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DEFINING AN INTEGRATED PEST MANAGEMENT (IPM) SYSTEM FOR INGARD® COTTON IN NORTH-WESTERN AUSTRALIA

A JOINT PROJECT OF

DEPARTMENT OF AGRICULTURE, WESTERN AUSTRALIA
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DEFINING AN INTEGRATED PEST MANAGEMENT (IPM) SYSTEM FOR INGARD® COTTON IN NORTH-WESTERN AUSTRALIA

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Acknowledgments

The cotton research project in the Kimberley has been a major collaborative effort that has benefited from the input of many individuals and organisations, some of whom are formally acknowledged here. Funding support from the Cotton Research and Development Corporation together with the Department of Agriculture has been fundamental to producing outputs and is gratefully acknowledged.

Commercial support from key industry groups including Monsanto, Cotton Seed Distributors and Colly Cotton have been very important to the project's success. Colly Cotton in particular had the vision and faith to commit resources to the construction of a small gin at Kununurra in partnership with the Ord River District Cooperative. This infrastructure enabled the participation of local farmers and the expansion of research to the paddock scale. This is an essential precursor to full-scale commercial development and has allowed realistic IPM systems research to be conducted. The expertise and commitment of Colly staff, especially David Farley, Kim Morison, Gary Coulton and Nick Gill are acknowledged as very important to overcoming the difficulties of initial years.

Several farmers have taken significant financial risks to produce IPM cotton with low economic returns due to the small scale and high cost structure of growing only a few hundred hectares of cotton. Wilhelm Bloecker and Torben Sass-Neilsen have been involved every season and strong support from Darryl Smith, Lindsay Innes, Michael Eppler, Barry Lerch, Pacific Seeds, Spike Dessert and Dave Menzel is also gratefully acknowledged.

Finally the research providers are acknowledged for their special efforts. Many organisations under the Cotton CRC banner have been enormously helpful and contributed to the research effort. There are too many to mention but certainly Greg Constable, Gary Fitt and Steve Yeates have contributed greatly along with all the Department of Agriculture staff dedicated to the cotton project, including Bob Shackles and the Frank Wise Institute staff. The local cotton project team including Amanda Annells, Andrew Dougall, Liz Green, Caleb Bailey, Margaret Rayner, Mark Weston and Maurie Darlington are acknowledged for their hard work and tireless efforts.

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BACKGROUND

Northern Australia offers potential for cotton industry development with an annual production value estimated to be $750M. However, past failures demonstrate the importance of rigorous industry planning and research to develop sustainable and ecologically sound management systems, particularly for insect pests.

CRDC funded a project (AWA.1C) to assess novel pest management systems in a tropical environment at Kununurra. Key features of the new system included winter cropping, INGARD® varieties, companion crops, insect food sprays and 'soft' chemicals. Preliminary results were very encouraging with on-farm yields averaging around 7.5 bales/ha with some paddocks over 9 bales/ha. IPM systems have showed promise with an average of less than four *Helicoverpa* sprays being required when using standard CottonLOGIC spray thresholds. INGARD® expression in the winter cropping season was consistently good with some paddocks not reaching *Helicoverpa* thresholds.

OBJECTIVES

Project AWA.2C aims:

1. to refine and enhance preliminary IPM systems for INGARD® in the Ord River Irrigation Area;
2. to involve farmers and monitor the test-farming of novel pest management strategies; and
3. to evaluate *Helicoverpa* thresholds in large scale trials

This report details the research conducted to achieve these project objectives.

IPM TEST-FARMING EVALUATIONS

The primary focus of this project is to develop sustainable, IPM based pest management systems for INGARD® in north-western Australia. Key elements for the system include companion crop utilisation, pest threshold refinement in winter cotton and appropriate refuge crop options for the development of a regional Bt resistance management strategy.

METHODOLOGY

The following describes the basic methodologies used throughout the project to achieve project objectives.

1. Seasonal pest abundance

There are four key lepidopteran pests that require careful management to achieve sustainable cotton production in the Kimberley. The pests are *Helicoverpa armigera*, *H. punctigera*, *Spodoptera litura* (cluster caterpillar) and *Pectinophora gossypiella* (pink bollworm). Each of these pests was recorded as being the most damaging pest in particular seasons during commercial cotton production at Kununurra during 1963-1974 (Michael and Woods, 1981).

The seasonal abundance of these pests was monitored in the Ord River Irrigation Area (ORIA) using a 6-site grid of pheromone traps, which were maintained throughout the year. The dry-funnel traps and pheromone dispensers were manufactured by AgriSense® and obtained from Dunluce International Pty Ltd. All traps were serviced weekly and moth numbers recorded. The pheromone lures were replaced every four weeks, as were the small pieces of Sureguard Pest Strip®, which were used as a killing agent in the funnels.

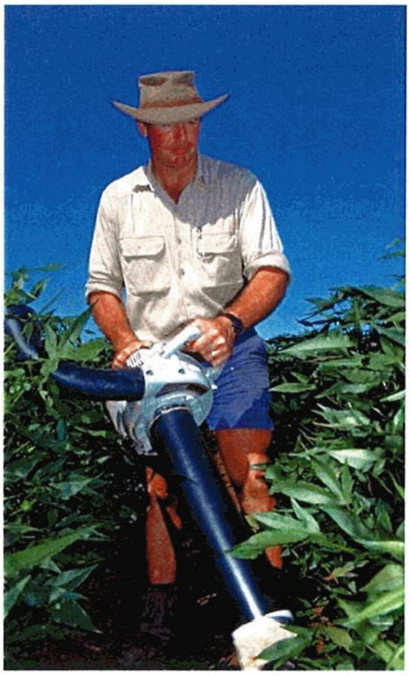
2. Pest pressure

All paddocks used in the IPM evaluations were scouted individually using CottonLOGIC protocols. Scouting occurred twice weekly, or more often if pest thresholds were close to being exceeded. All data were recorded so that individual paddock pest histories could be assessed.

3. Beneficial insect activity

In addition to CottonLOGIC data, more intensive data collection was used to measure the abundance of beneficial insect species in IPM cotton and supporting companion crops. All crops were suction sampled using Echo® blower-vac machines running on full throttle (air-flow approximately 10 m/sec). The resulting insect samples were immediately killed in the field using ethyl acetate killing bottles before being returned to the laboratory for processing. Each sample was collected by vacuuming 25 m row whilst walking at 1 m/second.

On rare occasions when time permitted, the samples were immediately sorted and the insect fauna identified and numbers recorded. However, generally the samples were sieved to remove extraneous material such as leaves and then frozen until time for processing became available.



1999 SEASON

Climate

Minimum temperatures during the growing season (April to September) were, on average, about one degree warmer each day than long term predictions. In spite of this there were 15 'cold shock' nights where temperatures were 11°C or lower. (Long-term averages predict 10.8 cold shock events at Kununurra but a record 30 cold shock nights occurred in 1967).

Maximum temperatures were almost identical to the long-term average despite a few quite cold days during mid-season. Figure 1 shows the 1999 seasonal temperatures relative to long-term means.

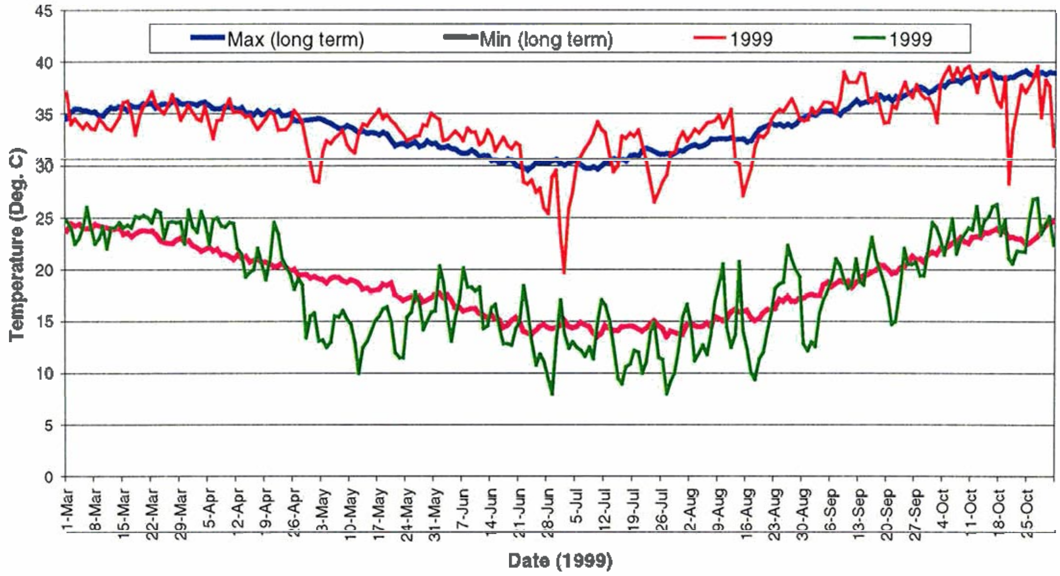


Figure 1. Minimum and maximum temperatures compared to long-term averages for the 1999 season at Kununurra.

Rain in March (265 mm) and over Easter (95 mm) hampered land preparation and delayed sowing from the target of late March/early April until the end of April and into May. The rainfall was approximately twice that expected from long-term averages. Late sowing limits the yield potential for the season and jeopardises fibre quality due to the increased risk of rain at picking.

Significant rainfall at the end of the season did not commence until 20 October but between then and 20 November, more than 200 mm was recorded. This seriously impacted on picking efficiency and caused quality downgrades.

Pest abundance

The seasonal abundance of the key lepidopteran pests, *Helicoverpa* spp. and *Spodoptera litura* is illustrated in Figure 2. *Spodoptera* moths were abundant most of the season and responsive to the late rain during Easter. Weekly trap catches exceeded 600 moths/week for much of the season but damage to cotton crops was minimal.

The abundance of *H. armigera* did not follow the expected pattern of low early abundance with a large peak in August/September. Instead, *H. armigera* peaked through May and then generally declined until the usual peak again in late September.

H. punctigera followed a similar pattern of abundance to that of *H. armigera* during the growing season including a high peak of abundance in May, suggestive of migration from outside the valley. The population was then erratic but generally more abundant than expected. Both *Helicoverpa* species recorded relatively high weekly trap catches.

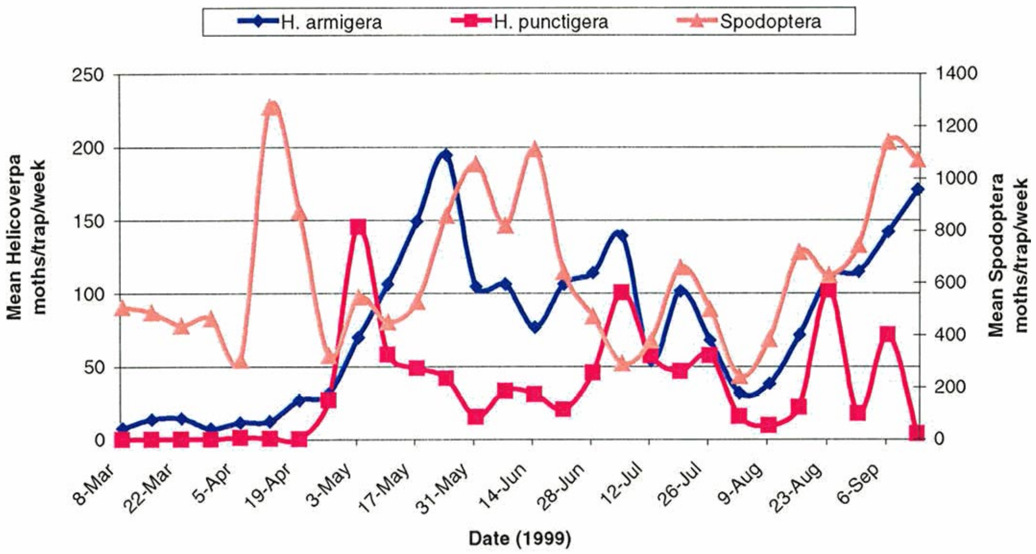


Figure 2. Seasonal abundance of *Helicoverpa armigera, H. punctigera* and *Spodoptera litura* in pheromone traps at Kununurra, 1999.

IPM trial treatments

Seven farmers participated in the large-scale IPM evaluation in the 1999 season and contributed a total of 20 paddocks that enabled replication of each of the systems under evaluation. Paddock size on farms ranged from 22 ha to 68 ha and smaller paddocks were also utilised on the Frank Wise Institute (FWI). The IPM treatments were essentially either INGARD® alone or INGARD® in combination with various companion crops as described below. The total area of the trials was approximately 900 ha.

1. Control

INGARD® cotton with a conventional spraying regime. Insecticide applications were applied when pests reached threshold as determined by CottonLOGIC. Soft chemistry was used for as long as possible followed by more conventional chemistries later in the season.

2. Lucerne

INGARD® cotton was grown with a lucerne companion crop. Lucerne strips (10.8 m wide) were placed every 300 metres (~ 168 beds). Insecticide applications were applied when pests reached threshold as determined by CottonLOGIC. Soft chemistry was used for as long as possible followed by more conventional chemistries later in the season.

