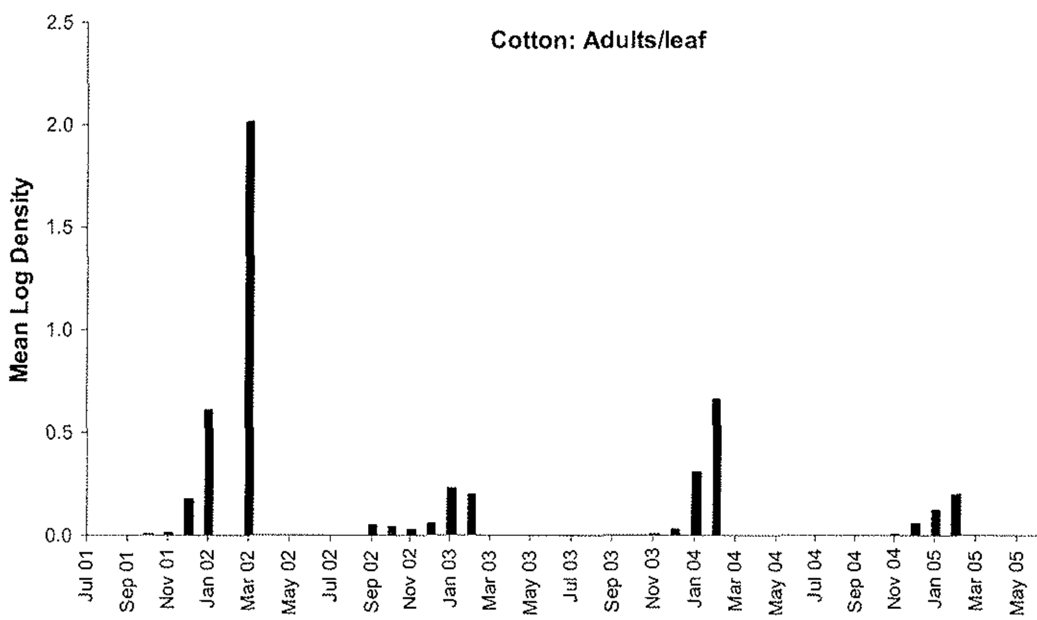


Fig. 4. Monthly mean density of SLW adults on cotton crops in the Emerald irrigation area. Data for 2001/02 courtesy of Dr. Paul De Barro, CSIRO.

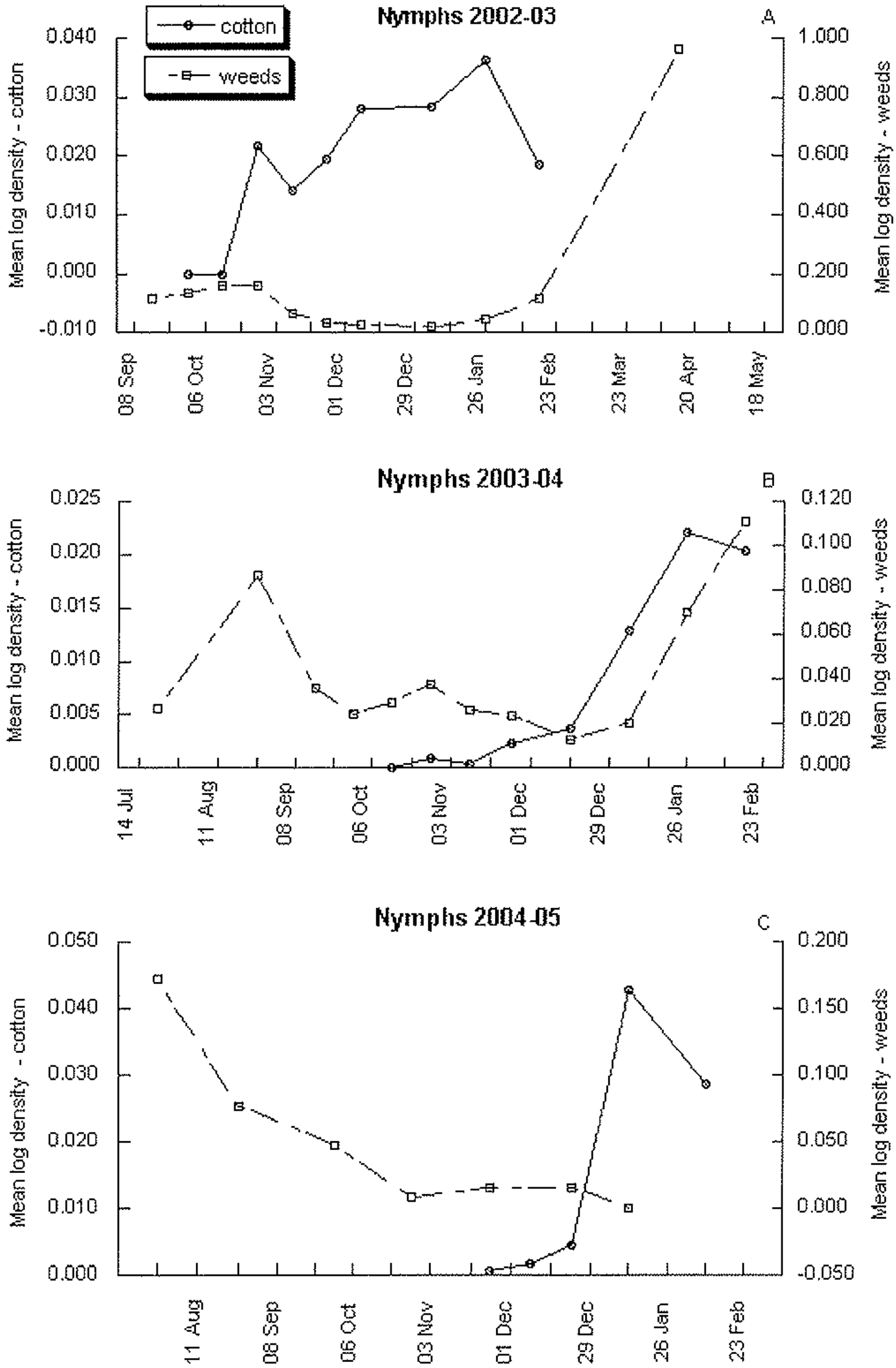


Fig. 5. Temporal density profiles of SLW large nymphs on cotton and weeds in the Emerald irrigation over three consecutive growing seasons. (A) 2002-03, (B) 200304, (C) 2004-05.

In the seasons following the outbreak of 2001/02, mean SLW density across all plant hosts declined and remained relatively low (Fig. 4). The biotic and abiotic factors largely thought to be responsible for the outbreak and the subsequent decline in the mean density profile include weather conditions, changes in management practices and mortality due to natural enemies. The latter will be discussed further in following sections.

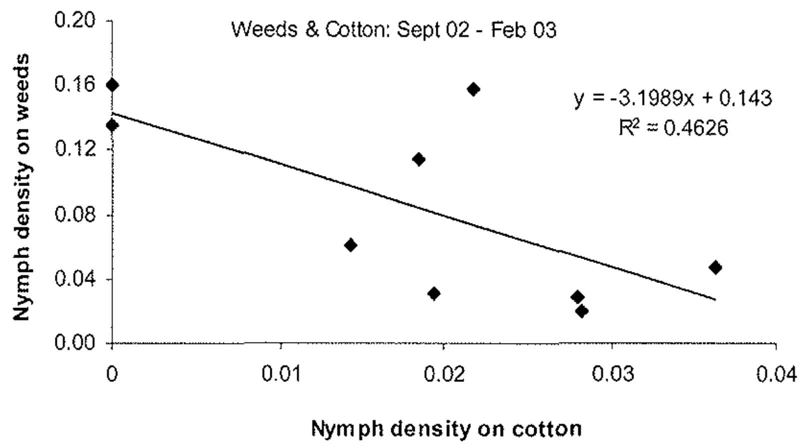


Fig. 6. Negative relationship between mean density of large SLW nymphs (3rd & 4th instars) on cotton and weeds, indicative of cyclical dispersal in spring and mid-summer.

The spatial and temporal abundance data point to the role of 'key' factors underlying the population dynamics and pest status of SLW in the region. In each sampling year, the Emerald irrigated cotton area (exceeding 20,000 ha in 2002/03) was the key biotic factor underlying the regional population dynamics of SLW.

Cotton crops planted in spring (September-October) served as the largest sink for steady, low-level dispersal from gradually diminishing stands of feral host plants (eg, *Sonchus* spp.) broadly scattered in and around the irrigation area. A reverse dispersal was evident later in the year when feral host plants became the primary recipients of SLW dispersing off finishing cotton crops in January and February. The cyclical pattern of movement between major system components is evident from the temporal synchrony between corresponding SLW population profiles on cotton and weeds (cf, Figs. 5 A-C; Fig. 6).

Although horticultural crops harboured substantial SLW populations (Fig. 7), they did not appear to contribute significantly to the regional pool or dispersal patterns primarily because of the small areas under these crops. However, in some instances localised impacts manifested as SLW hotspots in cotton fields directly adjacent to finishing rockmelon and pumpkin crops were readily apparent in the South East sector. Due to prevailing drought conditions in the 2004-05 season, there were no small scale horticultural crops of any significance in the region except the commercial rockmelon crops grown by one grower in the North East sector. These commercial crops were largely unaffected by SLW populations.

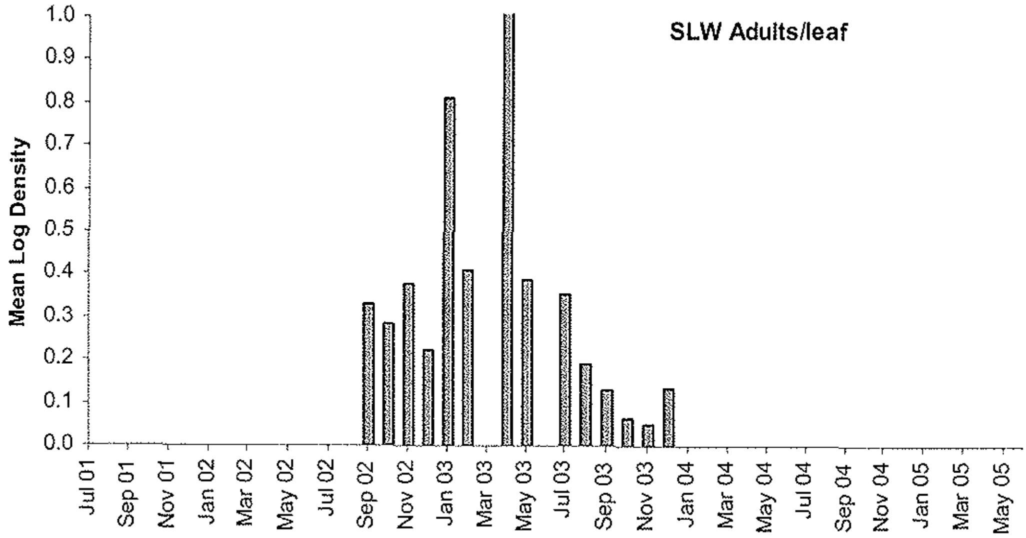


Fig. 7. Monthly mean density of SLW adults on horticultural (cucurbit) crops in the Emerald irrigation area over three consecutive growing seasons, 2002/03 – 2004/05.

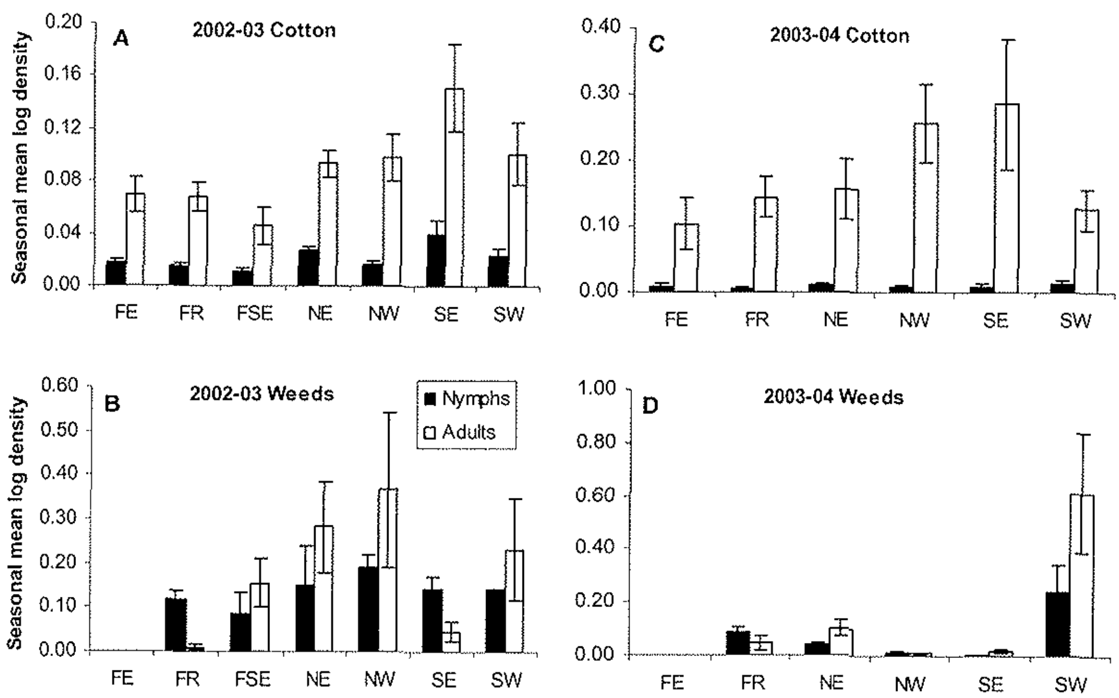


Fig. 8. Mean seasonal sector-wide density of SLW large nymphs and adults on cotton (A, C) and sowthistle weeds (B, D) over two growing seasons in the Emerald irrigation area. Error bars show SEM.

Mean seasonal SLW density on cotton crops varied among sampling sectors (Fig. 8 A, C). A higher mean seasonal density in the South East sector was most likely a reflection of the proximity of these crops to cucurbit crops. By comparison, mean seasonal SLW density on weeds was even more variable among sectors (Fig. 8 B, D), reflecting the heterogeneity in plant distribution and the highly ephemeral nature of weed stands. Under the severe drought conditions experienced during 2003/04, the abundance of SLW on weeds in the South West sector (Fig. 8 D) largely reflects the survival of weed stands in that sector, mainly in the vicinity and under storey of commercial citrus orchards.

SLW colonization of spring crops each year was likely to have been facilitated by populations over-wintering on weeds (Fig. 9). Citrus orchards around the Emerald irrigation area usually harboured sowthistle populations along the borders of management units (fields) and in the under-storey. SLW census data for August 03 are a case in point (Fig. 10). Mean sector-wide densities on weeds were very low in all sectors except the South West. Methomyl (Lannate®) had been used approximately two months before the census date in one large citrus orchard in the South West sector for control of citrus pests, which could account for the spike in SLW numbers and associated impacts on beneficial insects (see below).

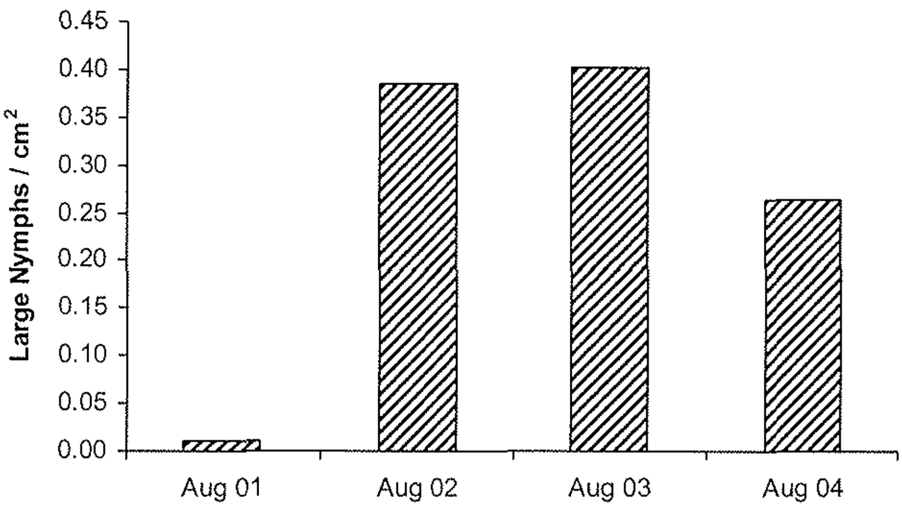


Fig. 9. Mean density of SLW large nymphs on weeds (sowthistle) in August over four consecutive years.

Summer crop hosts including sunflower, peanut, pulses (soybean, navy bean, Dolichos, adzucki bean) planted after cotton (December – February) in and around the Emerald irrigation area served as transitional hosts and sinks for SLW populations dispersing from finishing cotton crops in January and February. Sunflower and other crops as far away as 100 km from the irrigation area were colonized by SLW dispersing downwind from cotton in mid summer each year. Generally, sunflower and soybean were most attractive to dispersing SLW whereas lucerne and peanut were the least attractive in terms of colonization and population growth (Fig. 11).