3. Lucerne + Temik®

INGARD® cotton was grown with a lucerne companion crop, which was intended to be treated with Temik®. This treatment was designed to assess a 'trap and kill' approach for mirid control. Temik® was planned to be applied to the lucerne beds at a rate of 5 kg/ha. Other insecticide applications were applied when pests reached threshold as determined by CottonLOGIC. Soft chemistry was used for as long as possible followed by more conventional chemistries later in the season. (Equipment failures and other problems precluded the successful application of Temik® on these treatments, which effectively became additional replications of treatment 2).

4. Lablab

INGARD® cotton was grown with a *Dolichos lablab* var rongai (lablab) companion crop. Lablab strips (10.8 m) were placed every 300 metres (~ 168 beds). Insecticide applications were applied when pests reach threshold as determined by CottonLOGIC. Soft chemistry was used for as long as possible followed by more conventional chemistries later in the season.

Methods

All trials, except the six paddocks grown by Colly Cotton, were planted as two rows (80 cm apart) on 1.8 m beds, which is standard practice for other crops in the area. Colly planted their crops in the same way as they pant in eastern Australia, single rows spaced at 1 m. The target plant population was 9-11 plants/m row and this was generally achieved although plant establishment was uneven in some paddocks.

The standard variety used in all trials was Siokra L23*i*. Wherever possible, plots were separated from each other by at least 100 m in an effort to minimise pesticide drift and the confounding effects of inter-plot insect movements.

Standard pest thresholds contained in CottonLOGIC were used for all pest management decisions across all treatments. Insecticides were applied using ground rigs whenever possible but aerial application late in the season became mandatory when the crops grew too tall. Care was taken to ensure that spray conditions were suitable to avoid drift onto adjoining plots.

Yields were all estimated by gin output figures following commercial machine picking using a contractor with a four-row picker. (Yields were also estimated from single-row and hand harvest methods but these data are not presented here.)

Results and discussion

1. IPM assessments

Mean yields from all treatments were similar and reflected the very difficult growing season, which included a late start due to April rain and a very difficult picking situation with 200 mm of rain falling during harvest. Yields ranged from 4.38 to 7.73 bales/ha with a valley average of 5.85 bales/ha.

Table 1. The mean yields obtained from various treatments in the IPM trial at Kununurra, 1999.

Treatment[1]		Yield (bales/ha)
1.	Siokra L23*i* alone (no companion crop)	6.11 ± 0.35
2.	Siokra L23*i* + lucerne and IPM (soft) chemicals	5.45 ± 0.37
3.	Siokra L23*i* + lucerne + Temik®	5.71 ± 0.60
4.	~~Siokra L23 + lablab and IPM (soft) chemicals~~	~~6.13 ± 0.53~~
Valley average		5.85

[1] Due to failed Temik® applications, treatments 2 and 3 were effectively the same.

The main cotton pests at Kununurra are lepidopteran, including *Helicoverpa* spp., *Spodoptera litura* (cluster caterpillar), *Pectinophora gossypiella* (pink bollworm) and *Earias huegeli* (rough bollworm). The shift to a winter growing system was strongly influenced by the desire to minimise pest pressure from lepidopteran pests, especially pink bollworm and cluster caterpillar. These two pests, and others such as loopers, are known to be summer active and relatively rare in the cooler winter months. Cluster caterpillar is of special concern because the *Spodoptera* genus is known to be poorly controlled by INGARD®.

The winter growing strategy was successful in 1999 with no pink bollworm larvae being recorded on any plots, although low numbers of *Spodoptera litura* were evident throughput the season (Figure 3) but did not require specific control action.

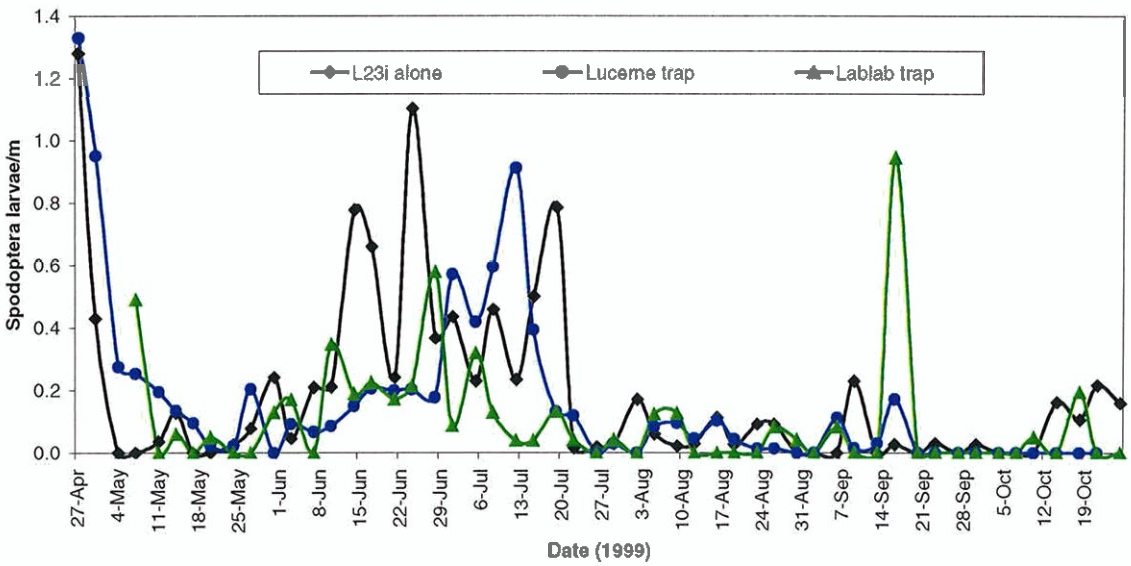


Figure 3. Mean *Spodoptera litura* larvae recorded on cotton IPM treatments at Kununurra, 1999.

Helicoverpa egg pressure for the 1999 season was relatively light, as indicated by the oviposition rates on the various treatments in Figure 4. These data indicate that peak oviposition was 12 eggs/m row and remained below 8 eggs/m for most of the season. The presence or absence of a companion crop did not significantly influence oviposition on cotton and trends in oviposition were seasonal rather than specific to IPM treatments.

Importantly, most *Helicoverpa* oviposition occurred in the early part of the season and tended to decline through the mid and late season. The abundance of threshold larvae was the reverse of this trend with threshold numbers appearing relatively late in the season as shown in Figure 5. This can be attributed to the performance of INGARD®, which effectively controlled early season lepidopteran pests.

Figure 5 also shows that larval numbers tended to be higher in the INGARD® alone treatments compared to IPM treatments that included companion crops of lucerne or lablab.

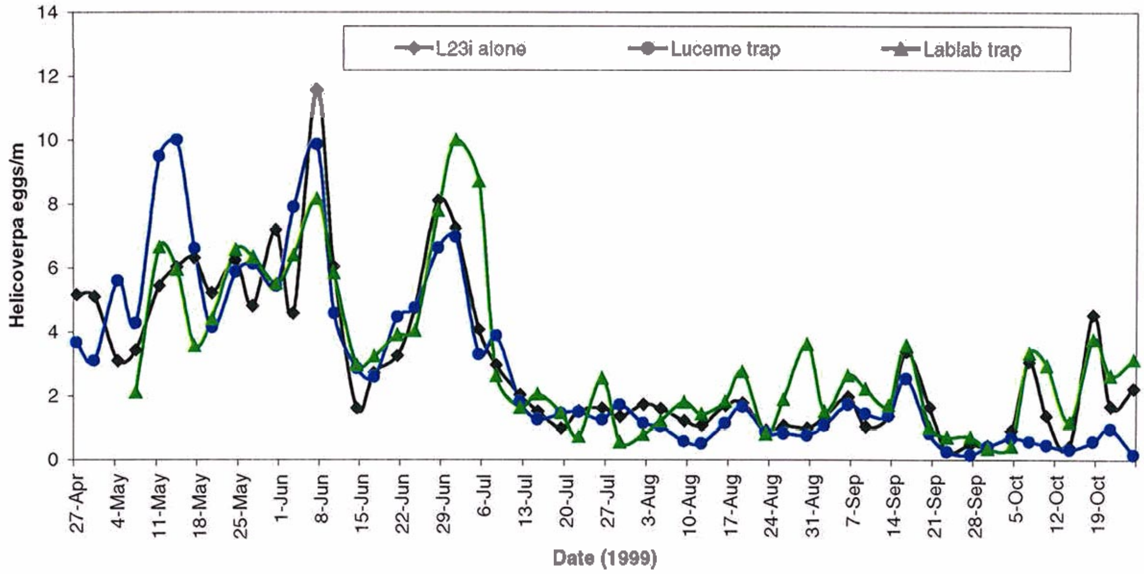


Figure 4. Mean *Helicoverpa* oviposition on cotton IPM treatments at Kununurra, 1999.

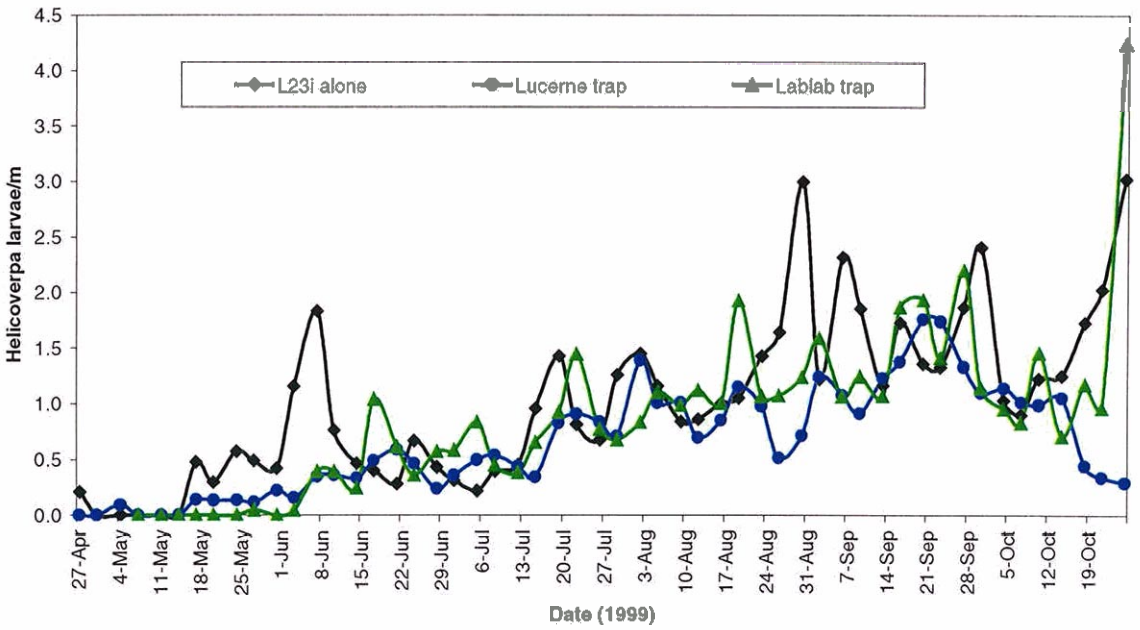


Figure 5. Mean number of threshold *Helicoverpa* larvae on cotton IPM treatments at Kununurra, 1999.

Table 2 summarises the insecticide requirements for each of the pest management treatments used in 1999. Mirids and aphids were in low abundance and most crops did not require insecticide applications for their control. The trend for fewer sprays on crops grown with a lucerne companion crop was observed this season.

Table 2. The mean number and purpose of spraying in the IPM trial, Kununurra, 1999

Treatment[1]	Mirid sprays	Heliothis sprays	Total sprays
1. Siokra L23*i* alone (no companion crop)	0.33	4.67	5.00
2. Siokra L23*i* + lucerne and IPM (soft) chemicals	0.25	3.50	3.75
3. Siokra L23*i* + lucerne + Temik®	0	3.67	3.67
4. Siokra L23*i* + lablab and IPM (soft) chemicals	0	4.50	4.50
Valley average	0.15	4.10	4.25

[1] All treatments were sprayed when CottonLOGIC thresholds were reached.
Due to failed Temik® applications, treatments 2 & 3 were effectively the same.

2. *Beneficial insect impact*

IPM systems are intended to increase the abundance of beneficial insects and thus create the opportunity for naturally occurring insects to assist in controlling pests. Regular suction sampling was used throughout the season to measure the abundance of beneficial insects in each of the IPM treatments being investigated. These data are summarised for predators (ladybirds, lacewings, big-eyed bugs, assassin bugs, hoverflies, etc.) and for parasitoids (*Trichogramma*, parasitic wasps, tachinids, etc.) in Figures 6 and 7 respectively.

The cumulative predators chart (Figure 6) shows that the number of predators in the INGARD® crops grown with companion crops were higher than those recorded from the INGARD® alone paddocks.