From a strategic perspective, the population dynamics data presented above clearly indicate that sustainable regional management of SLW cannot be successful without an integrated cropping system and key factor approach. Containment and control of SLW in CQ on cotton is the only approach with the potential to neutralise the threat to the non-cotton cropping industries in the region.

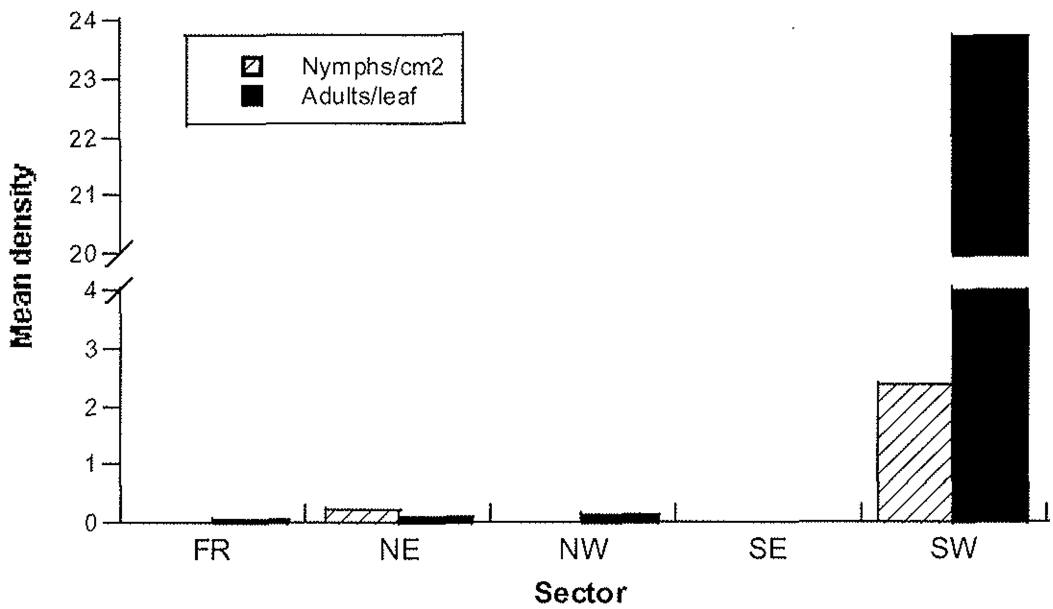


Fig. 10. Mean sector-wide density of SLW large nymphs and adults on sowthistle weeds in August 2003.

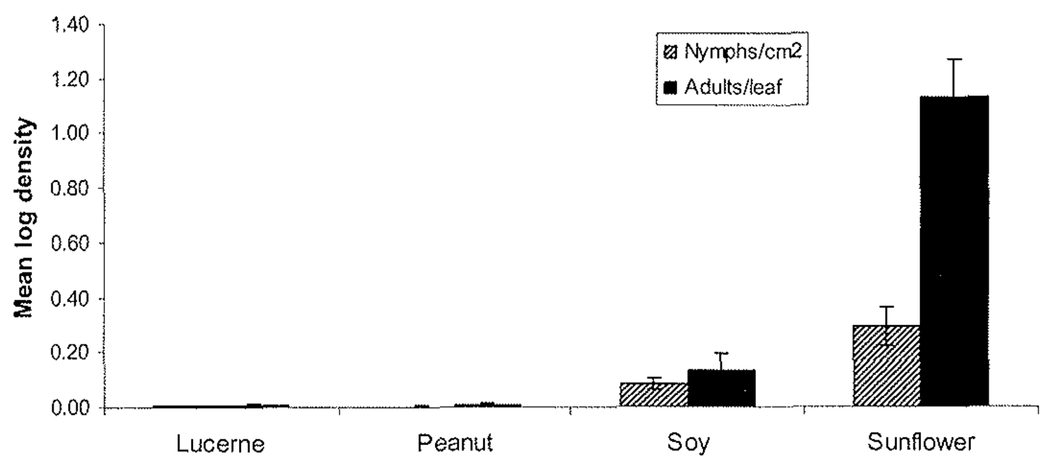


Fig. 11. Mean SLW densities on some non-cotton crops grown in and around the Emerald irrigation area in the 2002/03 growing season.

3.2.2 Population regulation - parasitism

The post-outbreak (2001/02) crash in overall SLW abundance and subsequent 'stability' of the population dynamics profile in CQ (Fig. 4) was due in large part to natural mortality caused by beneficial arthropods and environmental factors. Whilst SLW is attacked by numerous predatory and parasitic arthropods worldwide, aphilinid wasps from the genera *Encarsia* and *Eretmocerus* are among the most important in terms of natural or augmented biological control (De Barro 1995).

SLW sampling and collections over several years by Queensland Department of Primary Industries & Fisheries staff in the main grain cropping areas of Queensland have revealed the presence of at least 12 species of *Encarsia* and 3 species of *Eretmocerus* that are native to Australia (Dr. B. D. Franzmann, unpublished data). A comprehensive assessment of natural mortality of SLW in CQ was beyond the scope of this project. Parasitism by *Encarsia* and *Eretmocerus* species was assessed as a means of quantifying general trends in the activities of natural enemies of SLW in all CQ crops included in the population dynamics study (previous section). In view of the questionable taxonomic status of many of these species, parasitoid activity was assessed only at the generic level.

Materials & Methods

Following the same general protocol used to estimate SLW abundance (see previous section) in cotton and other field crops, a set of 30 leaves harbouring large nymphs (3rd and 4th instars) was collected from each GPS tagged site for examination under a microscope to determine the level of parasitism. The leaves were excised from randomly selected plants, one leaf from the bottom half of each plant. Leaf samples from sowthistle weed stands varied from 15-30 leaves, depending on the availability and size of the stands. The status of each large nymph (parasitized or healthy) was recorded along with the generic identity of the immature wasp discernible through the transparent integument of the nymph.

Results & Discussion

Parasitoid activity in cotton varied among seasons. Parasitism levels increased dramatically during the 2002/03 season, with >90% parasitism recorded in some fields (Fig. 12 A). Parasitism levels were substantially lower in the following two seasons. The differences in parasitoid activity among seasons can be attributed in part to pest management practices targeting sucking pests and *Helicoverpa* spp. A rapid build-up of parasitoid activity in cotton fields in 2002/03 is likely to have been facilitated by a voluntary move by Emerald cotton growers to minimise insecticide usage in cotton for management of other pests relative to the preceding outbreak and earlier seasons. The next two seasons were marked by higher sucking insect and *Helicoverpa* pressure, which resulted in increased insecticide usage early and mid season, accompanied by markedly lower levels of parasitism (Fig. 12 A).

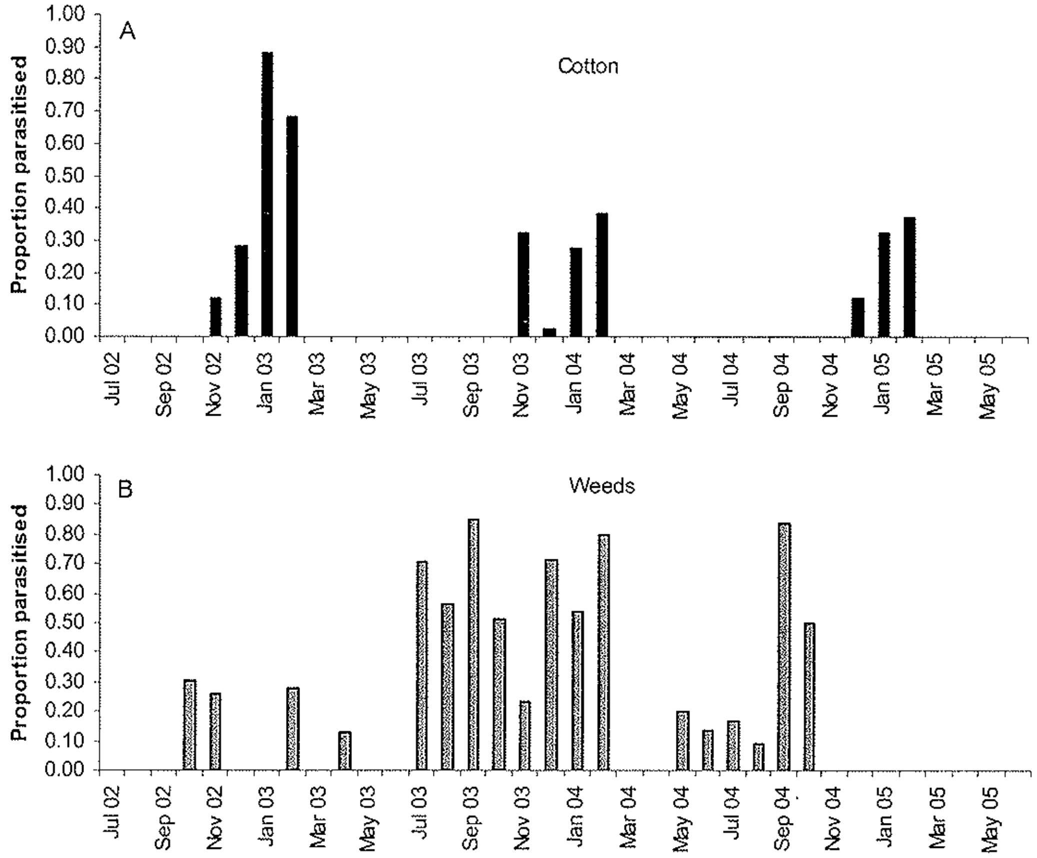


Fig. 12. Temporal fluctuations in mean proportion of large SLW nymphs parasitised on cotton (A) and weeds (B) in the Emerald Irrigation Area.