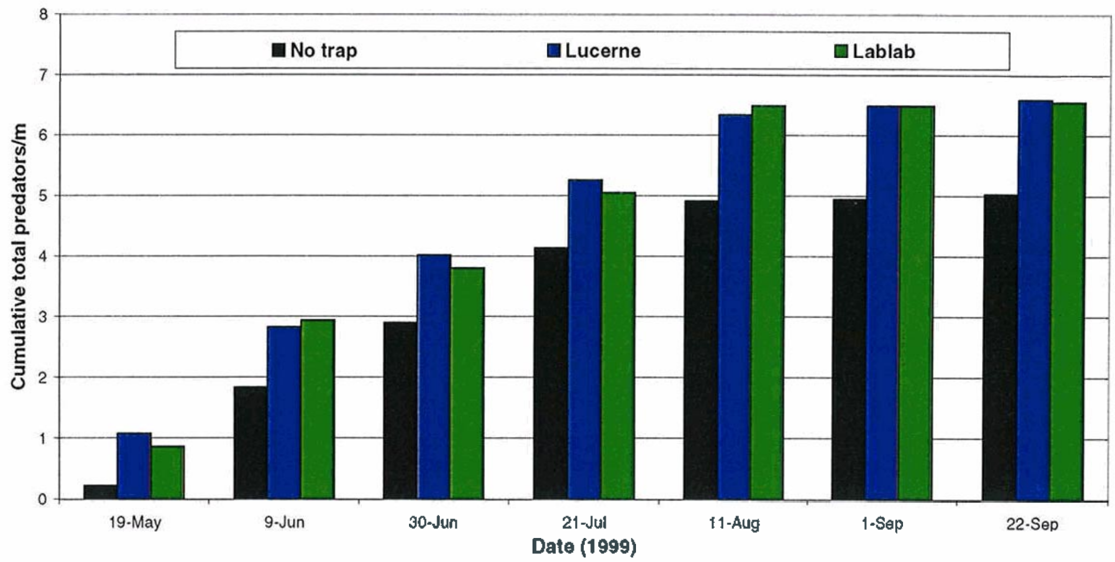


Figure 6. Total cumulative predators from suction samples in INGARD® cotton with or without companion crops at Kununurra, 1999.

The parasitoids (including ~~Trichogramma) followed the same trend as that seen for~~ predator abundance. The INGARD® treatment with the lucerne companion crop recorded the highest cumulative number of general parasitoids whilst the INGARD® alone cotton treatment had the least (Figure 7).

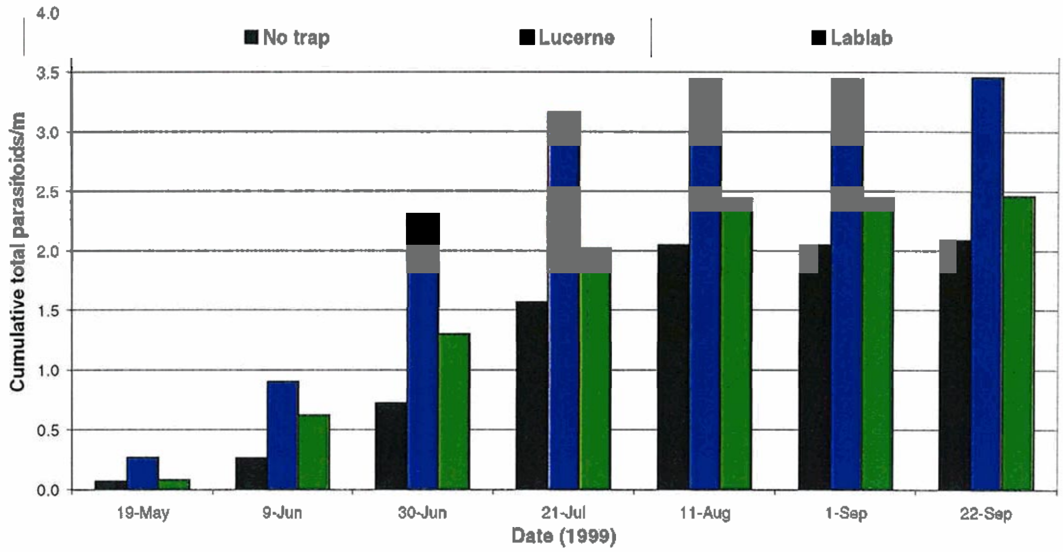


Figure 7. Total cumulative parasitoids from suction samples in INGARD® cotton with or without companion crops at Kununurra, 1999.

Trichogramma appear to be very robust in the Ord River Irrigation Area and have previously been observed to be virtually unaffected by insecticide applications (Strickland and Lacey, 1996). It is not known whether this phenomenon is associated with insecticide tolerance in the parasitoid or its capacity to rapidly reinvade sprayed crops from surrounding areas. Whatever the reasons, *Trichogramma* is an extremely important parasitoid of *Helicoverpa* spp. eggs in the area and maximising its effect is fundamental to successful IPM systems. Parasitism levels in *Helicoverpa* eggs are frequently around 70 per cent and in excess of 90 per cent on some occasions.

3. *Mirids and companion crops*

An important aspect of IPM systems being developed by Mensah (1997), Mensah and Khan (1997) and others in eastern Australia includes the use of lucerne strips as a trap crop for green mirids. Lucerne was also used in this trial and compared to lablab.

Mirids were not in high abundance during the 1999 season and mean total numbers (adults + nymphs) did not exceed 1/m in scouting data. Figure 8 shows the abundance of mirids in each of the IPM treatments. The most obvious conclusion from Figure 8 is that lablab appears to be an effective trap crop for mirids compared to lucerne or the INGARD® alone treatment. The performance of lucerne in this regard was disappointing but probably explained by the poor growth of the lucerne due to planting difficulties.

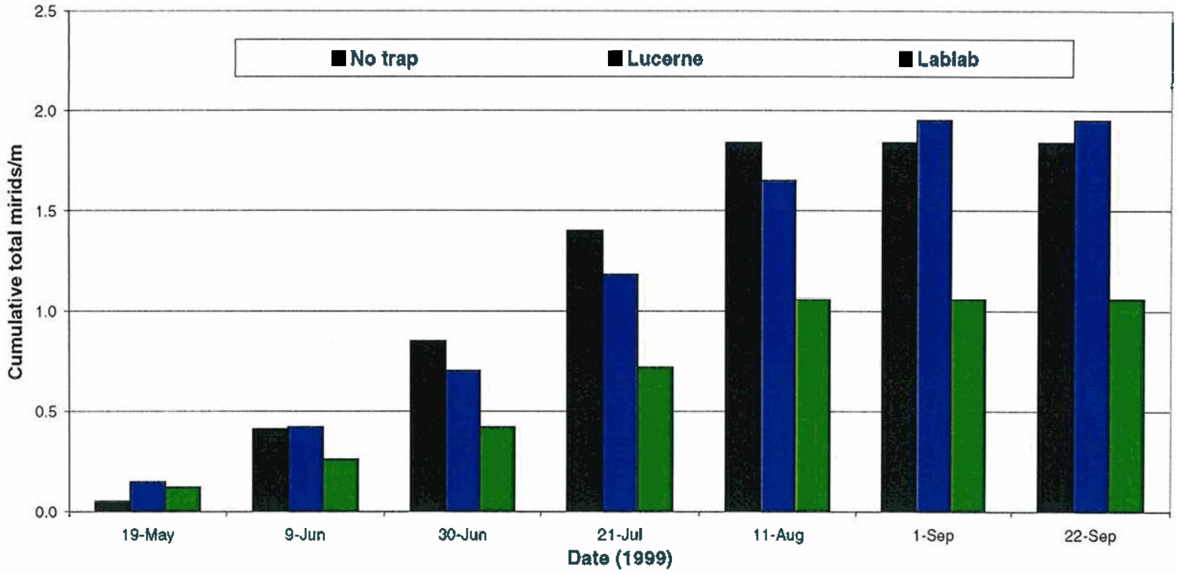


Figure 8. Total cumulative mirids from suction samples in INGARD® cotton with or without companion crops at Kununurra, 1999.

Cumulative mirid counts from the two companion crops themselves are shown in Figure 9. As expected from Figure 8, both lucerne and lablab trapped comparatively high numbers of mirids, but lablab was more effective.

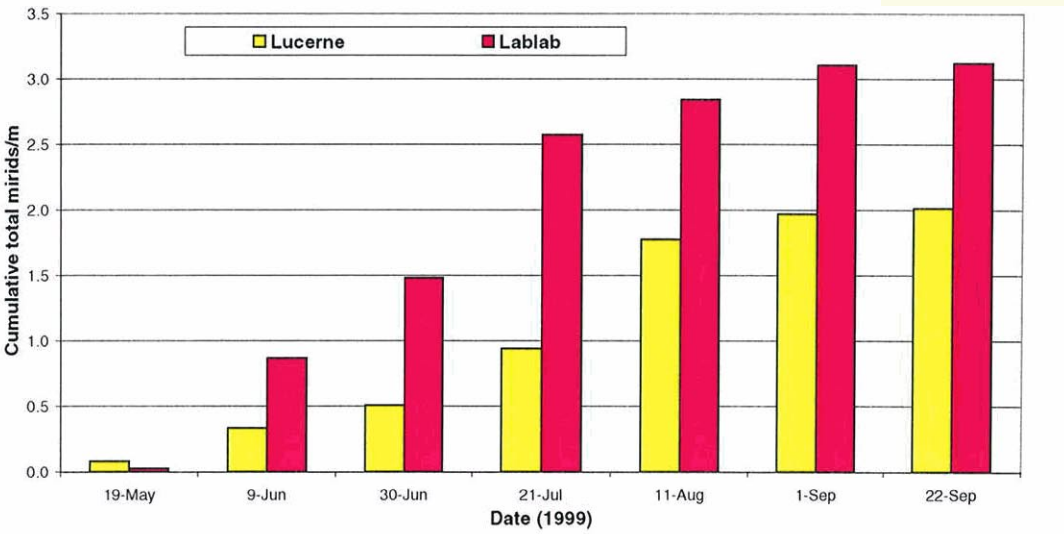


Figure 9. Total cumulative mirids from suction samples of trap crops near INGARD® cotton at Kununurra, 1999.

2000 SEASON

Climate

Weather data was collected daily from the weather station located at Frank Wise Institute (Bureau of Meteorology Station Number 002014). Temperatures in 2000 were generally cooler than the long-term averages. From January to June maximum temperatures were 1.3°C to 2.4°C cooler than the long-term average. In January to March, and also May, minimum temperatures reached the long-term average. Minimum temperatures were 2.4°C warmer in April and 1.2°C cooler in June. From July to September maximum temperatures were up to 1.4°C warmer than the long-term average but minimum temperatures were half a degree cooler. In October the maximum temperature was 1.4°C cooler than the long-term average. In late November and early December maximum temperatures were below average because a monsoon trough formed and steady rain fell for a week. After this period temperatures followed the long-term trend lines.

In 2000 there were eight nights when the temperature fell below 11°C, classified as 'cold shock events' and on a further seven nights minimum temperatures fell below 12°C, the accepted threshold temperature for cotton growth. The long-term climate data indicates an average of 10.8 cold shock events falling between May and September with most cold shock events occurring in July. In 2000 cold shocks were confined to a three-month period with one event in May, three events in June and four in July.

Late summer rain hampered land preparation and delayed sowing from the target of late March/early April until mid-May. Although this may have limited the yield potential for the season, the trials established well and a total of around 250 ha of experimental cotton was grown.

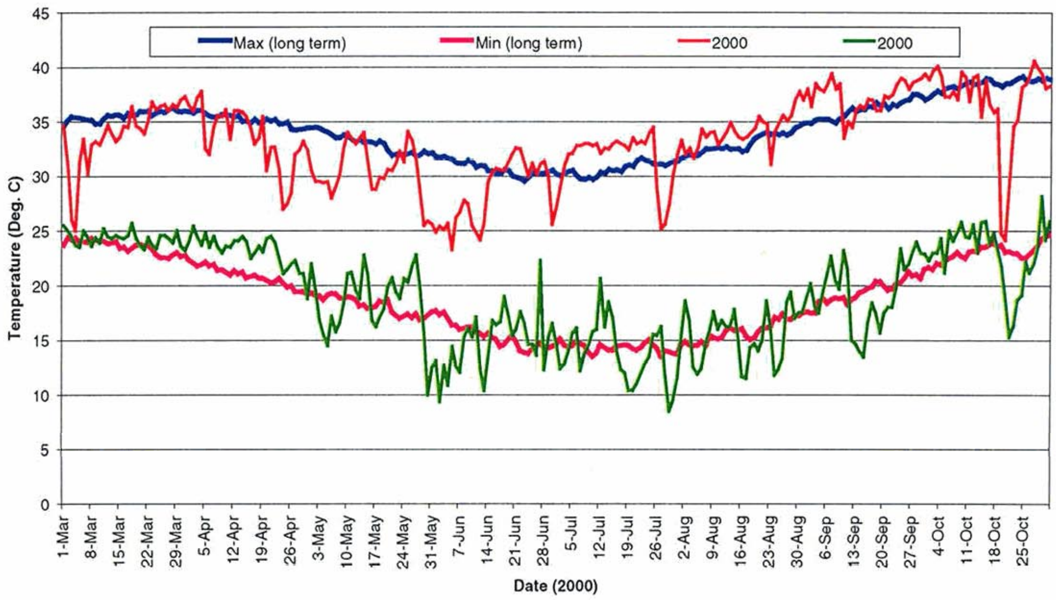


Figure 10. Minimum and maximum temperatures compared to long-term averages for the 2000 season at Kununurra.

Rain fell on one occasion throughout the growing season when 0.4 mm was recorded on 10 September. A further 50.1 mm of rain fell during October when the cotton was being harvested. This rainfall was spread over 10 days and most falls were less than 10 mm. The heaviest rainfall occurred on 15 October when 23 mm of rain was recorded.

The cooler temperatures experienced in the early part of the 2000 cotton growing season were reflected in the accumulated heat units and development of cotton. The extent of the effect of temperature on cotton growth was dependent on the sowing date. Cotton planted on 14 April was most severely affected by the cooler conditions because heat units were accumulated at a slower rate from late May until September, the entire period of fruit development (squaring, flowering and boll filling). Cotton planted on 10 May had a slower rate of development through June and early July, during squaring and early flowering. After early July the cotton accumulated heat units at the same rate as the long-term model. Cotton planted on 31 May was least delayed by the cool winter. The rate of development was slower from planting to mid-August so that squaring was the only growth stage affected by the cool weather.

Pest abundance

The seasonal abundance of the key lepidopteran pests, *Helicoverpa* spp. and *Spodoptera litura* is illustrated in Figure 11. The pheromone trap data suggests a typical seasonal activity pattern for *Helicoverpa* but unusually high levels of dry season activity by *Spodoptera*. Generally *Spodoptera litura* is very abundant in the summer months but declines to relatively low levels of activity during the cool winter months. However, the reverse was true in 2000.

H. punctigera were generally in low abundance during the early and late parts of the season. However, the sudden peak in June suggests a migratory flight rather than a local generation as the source of the population. In most seasons *Helicoverpa* spp peak noticeably in late August and *H. armigera* again showed this typical pattern of increasing abundance as the dry season cropping program progresses.

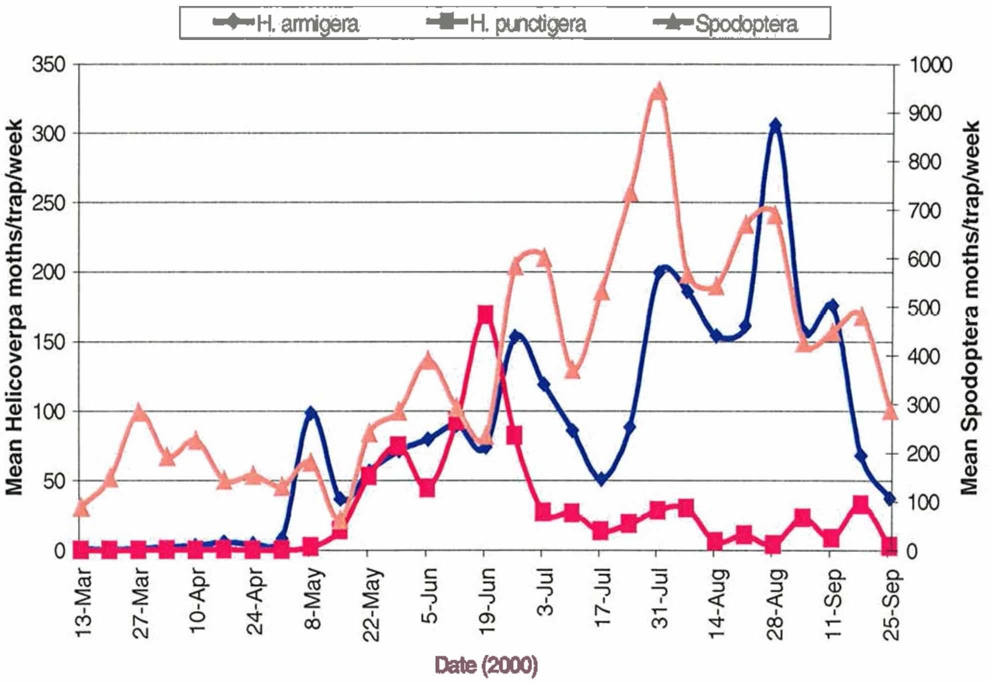


Figure 11. Seasonal abundance of *Helicoverpa armigera, H. punctigera* and *Spodoptera litura* in pheromone traps at Kununurra, 2000.

IPM trial treatments

The area available for cotton research was greatly reduced in 2000 with a total of about 225 ha being grown, mainly local growers test-farming IPM systems in collaboration with the Department of Agriculture. Reasons for the decline in farmer participation were numerous and included:

- The take-over of Colly Cotton by Twynam and Twynam's decision to withdraw from activities in northern Australia, creating uncertainty about the availability of the gin.
- Wettest wet season on record caused damage to the 1999 crop and very late sowing options in the current season.
- Disappointing yield performance from the local variety Siokra L23*i*.
- Pressure from the sugar mill operators for farmers to plant more sugar to prop up the financially troubled local industry.

Land preparation was severely hampered by the long and wet summer. Most crops were not sown until mid-May, with the exception of a single paddock, which was planted in mid-April. This paddock received high early pest pressure as a consequence of being one of very few host crops in the valley at that time of the season.

In order to advance the objectives of the project, replicated experiments test-farming various IPM treatments had been planted in previous seasons. However, due to the lack of sufficient paddocks in the 2000 season, farmers were able to select from a range of IPM systems used previously but replication of several systems on each farm was not possible. For this reason the trials are a series of system evaluations but not replicated experiments as such, although each system has been replicated in time in previous years.

The aim of the IPM field trial was to evaluate the performance of INGARD® alone compared with cotton grown with companion crops and 'soft chemicals'. The systems were:

1. INGARD® (Sicot 289*i* or Siokra V16*i*) alone;
2. INGARD® (Sicot 289*i* or Siokra V16*i*) with a lucerne companion crop;
3. INGARD® (Sicot 289*i* or Siokra V16*i*) with a lablab companion crop; and
4. INGARD® (Sicot 289*i* or Siokra V16*i*) with a pigeon pea companion crop.

The standard variety in previous trials was Siokra L23*i* due to its excellent early record in the area. However, yields have declined in recent seasons, perhaps as a result of *Alternaria* leaf disease, and the decision was taken to change varieties for the current season. Growers were given the choice of Sicot 289*i* or Siokra V16*i*, as both had performed well in recent CSIRO variety trials.

Methods

All trials were planted as two rows (80 cm apart) on 1.8 m beds, which is standard practice for other crops in the area. The target plant population was 9-10 plants/m row and this was generally achieved although plant establishment was uneven in some paddocks.

Plot size on farms ranged from 23 to 53 ha, depending on paddock availability. Wherever possible, plots were separated from each other by at least 100 m in an effort to minimise pesticide drift and the confounding effects of inter-plot insect movements.

Standard pest thresholds contained in CottonLOGIC were used for all pest management decisions across all treatments. Insecticides were applied using ground rigs whenever possible but aerial application late in the season became mandatory when the crops grew too tall. Care was taken to ensure that spray conditions were suitable to avoid drift onto adjoining plots.

Yields were all estimated by gin output figures following commercial machine picking using a contractor with a four-row picker. (Yields were also estimated from single-row and hand harvest methods but these data are not presented here.)

Results and discussion

1. *IPM assessments*

All plots in the IPM trial were scouted according to CottonLOGIC methods throughout the season and chemical control decisions were based on CottonLOGIC thresholds. Scouting was conducted by Department of Agriculture staff who maintained full control over spray decisions and advised on insecticide selection.

Due to the low level of replication it is difficult to speculate on the relative performance of each of the IPM treatments evaluated. However all systems yielded well. Yields and the purpose of spraying are summarised in Table 3 and Table 4 respectively. The change of varieties to Sicot 289*i* or Siokra V16*i* was vindicated by the higher yields (the average Siokra L23*i* yield from the previous season was 5.85 bales/ha).

Table 3. The mean and range of yields in the IPM trial, Kununurra, 2000

Treatment	*Helicoverpa* sprays	Yield (average)	Yield (highest)	Yield (lowest)
INGARD® alone (4 replications)	4.7	7.37	7.89	6.65
INGARD® with lucerne companion crop (no replication)	5.0	8.27	8.27	8.27
INGARD® with lablab companion crop (2 replications)	4.0	6.98	8.73	5.23
INGARD® pigeon pea companion crop (2 replications)	3.5	7.87	8.39	7.35

NB: All yields are in bales/ha.

Table 4. The number and purpose of sprays in the IPM trial, Kununurra, 2000

Treatment	*Helicoverpa* sprays	Mirid sprays	Aphid sprays	Total sprays
INGARD® alone (4 replications)	4.7	1.0	0	5.7
INGARD® with lucerne companion crop (no replication)	5.0	0	0	5.0
INGARD® with lablab companion crop (2 replications)	4.0*	1.5	1	6.5
INGARD® pigeon pea companion crop (2 replications)	3.5	1.5	0.5	6.0
Valley average	4.25	1.13	0.38	5.88*

* includes a spray for *Spodoptera litura*

The issue of variety selection is critical to profitability and a large plot variety trial was sown in order to be able to compare contemporary varieties picked and ginned by commercial equipment. The trial was conducted partly in response to the observed trend of declining yields for the standard on-farm variety, Siokra L23*i*. The results in Table 5 confirm that Siokra L23*i* is failing to yield adequately, although the reasons for the yield decline in this variety are unknown. In the early years of trials Siokra L23*i* was the outstanding performer in both yield and fibre quality.

Table 5. The results from a large plot variety trial at the Frank Wise Institute, Kununurra, 2000

Variety	Module weight (kg)	Lint weight (kg)	Turnout (%)	#Stat. bales	Yield (bales/ha)
Siokra V16*i*	13,120	5,322	40.6	23.4	7.89
NuCOTN 38	12,740	5,287	41.5	23.3	7.84
Sicot 289*i*	13,440	5,255	39.1	23.1	7.79
Sicot 51*i*	12,260	5,126	41.8	22.6	7.60
NuPearl	12,500	5,024	40.2	22.1	7.45
Siokra 201*i*	11,640	4,837	41.6	21.3	7.17
Siokra S-101*i*	12,000	4,608	38.4	20.3	6.83
Siokra L23*i*	11,200	4,496	40.1	19.8	6.67

NB: Each variety was 2.97 ha.

The varieties were also ranked in terms of their respective gross returns to farmers. The gross returns ($/ha) were calculated using both yield and quality data. Some varieties that yield well suffer from serious quality discounts, mainly length and colour downgrades, and this can significantly influence the profitability to growers. The results from Table 6 again confirm that the choice of varieties Sicot 289*i* and Siokra V16*i* was a wise one as both these varieties topped the list of gross returns/ha. In fact they outperformed the previous variety, Siokra L23*i* by almost $1,000/ha.

Table 6. Gross return analysis from a large plot variety trial at the Frank Wise Institute, Kununurra, 2000 (Data from Steve Yeates, CSIRO)

Variety	Yield bales/ha	Discount $/ha	Gross return $/ha
Sicot 289*i*	7.79	179	4,690
Siokra V16*i*	7.89	376	4,555
NuCOTN 38	7.84	494	4,406
NuPearl	7.45	430	4,226
Siokra 201*i*	7.17	333	4,148
Sicala 51*i*	7.60	845	3,905
Siokra 101*i*	6.83	401	3,868
Siokra L23*i*	6.67	420	3,749

Price ex Kununurra = $625/bale for base grade.

Helicoverpa pressure was low to moderate throughout the season, except for the single early planted crop which proved highly attractive to pests and received high early oviposition and remained attractive to *Helicoverpa* even after the other crops were well established (Figure 12).

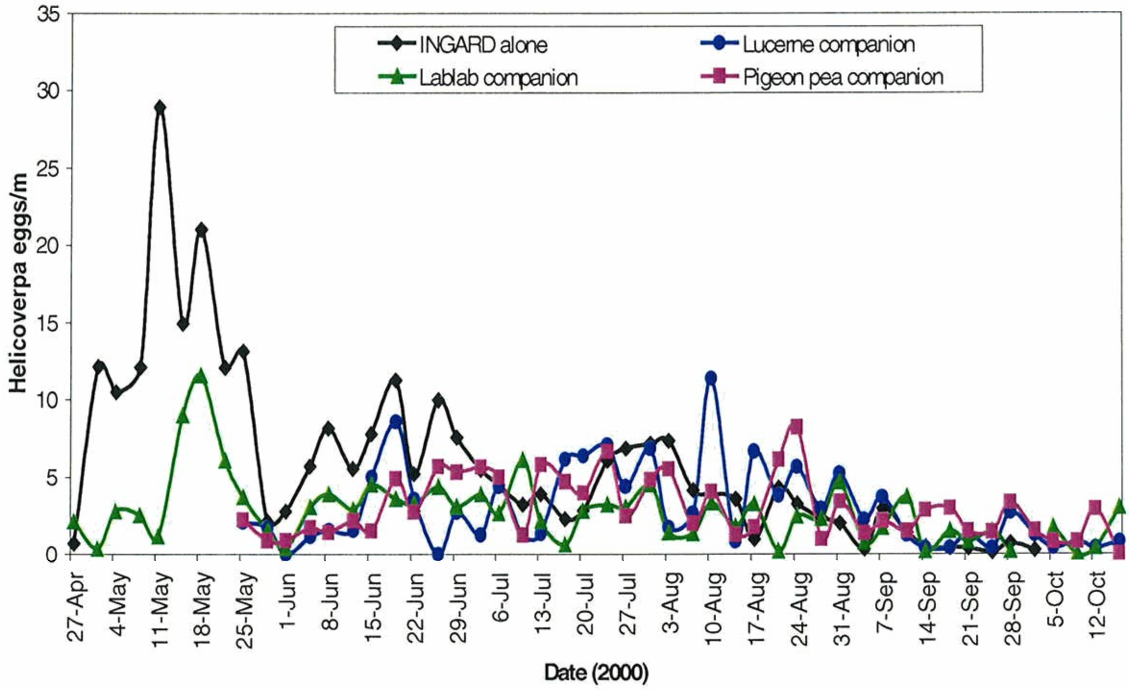


Figure 12. Mean *Helicoverpa* oviposition on cotton IPM treatments at Kununurra, 2000.