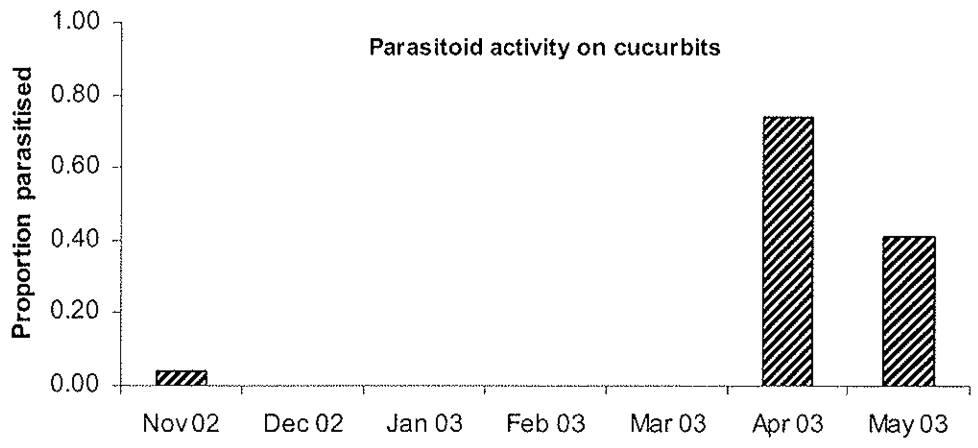


Fig. 13. Temporal fluctuations in mean proportion of large SLW nymphs parasitised on cucurbitaceous crops in the Emerald Irrigation Area

In contrast to the irrigated cotton scenario, parasitism of SLW on weeds in 03/04 and 04/05 fluctuated in tandem with the survival of weed stands under severe drought conditions experienced during these two seasons (Fig. 12 B). In both seasons, parasitism levels >90% were recorded at times in stable weed patches. These results suggest the potential for very high levels of parasitism by native aphelinid wasps in chemically untreated stands of certain host plants, including some crops. It follows that the SLW management challenge in crops such as cotton arises mainly from the need to manage other insect pests and the impact of insecticide usage on beneficial insect communities.

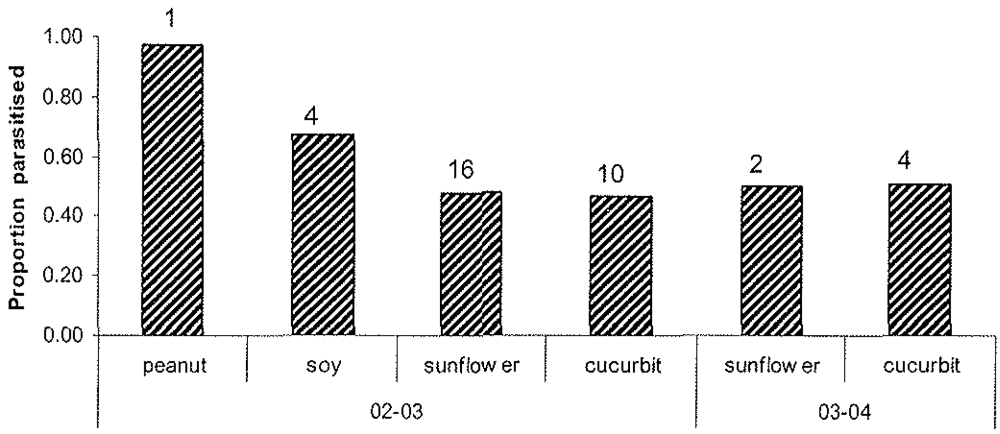


Fig. 14. Mean proportion of large SLW nymphs parasitised on cucurbit, grain, pulse and oilseed crops in the Emerald Irrigation Area. Number of sites sampled is shown at the top of each bar.

Parasitism of SLW on cucurbitaceous crops varied with time of year and availability of host plants (Fig. 13), sometime reaching levels >80%. In grain, pulse and oilseed host crops, levels of parasitism varied with the time of year and mode of colonisation. In crops that experienced a gradual build up of SLW, parasitism levels ranged from moderate to high (Fig. 14). Parasitism was particularly high in peanut although the crop did not appear to be particularly attractive to SLW. Wasp activity and parasitism were often found to be very low or negligible in crops (eg, sunflower and soybean) that experienced mass colonisation by SLW dispersing off cotton in mid summer.

3.2.3 Within-plant sampling distributions & Host preferences

In the first two years of the project, a number of field assessments were conducted at the Emerald Research Station to quantify host plant relationships, within-plant distribution and sampling aspects of SLW bionomics. These assessments were deemed vital for validation of overseas sampling protocols that were being used contemporaneously to quantify SLW area-wide spatial and temporal population dynamics, and to determine the risk to various field crops industries under CQ environmental conditions.

(1) Multi-crop assessment

Materials & Methods

Six crop host plant species *viz*, cotton (*Gossypium hirsutum* L. cv 'Delta Topaz'), lablab (*Lablab purpureus* (L.) Sweet cv 'Koala'), Mungbean (*Vigna radiata* (L.) R. Wilczek cv 'Emerald'), sesame (*Sesamum indicum* L. cv 'Edith'), soybean (*Glycine max* (L.) Merr. cv 'Jabiru'), and sunflower (*Helianthus annuus* L. cv 'Advantage') were compared with respect to SLW within-plant distributions, host plant preferences and colonisation success. Field plots of each host plant measuring 8 m x 5 m were laid out in a fully randomised design with three replicates.

Sampling of all crops began five weeks after planting. The first assessment was focussed on quantifying the distribution of SLW along the main stem to determine optimal sampling locations for each plant species. Vegetative branches and peripheral foliage was important only for cotton plants and were ignored in this study (but see following section). SLW adults and large nymphs were counted on the underside of each whole main stem leaf (all leaflets of trifoliate legume leaves) at every node, from 10-20 plants in each replicate. Subsequent assessments aimed at determining relative host preferences and changes in within-plant distribution over crop growth were based on a 3.88 cm^2 disk area (placed on middle leaflet of trifoliate legume leaves).

Results & Discussion

SLW nymph and adult distributions within plants (Fig. 15 A-D) varied among plant species and between growth stages. Adult SLW were usually found in the top half of the plant, feeding on the younger leaves, whereas large nymphs were concentrated around the middle or in the lower half. Compact distributions were associated with short-season, determinate species (mungbean, soybean), characterised by one or two 'most infested' nodes around the middle of the plant (Fig. 15 C, D). On sunflower SLW nymphs were found predominantly in the bottom half whereas adults were distributed evenly along main stem leaves (Fig. 16), reflecting the rapid growth rate and large size of this crop plant.

The relative attractiveness of each crop plant species to SLW was assessed in terms of mean egg density as an indicator of adult oviposition preference. The plant species tested fell into two preference categories. The highest egg densities were recorded on soybean and lablab (Fig. 17), confirming the status of the former as being among the most SLW susceptible field crops. Significantly fewer eggs were laid on cotton, mungbean and sunflower (ANOVA, $P < 0.001$).

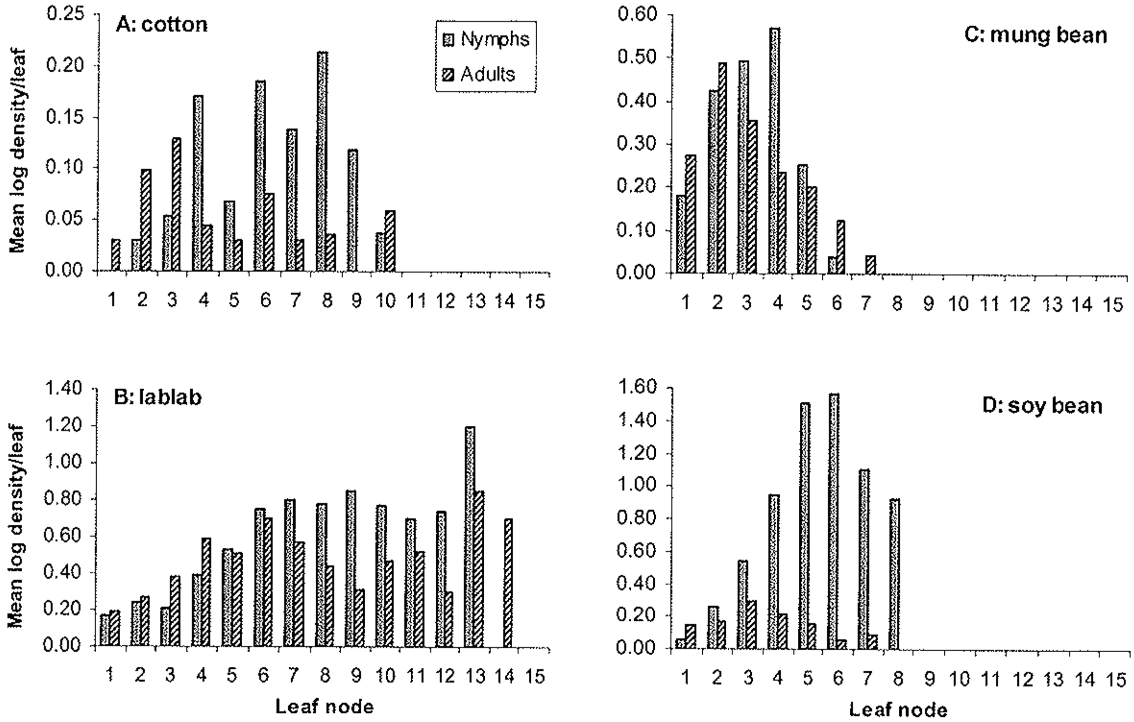


Fig. 15. Distribution of SLW nymphs and adults along main stem leaves of (A) cotton, (B) lablab, (C) mungbean, and (D) soybean.

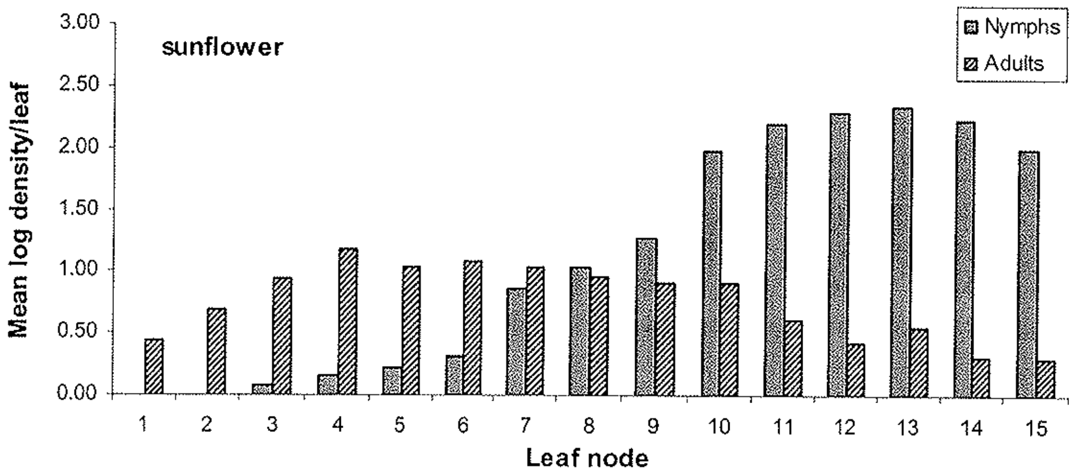


Fig. 16. Distribution of SLW nymphs and adults along main stem leaves of sunflower.

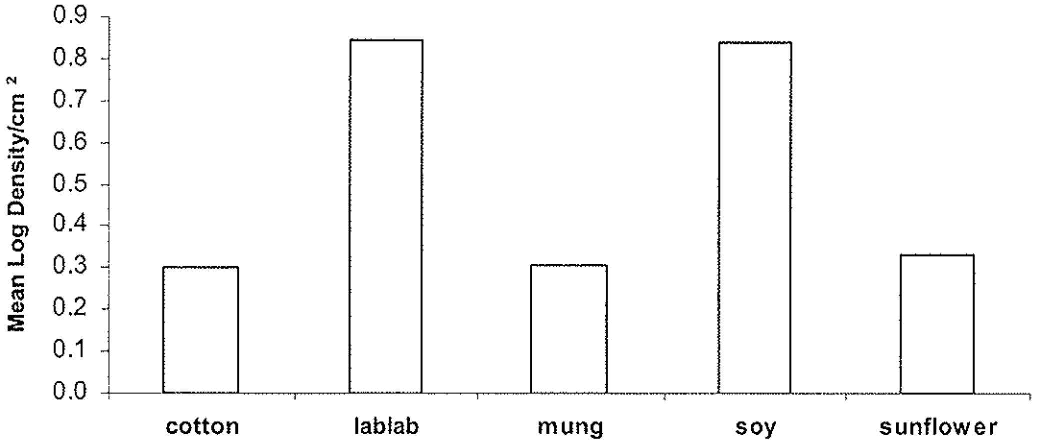


Fig. 17. Mean egg density as an indicator of SLW adult oviposition preferences when given a choice of crop host plants under field conditions.

The nymphal transition index (Moore et al. 2004) defined as the ration of large nymphs (instars III + IV) to small nymphs (instars I + II), was deployed as a means of quantifying relative host plant suitability for development of juvenile SLW stages among the five crop plant species tested (Fig. 18). Mungbean had the lowest (statistically significant, ANOVA P = .016) index value relative to the other crops, indicating poor survival of eggs and early instars. The index value for cotton was the second lowest, indicating less survival on this crop relative to lablab, soy and sunflower, although the differences were not statistically significant.

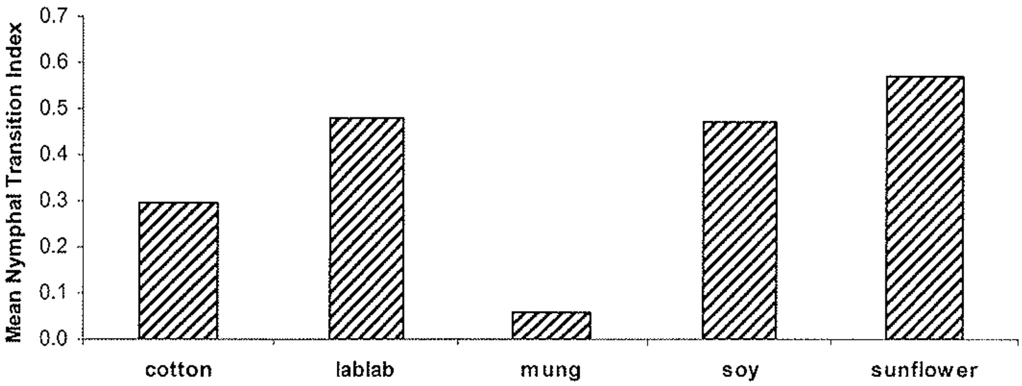


Fig. 18. Mean values of the Nymphal Transition Index defined as the ration of large nymphs (instars III + IV) to small nymphs (instars I + II), indicating relative survival of juvenile stages of SLW on various crop plant species.

The foregoing results are consistent with literature reports and field observations which indicate that cotton is neither highly preferred for oviposition nor a high quality host for juvenile development of SLW in comparison to many other plant species within the host plant range. The proven ability of cotton to host large populations and fuel the regional pest status of SLW stems from the intensity of cropping and the large areas under production rather than its suitability as a host plant. By comparison, mungbean is clearly a very poor host for juvenile development, in addition to being unattractive for oviposition. Therefore mungbean is the crop of choice for production in areas or cropping systems where SLW is an endemic problem.

(2) Mungbean cultivar screening

Materials & Methods

Five commercial mungbean varieties (White Gold, Emerald, Delta, Green Diamond and Berken) were evaluated for relative SLW preference and colonisation success (immature survival) in a randomised block design with three replicates. Each cultivar was allocated to one field plot of dimensions 8 m x 10 m on 1-m row spacing.

The most heavily infested node for sampling purposes was determined in the first assessment four weeks after planting. At each of nodes 1-6 (1= first unfurled leaf at the terminal) adult and large nymph numbers were counted on the whole leaf (10 leaves/node x 5 varieties x 3 replicates; middle leaflet of legume trifoliate).