Despite high oviposition pressure on the early crop, very few larvae developed early in the season as shown in Figure 13. This can reasonably be attributed to INGARD® efficacy, which is reliable during that part of the season. *Helicoverpa* larval populations did develop later in the season and threshold and near threshold populations were common throughout the July to September period. Two paddocks were sprayed on six occasions for *Helicoverpa* control, much more frequently than previous seasons. Overall the valley average was almost 6 sprays/crop, including aphids and mirid sprays. This was the highest level of INGARD® spraying since the commencement of trials.

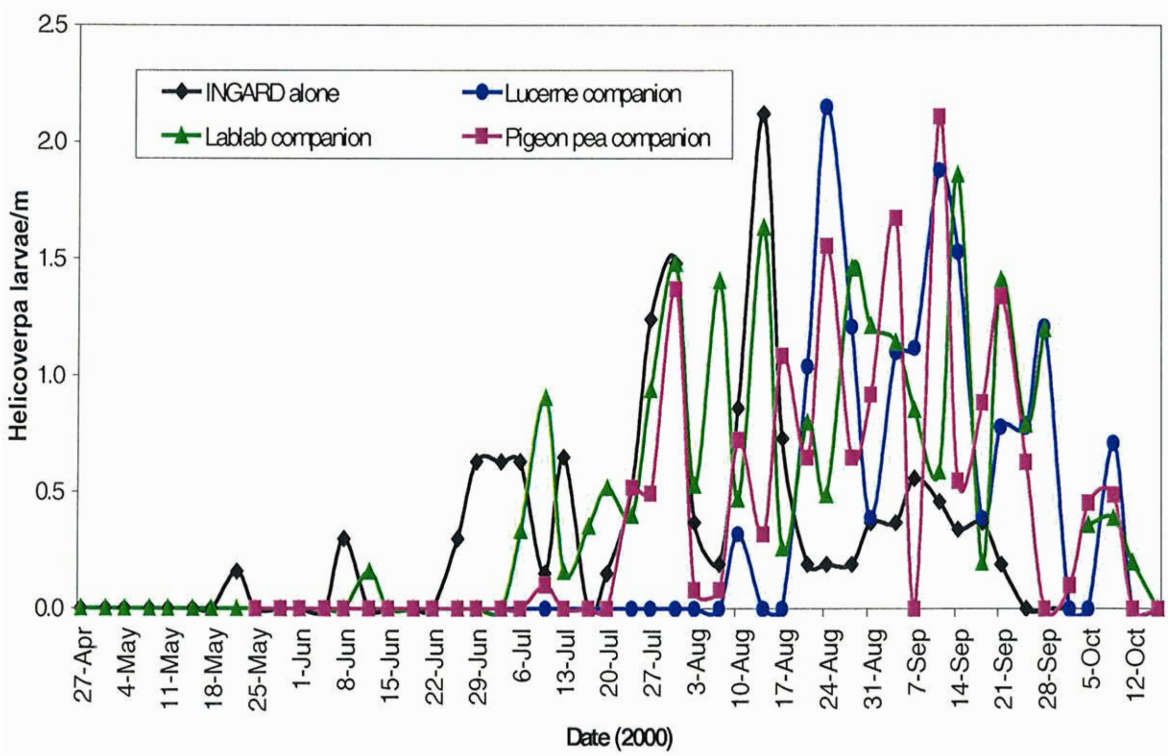


Figure 13. Mean *Helicoverpa* threshold larvae on cotton IPM treatments at Kununurra, 2000.

Cotton aphid, *Aphis gossypii*, is an increasing problem on low spray cotton. It has particular importance in Kununurra where the cucurbit industry is vulnerable to several serious viruses (especially zucchini yellow mosaic virus - ZYMV), which are transmitted by *A. gossypii*. The interaction between cotton and cucurbits is locally important and sometimes a contentious issue.

Scouting data show that aphid infestation levels peaked at about 50 per cent of plants being infested. However it was clear that aphids were much denser in some patches and that infested plants were often heavily infested, with large amounts of honey dew clearly visible. Despite the aphid pressure, only three paddocks were sprayed for aphid control and lady beetles and hoverflies were usually able to control the populations. Early in the season, cotton with lablab companion crops appeared to harbour more aphids than other crops but by mid-season there were no apparent associations between cotton with particular companion crops.

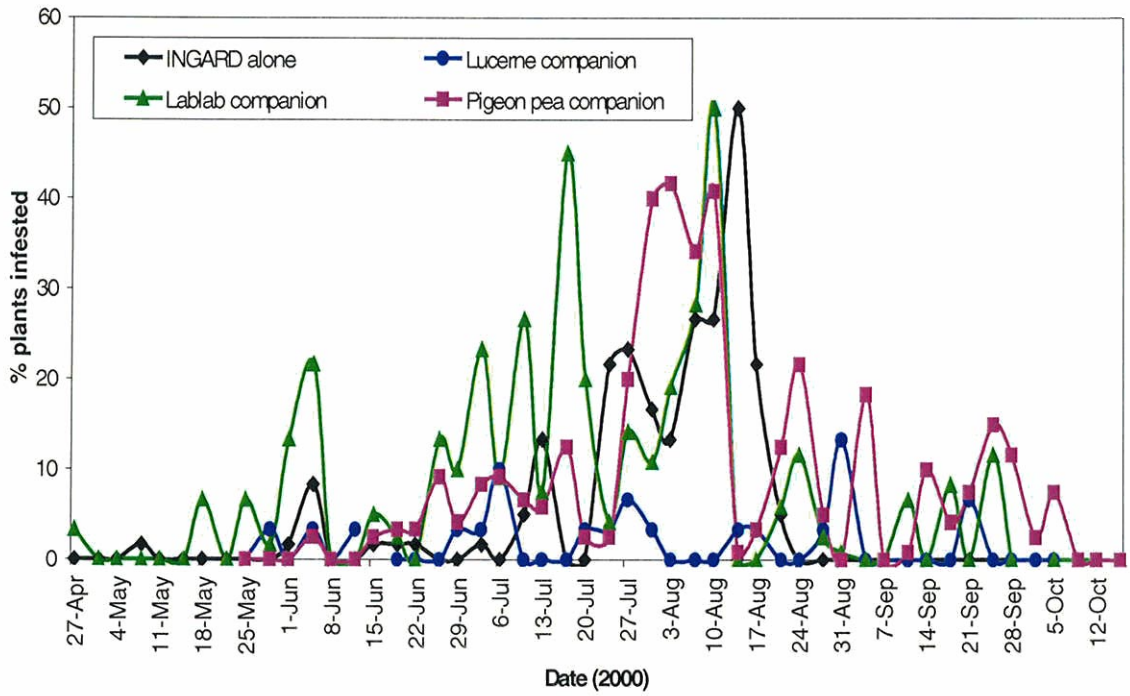


Figure 14. Mean percent aphid infested cotton plants in IPM treatments at Kununurra, 2000.

Spodoptera litura is poorly controlled by INGARD® and for that reason the pest remains a concern. Pheromone trap catches over the past two seasons have shown that the pest is becoming more active in the dry season and this has been reflected in the scouting data for the current season. In 1999, *Spodoptera* reached a maximum level of 1 larva/m on a single occasion. However, in the current season, this level of abundance was reached or exceeded on several occasions (Figure 15). One crop was sprayed specifically for *Spodoptera* control but because there are no established thresholds for the pest it is difficult to reach spray decisions.

In conventional cotton *Spodoptera litura* tend to be voracious foliage feeders and will also attack the reproductive parts of the plant, but to a lesser extent. Behaviour on INGARD® cotton seems quite different with the larvae demonstrating a reluctance to feed extensively on leaves. Instead they tend to graze leaf surfaces when very small and progress to bracts when they get older. The damage does not appear yield threatening unless the larvae then progress in their feeding to flowers, where they feed on pollen, and finally attack bolls. When this occurs the larvae are considered equally as damaging as *Helicoverpa* and thresholds are then triggered.

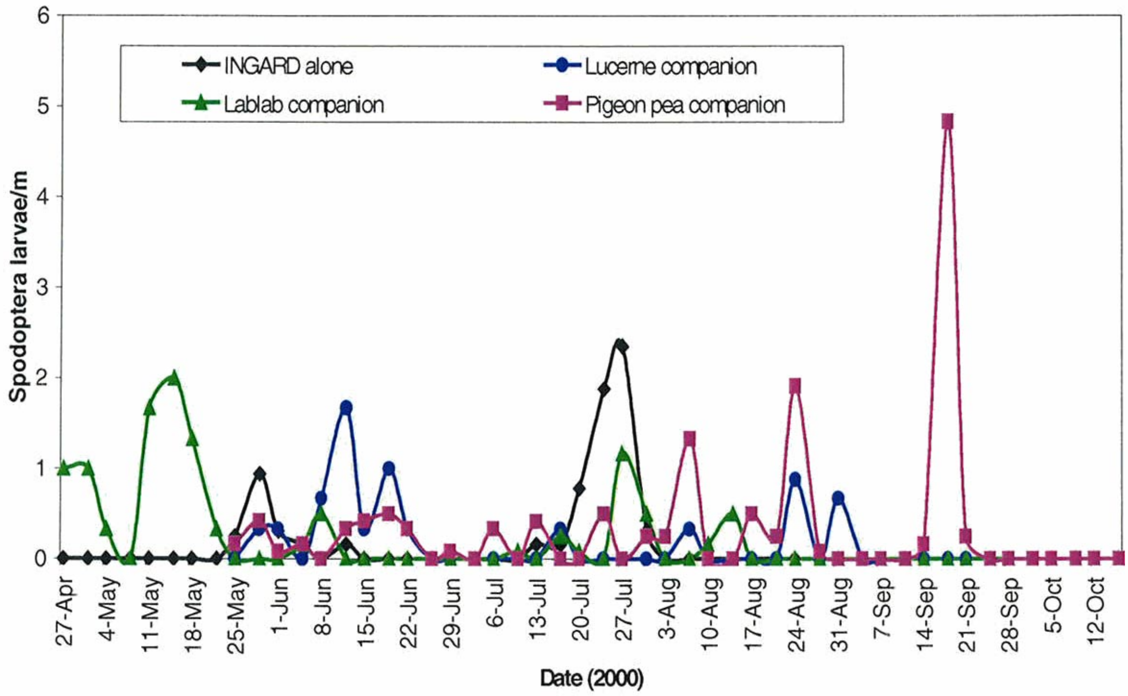


Figure 15. Mean *Spodoptera* larvae/m in cotton IPM treatments at Kununurra, 2000.

2. Beneficial insect impact

IPM systems are intended to increase the abundance of beneficial insects and thus create the opportunity for naturally occurring insects to assist in controlling pests. Regular suction sampling was used throughout the season to measure the abundance of beneficial insects in each of the IPM treatments being investigated. These data are summarised for predators (ladybirds, lacewings, big-eyed bugs, assassin bugs, hoverflies, etc.) and for parasitoids (parasitic wasps, tachinids, etc.) in Figures 16 and 17 respectively. Although *Trichogramma* is a very important parasitoid, it is not included in these data because suction sampling is a poor technique for estimating numbers of this tiny wasp.

The cumulative predators chart (Figure 16) shows that the number of predators in the various management systems were similarly low early in the season but cumulative data again demonstrated a higher number of predatory insects in cotton grown in association with lablab. These results are consistent with suction sampling data from the 1999 season.

Pigeon pea was the outstanding companion crop in terms of providing parasitoids to cotton. This is probably related to its early flowering, which attracts pests and their parasitoids earlier than the other crops. Neither lucerne nor lablab increased the number of parasitoids in the cotton to above that in the cotton grown alone (Figure 17).