Differential attractiveness to SLW and colonisation success (survival of immature stages) among varieties was the focus of subsequent assessments at six and eight weeks after planting. The number of large nymphs on the whole leaf (middle leaflet for trifoliate legume leaves) at nodes 2 and 3 were counted (20 plants/node x 5 varieties x 3 replicates).

Results & Discussion

The results of the multi-crop comparison showed clearly that mungbean has the greatest potential as a 'whitefly resistant' cropping alternative to susceptible legumes and other crops. However, commercial cultivars of any crop plant species can exhibit enormous levels of genetic variability for most phenotypic and physiological traits. This is reflected in the results of the mungbean varietal screening.

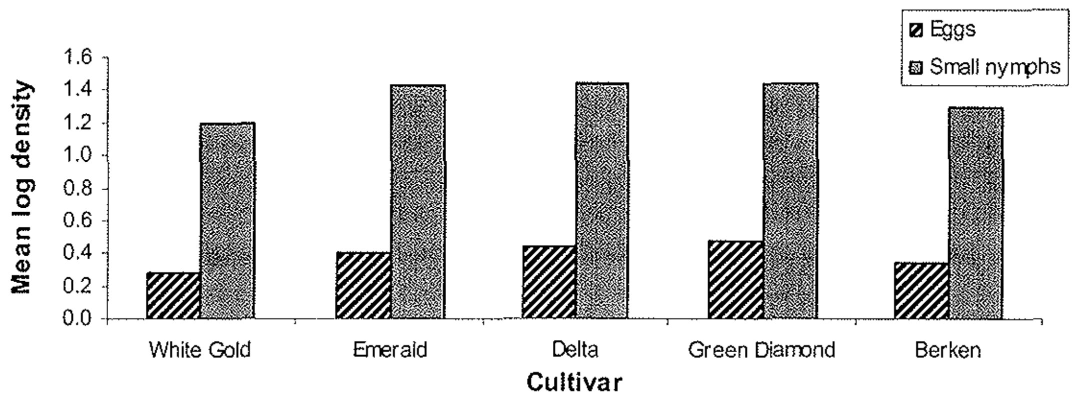


Fig. 19. Mean density (per cm^2) of SLW eggs and small nymphs on commercial mungbean varieties.

SLW egg and small nymph densities were not significant different among cultivars although White Gold had consistently lower densities of both than the others (Fig 19). This suggests that the cultivars tested do not differ significantly with respect to adult SLW oviposition behaviour.

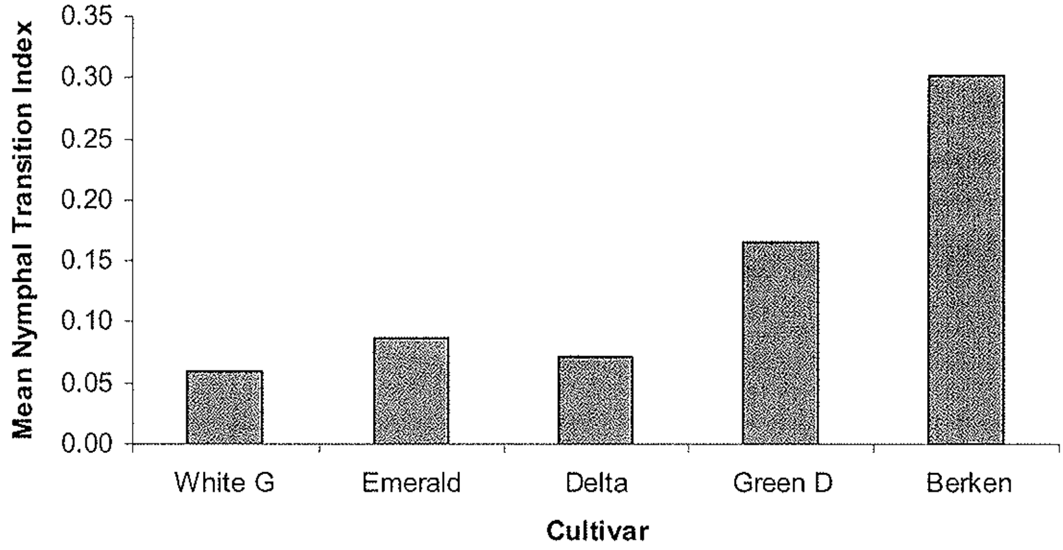


Fig. 20. Differential survival of SLW small nymphs on various commercial mungbean cultivars. See text for definition of Nymphal Transition Index.

There are, however, significant differences between cultivars with respect to survival of early juvenile stages through to the fourth instar (red-eye nymph) stage (Fig. 20). White Gold, Emerald and Delta had significantly lower values of the Nymphal Transition Index, indicating poor survival of early instars on these cultivars. The factors underlying deferential juvenile mortality among mungbean cultivars and generally lower survival on this crop plant relative to other crop species have not been investigated.

(3) Navy bean cultivar screening

Materials & Methods

In September 2003, a field trial conducted by Bean Growers Australia to determine the feasibility of growing navy beans in early spring was monitored for SLW infestation. Four commercial navy bean varieties (Spearfelt, Sirius, Rainbird and Actolac) were evaluated for relative SLW preference and colonisation success (immature survival) in a randomised block design with three replicates. Each cultivar was allocated to one field plot of dimensions 4 m x 5 m on 1-m row spacing.

SLW juvenile stages (eggs and nymphs) were recorded every 10-12 days at four sampling times during the life of the trial, beginning at four weeks after planting. One leaf was randomly selected from the middle of each of 30 plants randomly selected from each plot. The number of eggs and nymphal stages I-IV within a 3.88 cm^2 disk area were recorded.

Results & Discussion

Low crop vigour caused by adverse weather conditions precluded the successful completion of this trial, suggesting that spring production of this crop may not be viable in CQ. For these reasons, the SLW abundance monitoring aspect of the trial was also only partially successful.

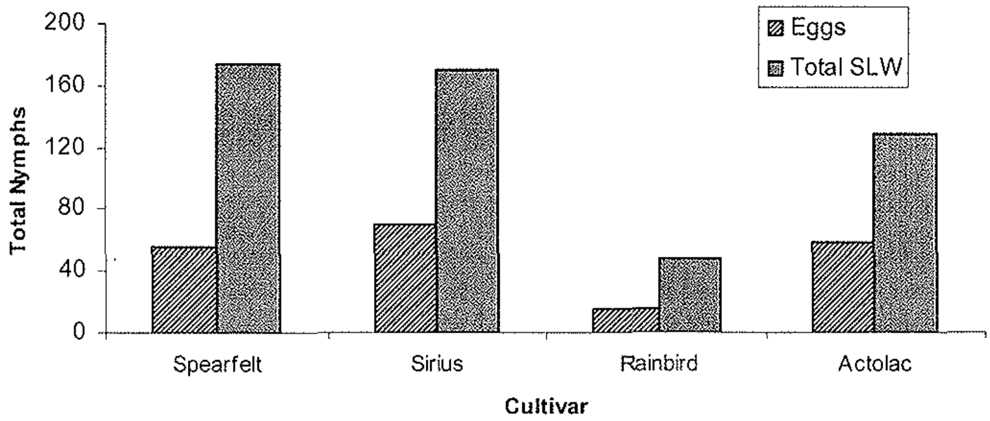


Fig. 21. Abundance of eggs and total juvenile SLW (all stages) on commercial navy bean cultivars.

The limited data available indicate the likelihood of differences between navy bean cultivars with respect to SLW affinity and possibly host quality for juvenile stages. Analysis of total SLW numbers (all stages) shows significant differences in density between Rainbird and the other cultivars (Fig. 21).

3.2.4 Sampling & management in commercial cotton

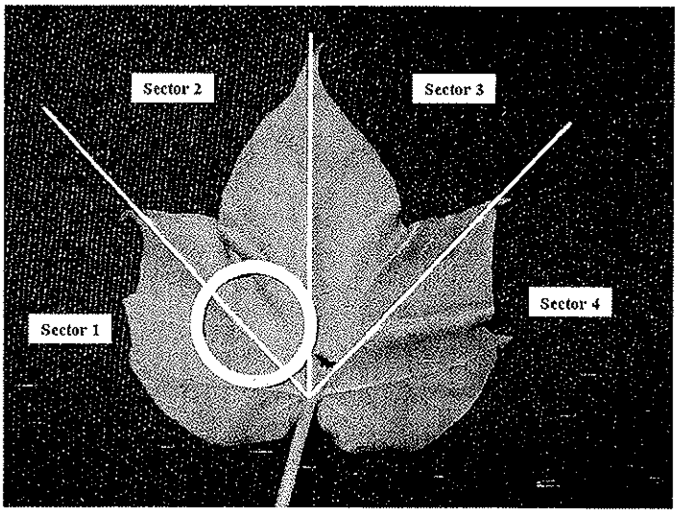
The SLW threat to cotton comes mainly from the sugary secretion (honeydew) of adults and nymphs feeding on the underside of leaves, although yield loss resulting from the feeding impact of large populations on the plant cannot be excluded. Honeydew deposits on open cotton bolls make the lint sticky and unmarketable. Due to the biological characteristics (small size, mode of feeding and reproductive potential) of this pest and the nature of damage to cotton, field control is normally based on population thresholds, as opposed to damage thresholds.