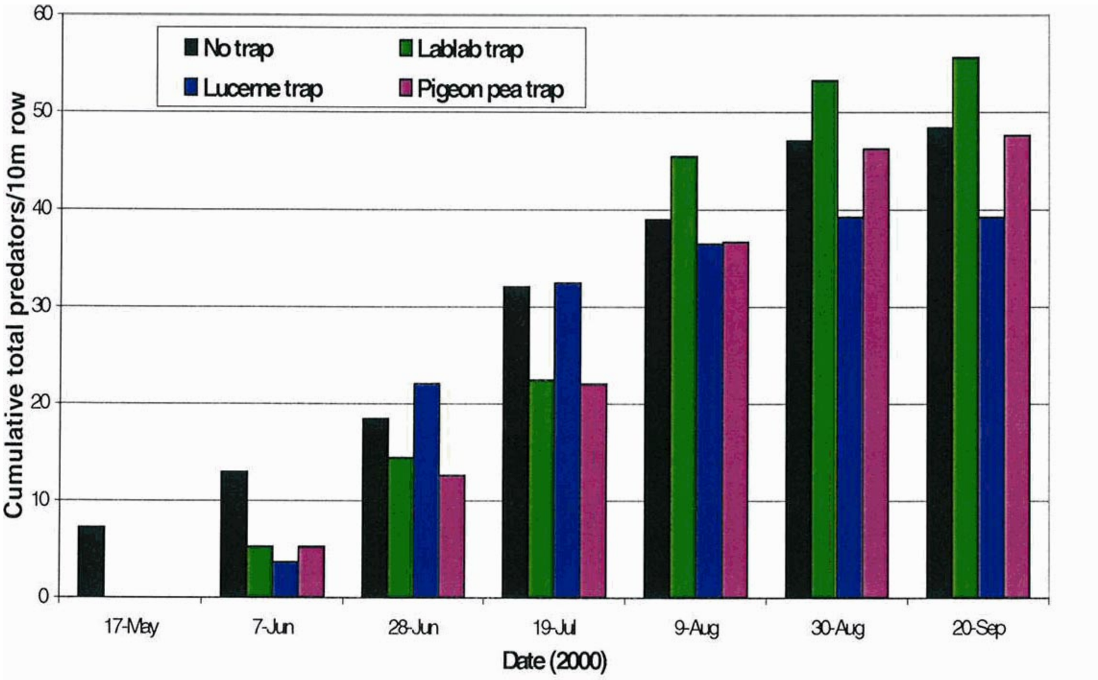


Figure 16. Total cumulative predatory insects from suction samples in INGARD® cotton with or without companion crops at Kununurra, 2000.

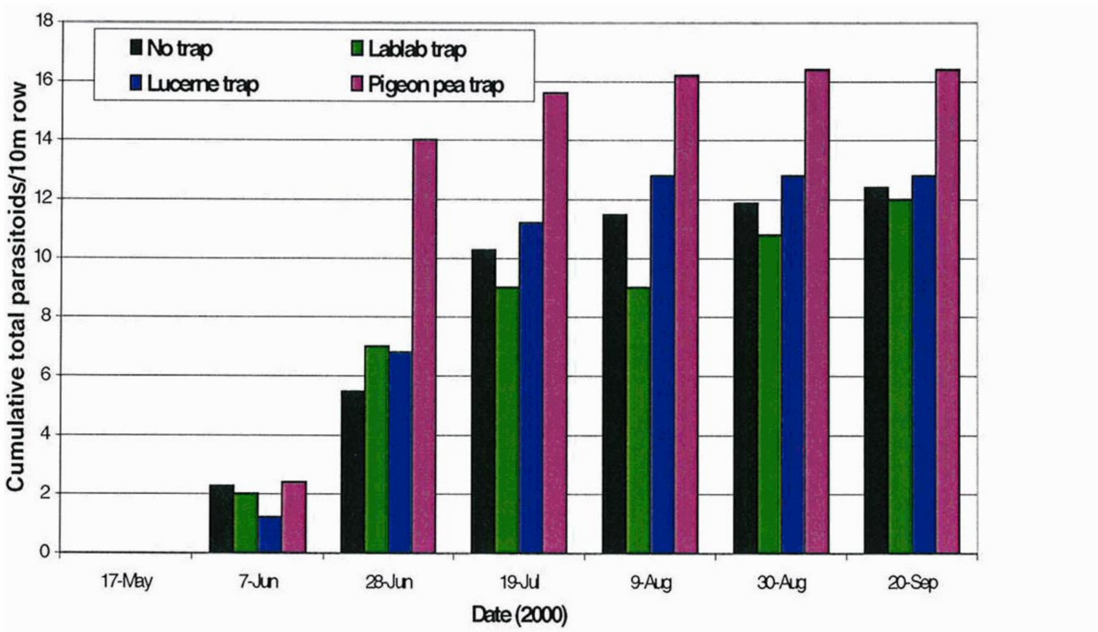


Figure 17. Total cumulative insect pest parasitoids from suction samples in INGARD® cotton with or without companion crops at Kununurra, 2000.

Trichogramma pretiosum is recognised as the most important parasitoid in the cotton agrosystem at Kununurra where it is often responsible for parasitising in excess of 70 per cent of *Helicoverpa* eggs. This is critical in high pressure seasons because it reduces the levels of neonate damage to pin squares in particular, and reduces larval populations generally. However, *Trichogramma* will not be featured in this report due to a detailed ecological study being in progress as a PhD project being undertaken by Andrew Davies.

3. Mirids and companion crops

Suction samples were taken from cotton and companion crops every three weeks and all insects collected were sorted, identified and counted. The following summarises the more important findings from these data.

The attractiveness of a companion crop to mirids is one of its most important functions. In addition to being attractive to the pest it is equally important that the companion crop be able to retain the mirid population and not act simply as a nursery to supply mirids to the adjoining cotton crop. By sampling both the cotton and the companion crop some insights into this relationship can be developed.

Figure 18 illustrates the abundance of green mirids in INGARD® cotton grown either alone or in combination with lablab, lucerne or pigeon pea companion crops. The Figure shows that cotton grown without a companion crop contained higher populations of mirids than when grown with a companion crop. However, as discussed previously, this effect may be due to one of the INGARD® alone treatments being planted a month earlier than the other treatments and consequently being highly attractive to a range of insects in the valley.

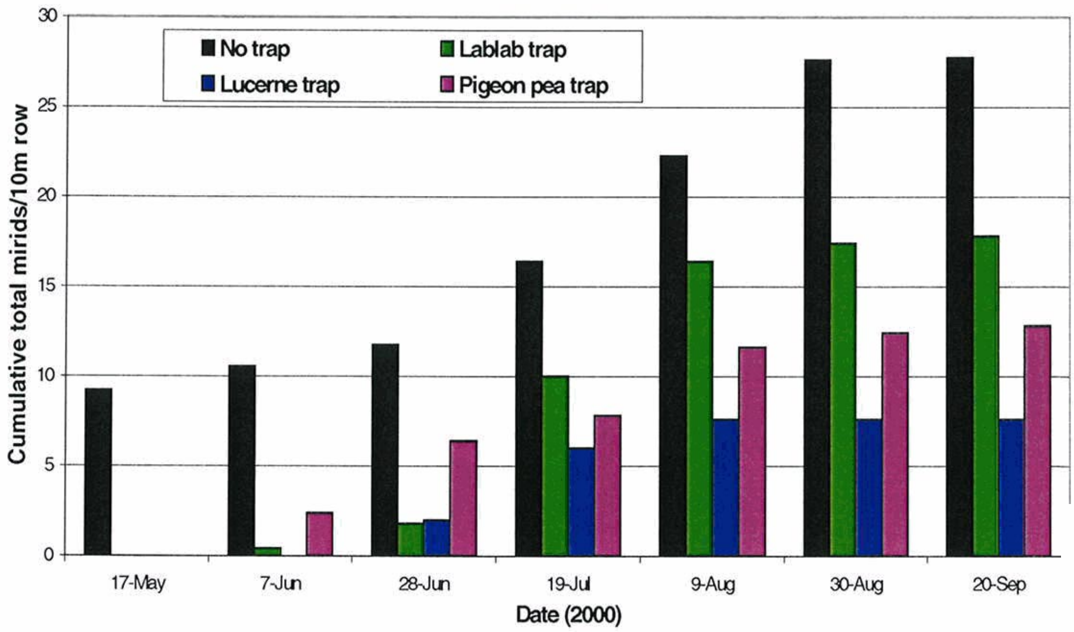


Figure 18. Total cumulative mirids from suction samples in INGARD® cotton with or without companion crops at Kununurra, 2000.

Figure 19 illustrates the relative attractiveness of the three companion crops as mirid traps compared to INGARD® cotton alone. As in all previous seasons, the companion crops, especially lablab, are far more attractive to mirids that the cotton itself. Lucerne appears to be an exception to the rule in the current season but this can be attributed to the poor establishment of the lucerne strips in the only paddock that it was attempted.

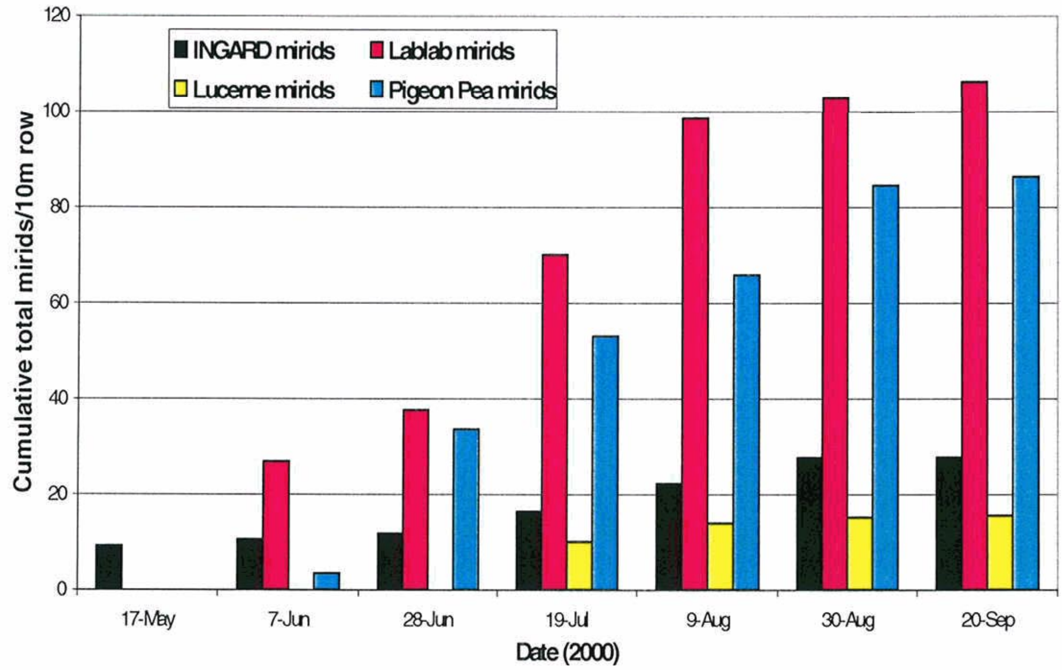


Figure 19. Total cumulative mirid numbers from suction samples in INGARD® and companion crops at Kununurra, 2000.

Apart from trapping and retaining mirids, the other important function of companion crops is the production of beneficial insects including parasitoids such as *Trichogramma*, and predators such as lady beetles, hover flies, lacewings and assassin bugs. The relative performance of the three companion crop options in terms of total predator and parasitoid abundance throughout the season is shown in Figures 20 and 21 respectively. Due to its poor establishment, lucerne was uncharacteristically poor in terms of beneficial insect species recorded. However, both lablab and pigeon pea contained high populations of beneficial insects relative to INGARD® cotton alone.

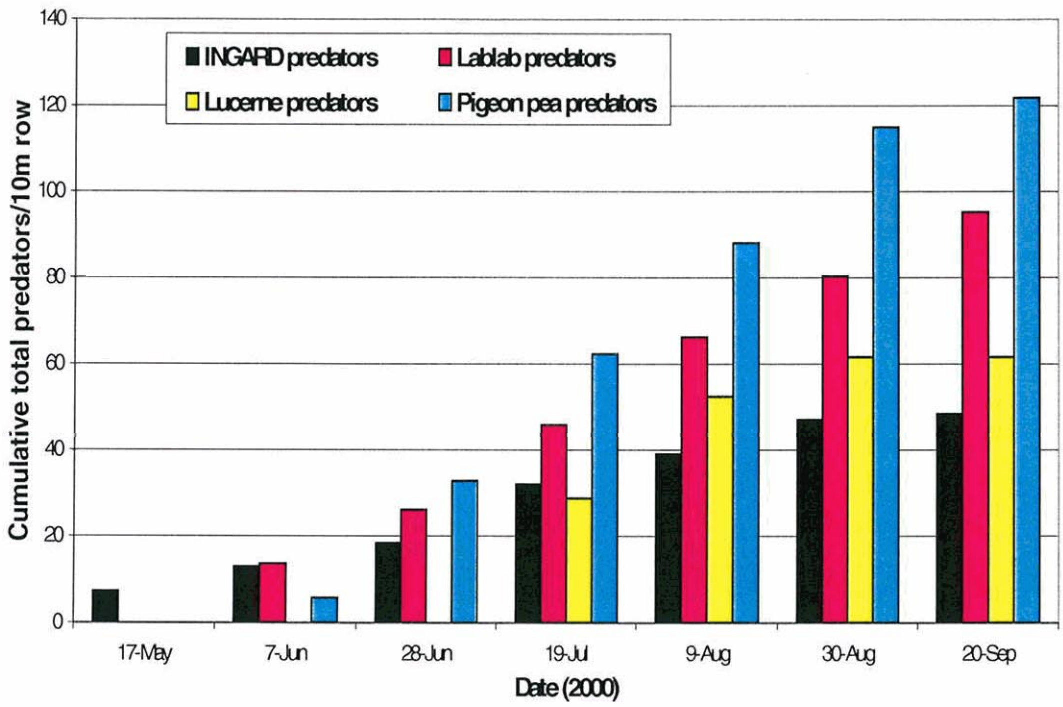


Figure 20. Total cumulative predator numbers from suction samples in INGARD® and companion crops at Kununurra, 2000.

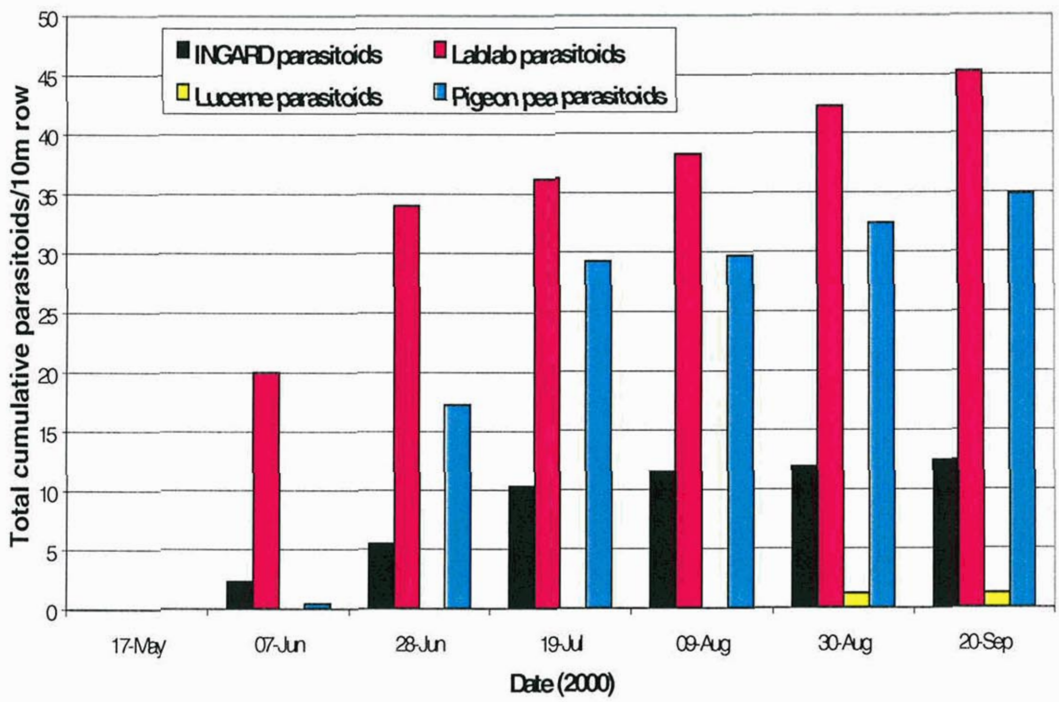


Figure 21. Total cumulative parasitoid numbers from suction samples in INGARD® and companion crops at Kununurra, 2000.

2001 SEASON

Climate

Day-degree calculations showed that the season was close to that predicted by long-term weather data, although Figure 22 shows considerable variation in achieving an 'average season'. Minimum temperatures are of greatest concern in the winter production system because they impact negatively on fibre quality and can lead to fruit shedding in some situations. Minimum temperatures were generally a little warmer than average in June and July, but colder in May and August. A total of 15 'cold shock' nights, with minimum temperatures of 11°C or less, were recorded compared to a long-term average of 10.8 cold shocks. Since trials began in 1996, the number of cold shock nights has ranged from three to 15, making the 2001 season equal coldest in terms of cold shocks.

Rainfall was well above average during the harvest and stalk mulching period with 27.4 mm being recorded in September on a single day and 37.6 mm falling in October on three days compared to long term averages of 3 mm and 22 mm for September and October respectively. The rain caused colour downgrades and reduced yield.

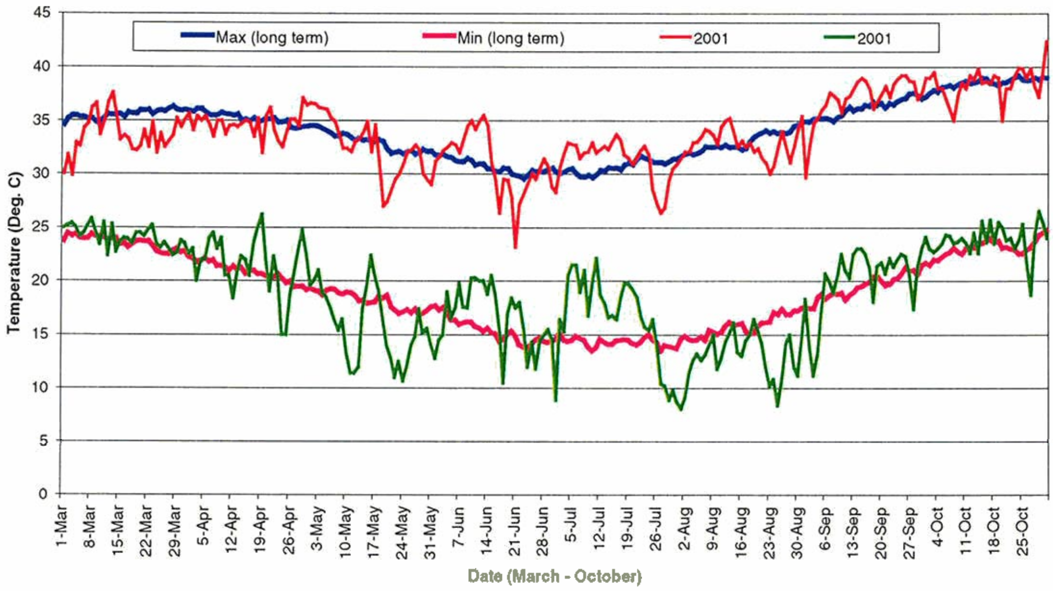


Figure 22. Minimum and maximum temperatures compared to long-term averages for the 2001 season at Kununurra.

Pest abundance

The seasonal abundance of the key lepidopteran pests, *Helicoverpa* spp. and *Spodoptera litura* is illustrated in Figure 23. The pheromone trap data suggests a year of atypical seasonal activity for most pests. Generally *Spodoptera litura* is very abundant in the summer months but declines to relatively low levels of activity during the cool winter months. However, the reverse was true in 2001.

H. punctigera was in low abundance throughout the whole season. In most seasons both species of *Helicoverpa* peak noticeably in August but this did not occur for *H. punctigera* in 2001. However, *H. armigera* did show a typical dry season build-up through a series of modest peaks before climaxing in late August and then declining again as dry season crops dried off before harvest. Atypically, *S. litura* appear to follow a similar pattern of abundance as *H. armigera* in the 2001 season.

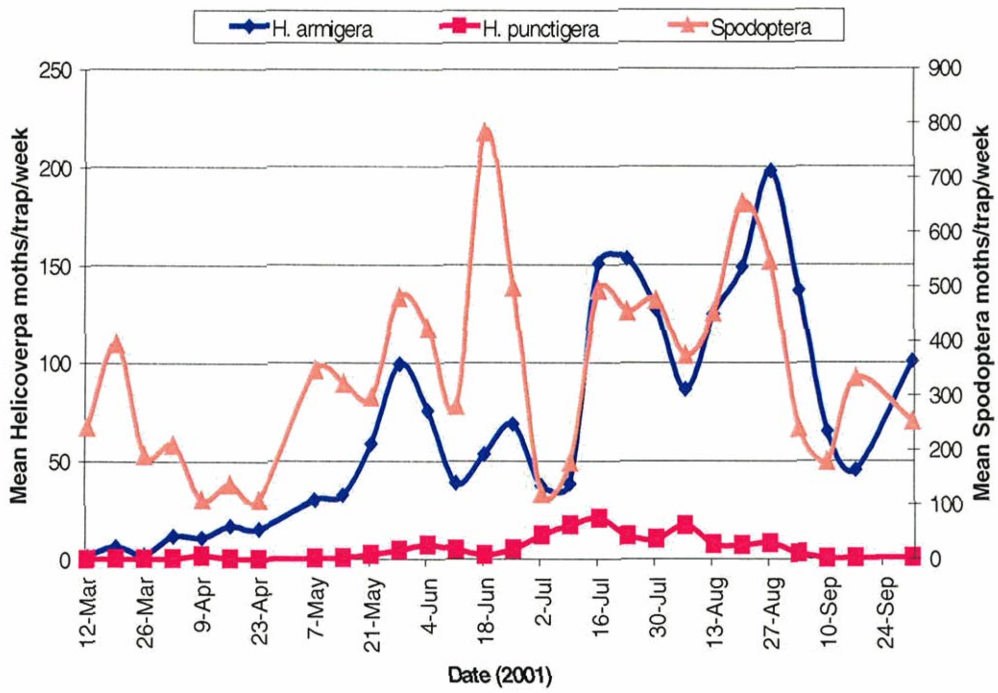


Figure 23. Seasonal abundance of *Helicoverpa armigera, H. punctigera* and *Spodoptera litura* in pheromone traps at Kununurra, 2001.

IPM trial treatments

The IPM cotton research project was well supported in 2001 with four farmers (including one new grower) committing to the strategy of test-farming systems collaboratively with the Department. A total area of 385 ha was planted at Kununurra, the majority being for INGARD® IPM evaluations.

The aim of the IPM field trial was to evaluate the performance of INGARD® alone compared with cotton grown with companion crops and 'soft chemicals'. The systems were:

1. INGARD® (Sicot 289*i* or Siokra V16*i*) alone;
2. INGARD® (Sicot 289*i* or Siokra V16*i*) with lucerne/niger companion crops; and
3. INGARD® (Sicot 289*i* or Siokra V16*i*) with lablab companion crops.

(A single paddock with a pigeon pea companion crop was also grown on the Frank Wise Institute but not replicated elsewhere).

The lucerne/niger seed mix strategy aimed to overcome the difficulty of establishing an attractive companion crop of lucerne. Hot planting conditions and the small seed size of lucerne make establishing vigorous stands very difficult at Kununurra and few farmers have permanent lucerne strips available. On the other hand, niger germinates, establishes and flowers in about 35 days from sowing. Its rapid growth makes it highly attractive to sucking pests and to *Helicoverpa.* The disadvantage of niger is that it dries off after setting seed and requires replanting several times during the season to maintain an attractive plant stand.

The idea of sowing a seed mix of lucerne and niger was to exploit the early growth attributes of niger whilst the lucerne established in the lower canopy. As the niger dries off, the lucerne grows through the canopy and becomes the dominant plant species. The lucerne is then managed by slashing as normal and its attractiveness is enhanced by the germination of niger seed scattered by slashing. The lucerne/niger system was used very successfully at Broome in the 1999 season.

In all cases, the Department maintained responsibility for crop scouting and insecticide recommendations. CottonLOGIC thresholds were utilised as a basis for all spray decisions. Farmers had the choice of growing either Sicot 289*i* or Siokra V16*i* as both these varieties had performed well in CSIRO variety trials and in the previous season generally.

Methods

All trials were planted as two rows (80 cm apart) on 1.8 m beds, which is standard practice for other crops in the area. The target plant population was 9-10 plants/m row and this was generally achieved although plant establishment was uneven in some paddocks.

Plot size on participating farms ranged from 10 to 50 ha, depending on paddock availability. Wherever possible, plots were separated from each other by at least 100 m in an effort to minimise pesticide drift and the confounding effects of inter-plot insect movements.

Standard pest thresholds contained in CottonLOGIC were used for all pest management decisions across all treatments. Insecticides were applied using ground rigs whenever possible but aerial application late in the season became mandatory when the crops grew too tall. Care was taken to ensure that spray conditions were suitable to avoid drift onto adjoining plots.

All yields were estimated by gin output figures following commercial machine picking using a contractor with a four-row picker. (Yields were also estimated from single-row and hand harvest methods but these data are not presented here.)

Results and discussion

1. IPM assessments

Preliminary conclusions from the paddock-scale IPM studies have been drawn from previous research reported from project AWA.1C. Statistical analysis of this research is difficult because replication on a range of farms with different management practices creates variability that is difficult to account for in classical statistical methods. However there has been a consistent trend for INGARD®, grown in association with a companion crop (lucerne, niger, lablab or pigeon pea) to produce a yield higher and require fewer sprays than INGARD® grown in the absence of companion crops.

However, in the 2001 season there were no significant differences in yield or number of sprays between the crops grown alone or in association with a companion crop. A summary of yields and sprays from the farms with replicated IPM plots follows in Table 7.

Table 7. Yields and sprays required in the IPM trials at Kununurra, 2001

IPM Treatment	Aphid sprays	Mirid sprays	Heliothis sprays	Total sprays	Average yield (b/ha)	Yield range (bales/ha)
INGARD® alone	0	0.17	2	2.17	4.69	2.1 - 6.30
INGARD® + lucerne & niger mix	0	0.25	1	1.25	4.44	1.78 - 5.77
INGARD® + lablab	0	0.5	0.75	1.25	4.66	2.53 - 5.94
INGARD® + pigeon pea	1	2	0	3	6.17	One plot

Average yields were generally disappointing with a huge range in paddock performance from 1.78 bales/ha to 8.35 bales/ha. The yield variability is difficult to account for in pest management terms given that the season was characterised by low pest pressure. The highest yielding paddock received only a single application of Ovasyn® yet produced 8.35 bales/ha. On the other hand, a sprayed paddock yielded as low as 1.78 bales/ha. Yield variability is summarised in Table 8 for each grower.