Following the area-wide outbreak in 2001/02, a SLW field sampling and management plan developed and used successfully in Arizona (USA) cotton crops (Ellsworth & Martinez-Carrillo 2001) was implemented in CQ cotton as a stop-gap measure until a strategy tailored to local crop management practices and environmental conditions was developed. Validation of the Arizona plan under CQ field conditions was a logical first step in the development of a local management strategy. Rapid adaptation of the highly successful Arizona plan to CQ conditions would circumvent the need for innovation with regard to SLW management.

Briefly, the Arizona SLW management plan involves use of highly effective and well-timed insecticides (insect growth regulators) based on accurate population estimation (sampling) anchored within a broadly based integrated pest management framework (Naranjo & Flint, 1994, 1995; Naranjo et al. 1997). The timing of insecticide application is guided by the use of population thresholds at which maximum efficacy of control is expected. In Arizona cotton crops, chemical intervention is recommended when SLW population density is at or above a dual threshold of 3 adults per leaf and 1 large nymph per disc ($3.88cm^2$) at the 5th main-stem node (1^{st} fully unfurled terminal leaf = node 1).

Materials & Methods

SLW nymphal distribution parameters on individual leaves, whole plants and within crops that form the basis of sequential and binomial sampling plans underpinning the Arizona management plan (references) were estimated, along with alternative parameters, from dedicated sampling activities conducted in 2003/04 and 2004/05. Samples of 15-30 whole plants were collected from crops of varying ages and at several sites (fields). Every leaf from each plant was carefully scrutinised in the laboratory to estimate total plant populations of SLW and to characterise the distribution of large SLW nymphs at several main stem node and lateral leaf locations. Parameters of theoretical probability distributions fitted to the data were used to test the fit of Arizona sequential and



Cotton leaf showing a sampling disc and 4 sectors demarcated by the major veins binomial sampling schemes and possible alternatives to local SLW abundance patterns. The 2002/03 and 2003/04 population dynamics data on SLW in cotton (Section 3.2.1) were used to examine the mechanics of some aspects of SLW management in CQ cotton crops according to the Arizona management guidelines and in parameter validation.

Results & Discussion

From a pest management perspective, the principal objective of sampling is to obtain an estimate of pest population density with the least effort (time and resources) and the greatest possible accuracy (Pedigo 1994). Due to their sessile nature, the spatial distribution of juvenile SLW on the plant mirrors adult activity. Sampling of juvenile stages also provides a more accurate estimate of total population density than sampling the highly mobile adults. Nevertheless, sampling SLW in the field is laborious and time consuming, particularly for the nymphal stages. For these reasons, under the Arizona management plan, SLW density in the field is estimated using a two-step process that is underpinned by a number of assumptions and statistical relationships.

In the first step, SLW density on the whole plant is estimated from the density on a single main stem leaf, most appropriately the one with the least variation in insect counts over time (lowest coefficient of variation). In Arizona crops, the 5th main stem leaf consistently harbours the greatest concentration of nymphs and adults ('most-infested' leaf) over time, with the lowest coefficient of variation, making it the sampling unit of choice. In CQ crops there does not appear to be a most-infested leaf (Fig. 22 A) or one with the lowest variability in nymph densities (Fig. 22 B).

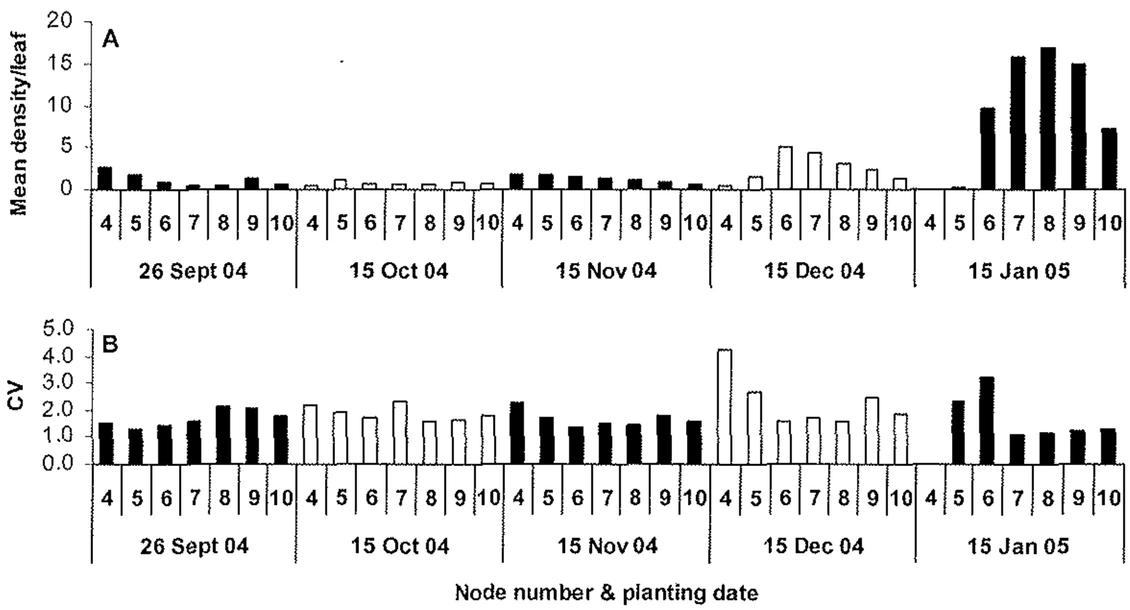


Fig. 22. (A) Mean density of SLW large nymphs on main stem node 4-10, and (B) the Coefficient of Variation (CV = SD/Mean) for each node in cotton crops planted at different time.

The second step in estimating field density is designed to further minimise sampling time. SLW nymph density on the 5th node leaf is estimated from counts within a 3.88 cm^2 disc, thereby circumventing the need for obtaining whole leaf counts. In Arizona cotton crops, a strong positive correlation ($R^2 > 0.77$ among cultivars) between leaf disc counts and the corresponding whole leaf counts underpins the nymph sampling strategy (Naranjo & Flint 1994). By comparison, in CQ crops disc counts are not correlated or at best very weakly so with the corresponding whole leaf counts of large nymphs (Fig. 23 A). This indicates that the leaf disc method for estimating SLW nymphal densities in CQ cotton may not only be inadequate but also unreliable. A strong positive correlation between counts from distal leaf sectors (2 or 3) and the corresponding whole leaf counts (Fig. 23 B) indicates the suitability of the former as a substitute for the leaf disc in estimating SLW abundance in CQ cotton.

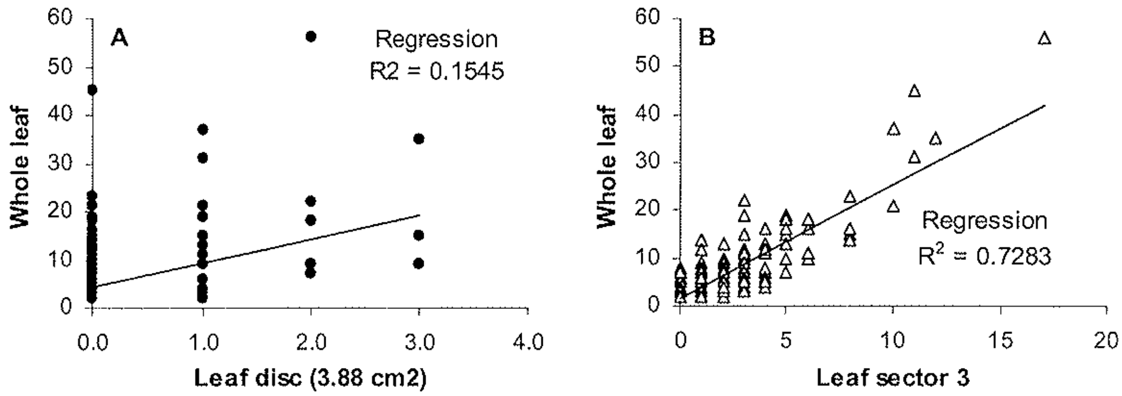


Fig. 23. The correlation of SLW large nymph counts on the whole leaf with (A) counts within a leaf disk (3.88 cm^2), and (B) counts within leaf sector 3 at the 5th main stem node.

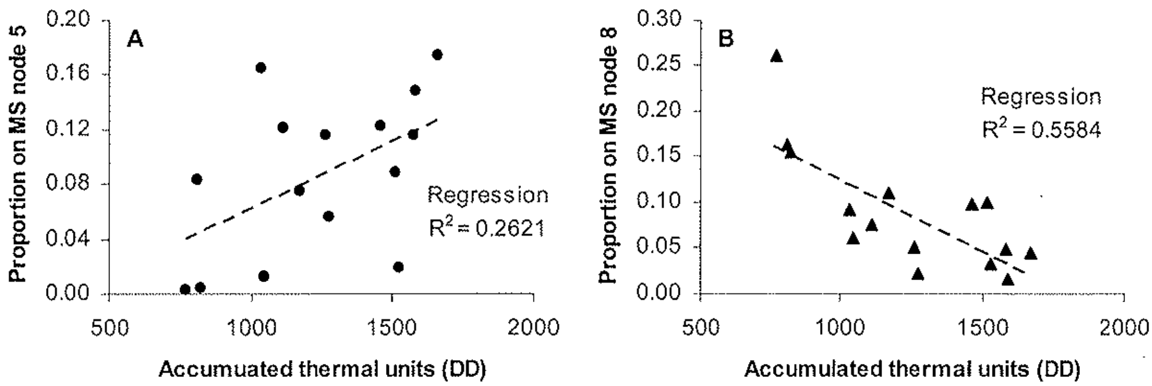


Fig. 24. Proportionality between counts of SLW large nymphs on the whole plant and indicator leaves at nodes 5 and 8 (A and B, respectively).

Accurate estimation of SLW abundance on the whole plant from 5th node (or any other node) indicator leaf counts depends on the premise that the proportionality between whole plant and indicator leaf counts either remains relatively constant or changes in a predictable direction with plant age. The position of the most infested leaf varies by just over 1 node over a span of 1400 degree days (12.8/30 °C) in Arizona crops (Naranjo & Flint 1994), indicating the stability of the proportionality between whole plant and indicator leaf counts.

In CQ crops, 5th node leaf counts of large SLW nymphs represent a highly variable proportion of whole plant counts (Fig 24 A). The proportionality between 8th node leaf and whole plant counts of large nymphs is mathematically more tractable (Fig. 24 B). This suggests that the 8th main stem leaf may be a better sampling unit than the 5th node leaf in CQ crops.

The foregoing results collectively indicate that the Arizona sampling plan will not facilitate accurate population estimation in CQ cotton crops without significant modification and recalculation of parameters.

4.0 General discussion & future directions

Since its introduction in the late 90s, Bt (GM) cotton technology has rapidly become the corner stone of IPM in the cotton industry. Whilst second-generation Bt cotton (Bollgard II®) varieties offer outstanding control of most caterpillar pests, they still require insecticide application for sucking pest management. Development of resistance to the Bt transgenes in *Helicoverpa* populations remains the biggest threat to Bt cotton. Ensuring the long-term viability of Bt cotton technology will require new, comprehensive IPM approaches that provide cost-effective control of sucking pests and minimise *Helicoverpa* selection pressure. The *Helicoverpa* research outputs of this project indicate the potential for such a novel approach to IPM by exploiting host plant selection and behaviour of insect pests by crop canopy manipulation. The outputs reported here raise more research questions than they answer. The canopy manipulation technique warrants further analytical experimentation in the field.

The results and conclusions presented in this report clearly point to the pivotal role of cotton as the driver of SLW pest status in the CQ region. From a cropping system perspective, successful management of the pest in cotton crops could be defined as the prevention of a population build up and dispersal to other susceptible crops at the end of the cotton season. In view of the marginal monetary returns from broadacre sunflower and legume crops, insecticidal control of SLW control on these crops is not economically viable and therefore unrealistic. However, control of SLW on crops such as sunflower may not always be warranted. Sunflower can tolerate moderate to high densities of SLW provided infestation does not occur in the very early seedling stages. It is still unclear whether or not SLW feeding has a physiologically adverse impact resulting in yield and/or quality decline in sunflower. This important issue was beyond the scope of DAQ 120C primarily due to resource (glass house, etc) limitations and remains a future priority. From a broader perspective, however, the best hope for management of SLW on non-cotton crops in CQ is successful management in cotton.

Management of SLW in cotton currently relies on population estimation guidelines from overseas protocols that need to be modified and adapted to CQ crop phenology, insect population dynamics and environmental factors. As results and discussion in the preceding section have shown, the overseas protocols are readily applicable in principle but not in practice. In this regard, knowledge gaps and potential research targets (*eg*, alternatives to Arizona SLW sampling parameters and protocols) have largely been identified through the outputs of this project. The development of locally relevant sampling plans and intervention thresholds will be a priority for successful management of SLW in CQ cotton.

5.0 Relevance to CRDC outputs – Sustainability, Profitability & Communities

Sustainability

Bt cotton technology is 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. Whilst second-generation Bt cotton (Bollgard II®) varieties offer outstanding control of most caterpillar pests, they still require insecticide application for sucking pest management. Development of resistance to the Bt transgenes in *Helicoverpa* populations remains the significant threat to Bt cotton. Ensuring the long-term viability of Bt cotton technology will require new, comprehensive IPM approaches that provide cost-effective control of sucking pests and minimise *Helicoverpa* selection pressure. The *Helicoverpa* research outputs of this project indicate the potential for such a novel approach to IPM that exploits host plant selection and behaviour of insect pests by crop canopy manipulation.

SLW is currently the most significant immediate threat to the viability of cotton in CQ. The futility of traditional reliance on chemical insecticides for the control of this pest has been amply demonstrated during the 2001/02 outbreak in CQ when insecticidal control failed. Successful control on SLW in cotton requires smart science and integration of cultural, biological and chemical tactics. This project has provided a detailed understanding of the organism's fit with its environment, which is the basis of all successful and environmentally responsible management solutions.

Profitability

The outputs of this project are linked to increasing profitability at the farm gate and beyond. Application of insect growth regulator (IGR) products (eg, Admiral®) for SLW control in cotton, currently costing $100 per hectare, is a highly significant cost of production. Sticky lint resulting from whitefly activity is the greatest risk to profitability of the CQ (and, by association, national) cotton industry. Quality discounts, rejection of Australian cotton due to stickiness of lint and negative marketing sentiment will inevitably result in crippling financial losses to growers and the regional economy.

The project has identified knowledge gaps and inadequacies in current SLW management practices in CQ that underpin profitability in terms of costs of crop protection, marketability and environmental sustainability in the region. The outputs of the project have identified potential solutions that will help to address these deficiencies, facilitate maximum uptake of new technology such as Bollgard II and minimise variability of production/profitability, thereby ensuring the long-term survival of the cotton industry in CQ.

Communities

The project's outputs will facilitate reductions in community impacts of production through improved quality of life for town residents as a result of reduced insecticide usage and associated drift, contamination and chemical odour problems.

6.0 Likely impact of the research project for the cotton industry

The results and conclusions presented in this report clearly point to the pivotal role of cotton as the driver of SLW pest status in the CQ region. From a cropping system perspective, successful management of the pest in cotton crops could be defined as the prevention of a population build up and dispersal to other susceptible crops at the end of the cotton season. Prior to this project, there was little or no information and data on the field ecology of SLW in field crops in Australia. This paucity of knowledge severely restricted the ability of crop protection and management specialists to combat the SLW pest problem, particularly in cotton. The project has developed a comprehensive body of information and protocols that will be now be useful to cotton and other field crops production systems beyond CQ and Queensland.

From a cotton perspective, the findings of this project serve to flag the risk in the use of overseas protocols without modification or adaptation to local production and biotic parameters. The outputs provide guidelines for the development of new protocols and guidelines tailored to Australian conditions for sampling and population estimation in cotton.

7.0 Follow-up research requirements

The development of locally relevant sampling plans and intervention thresholds will be a priority for successful management of SLW in CQ cotton.

It is still unclear whether or not SLW feeding has a physiologically adverse impact resulting in yield and/or quality decline in sunflower. This important issue was beyond the scope of DAQ 120C primarily due to resource (glass house, etc) limitations and must be considered a future priority.

8.0 Literature cited

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9.0 List the publications arising from the research project

The outputs of DAQ 120C will be compiled into a monograph on SLW field ecology that will be published as a QDPI&F/CRDC Technical paper.

A minimum of three refereed publications are expected within 18 months of project completion.