Table 8. Yield range and areas grown in the IPM trials at Kununurra, 2001

Farm #	Area grown	Average yield (bales/ha)	Yield range (bales/ha)
1 (FWI)	67 ha	5.13	4.37 - 6.17
2	159 ha	5.17	4.95 - 6.30
3	80 ha	3.72	1.78 - 5.39
4	56 ha	8.12	7.47 - 8.35
5	50 ha	3.72	N/A
Unsprayed Siokra 1-4 refuge	8 ha	5.73	4.69 - 7.47

Of extreme concern is that two unsprayed refuge crops of Siokra 1-4 yielded 4.69 and 7.47 bales/ha. In one of these cases the refuge yielded more than 1 bale/ha better than the managed INGARD® crop in the same paddock. This raises the issue of the suitability of INGARD® varieties in the Ord region and the possibility of "gene load" depressing yields in some circumstances.

Helicoverpa pest pressure was very low throughout the season. Figure 24 shows that oviposition levels did not even reach 10 eggs/m at anytime during the season. This continues the trend of recent seasons and is consistent with long-term pheromone trap results which have also shown declining numbers of *Helicoverpa* in the ORIA. The reasons for the decline in *Helicoverpa* pressure are most likely associated with changes in crop selection in the area rather than to improved area wide management tactics, although these may have some role. The area of sugar cane has increased to almost 50 per cent of the valley and this has replaced areas of maize and chickpea, both of which are major nursery crops for *Helicoverpa*.

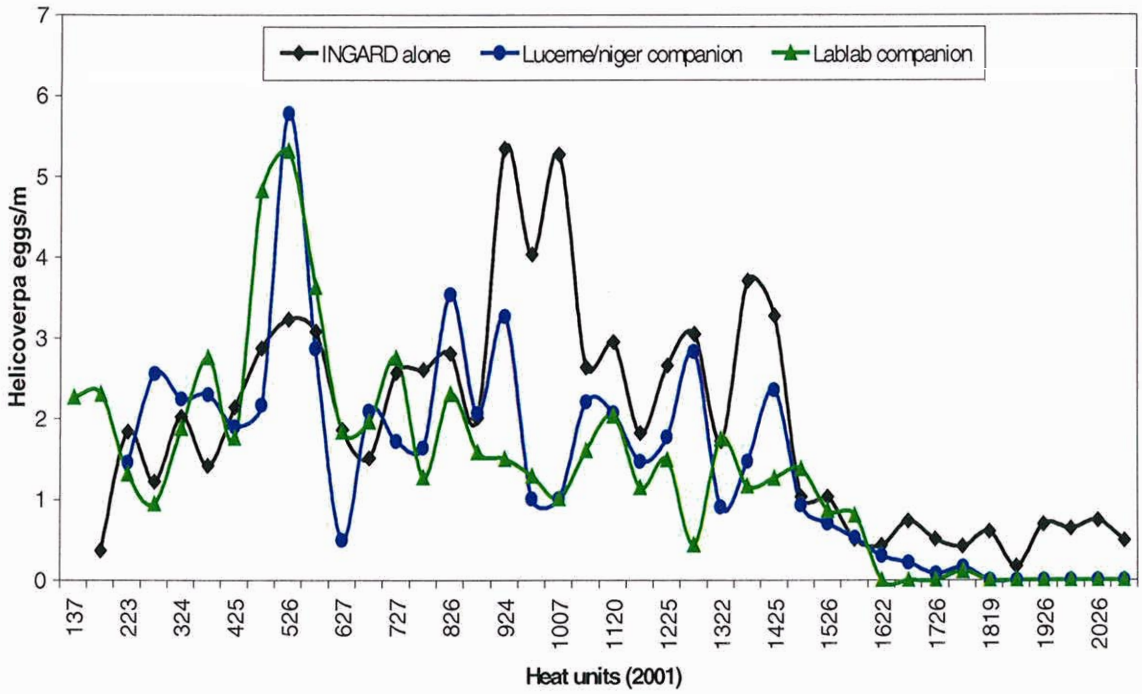


Figure 24. Mean *Helicoverpa* oviposition on cotton IPM treatments at Kununurra, 2001.

Helicoverpa larval populations in all crops followed the typical pattern of low initial numbers when INGARD® efficacy is at its maximum, and higher numbers later in the season as efficacy declines. Larval numbers peaked first at about 1,000 heat units and then fluctuated between 1-2 larvae/m until about 1,850 heat units, after which they declined rapidly. The standard spray threshold of 2 larvae/m was rarely reached and less than two sprays were required per crop. Numbers of threshold larvae tended to fluctuate more in the INGARD® alone treatment than in cotton with companion crops (Figure 25).

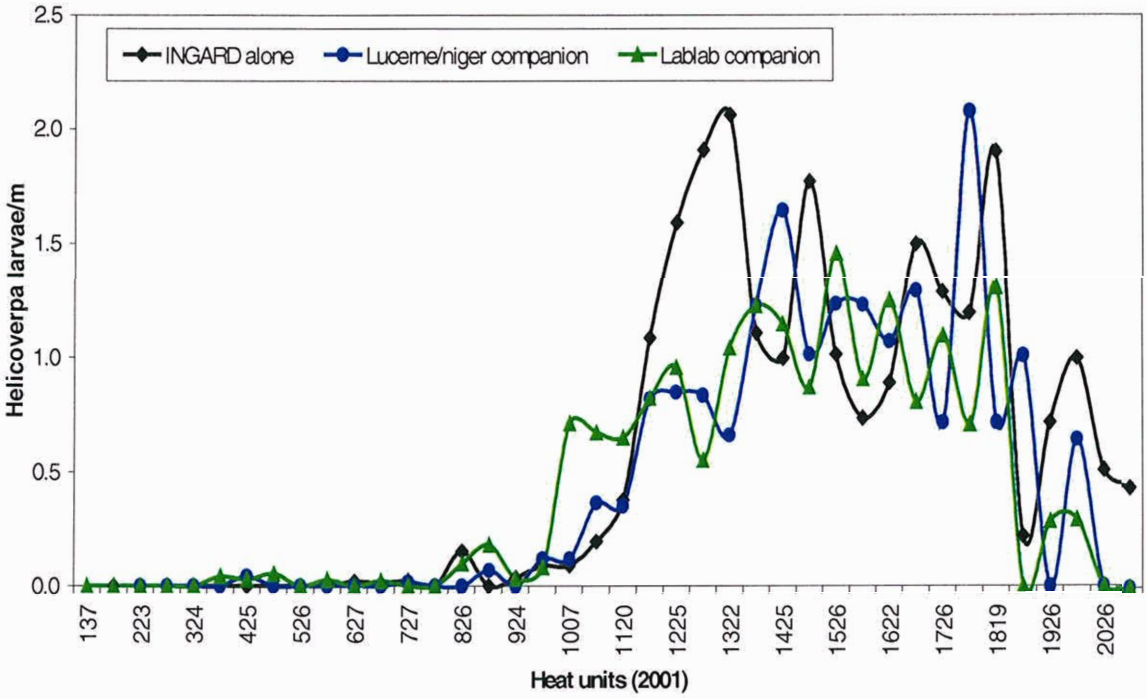


Figure 25. Mean *Helicoverpa* threshold larvae on cotton IPM treatments at Kununurra, 2001.

Populations of *Aphis gossypii* were also relatively low at the start of the season and showed a tendency to build-up later in the season (Figure 26). Aphid populations in INGARD® alone crops were considerably higher and more persistent than those grown with companion crops.

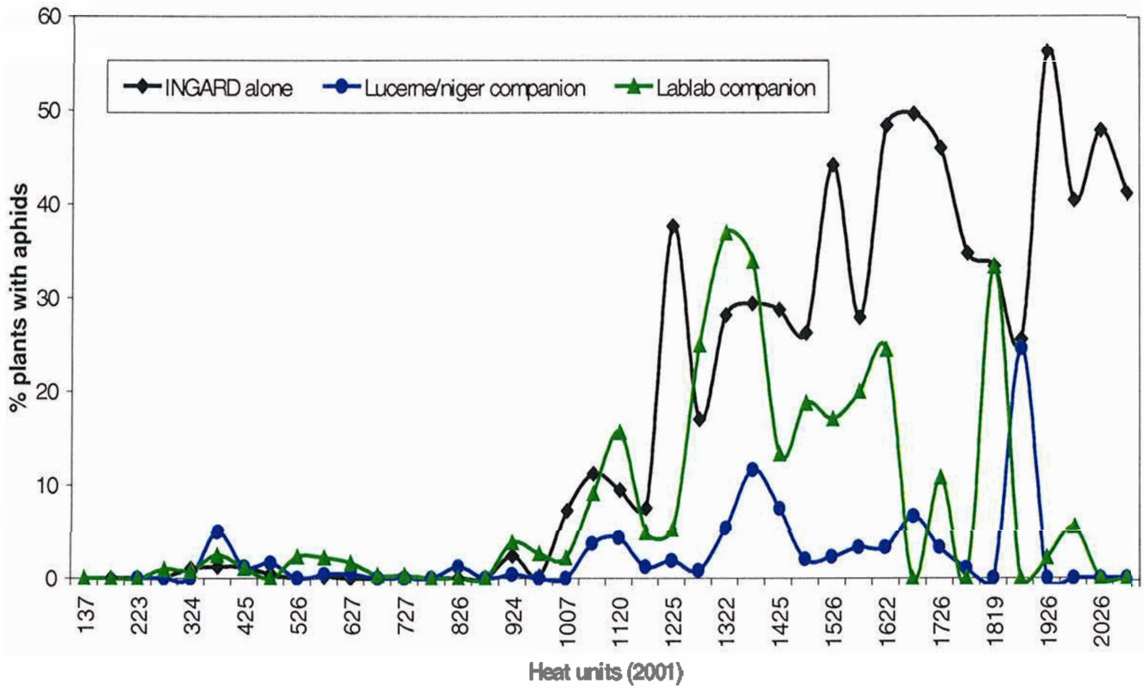


Figure 26. Mean aphid infestation rate on cotton IPM treatments at Kununurra, 2001.

2. Beneficial insect impact

Trichogramma pretiosum remains an extremely important beneficial insect in the agricultural system at Kununurra. However the abundance of the parasitoid will not be discussed in this report because its ecology is the subject of a PhD study (Andrew Davies) which is currently in progress.

The following two Figures summarise cumulative numbers of predatory and parasitic insects recorded from D-vac sampling of the various IPM treatments. Somewhat surprisingly there were no clear differences between cotton that had companion crops and cotton that did not. This is the first time in six seasons that no differences attributable to companion crops were seen.

The only exception was that cotton grown with a lablab companion had markedly fewer parasitoids than the other crops. This is probably explained by the higher populations of prey insects in the lablab making it more attractive to parasitoids than the other options with low prey numbers. The attractiveness of the lablab crop may have retained the parasitoids rather than causing them to move into the surrounding cotton in search of hosts.

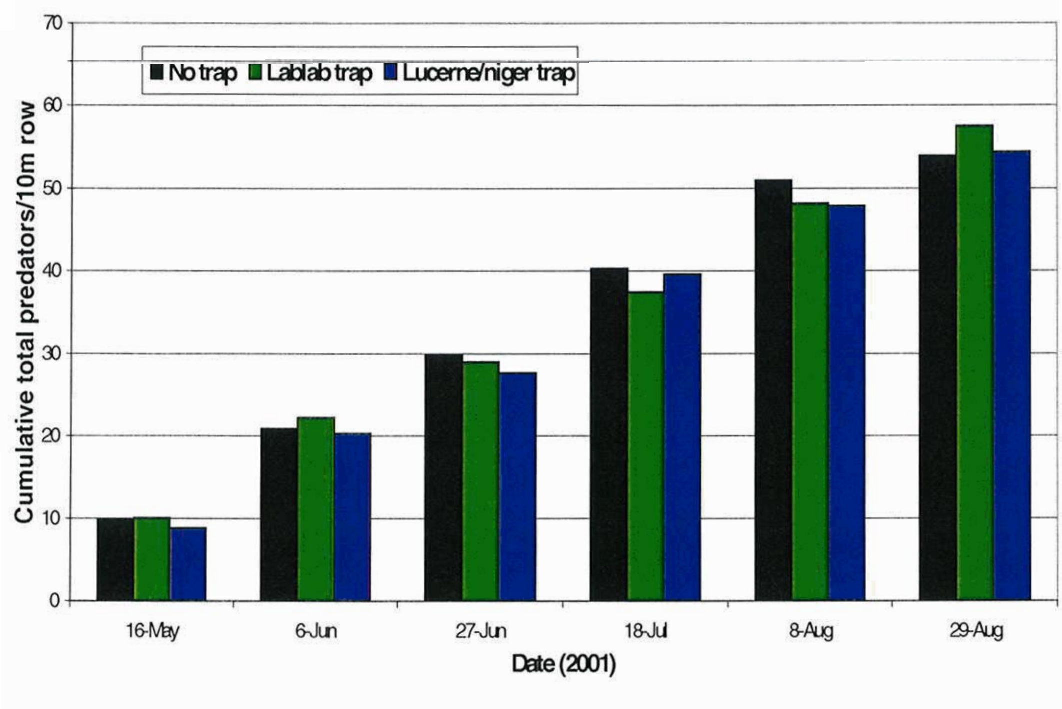


Figure 27. Total cumulative predatory insects from suction samples in INGARD® cotton with or without trap crops at Kununurra, 2001.

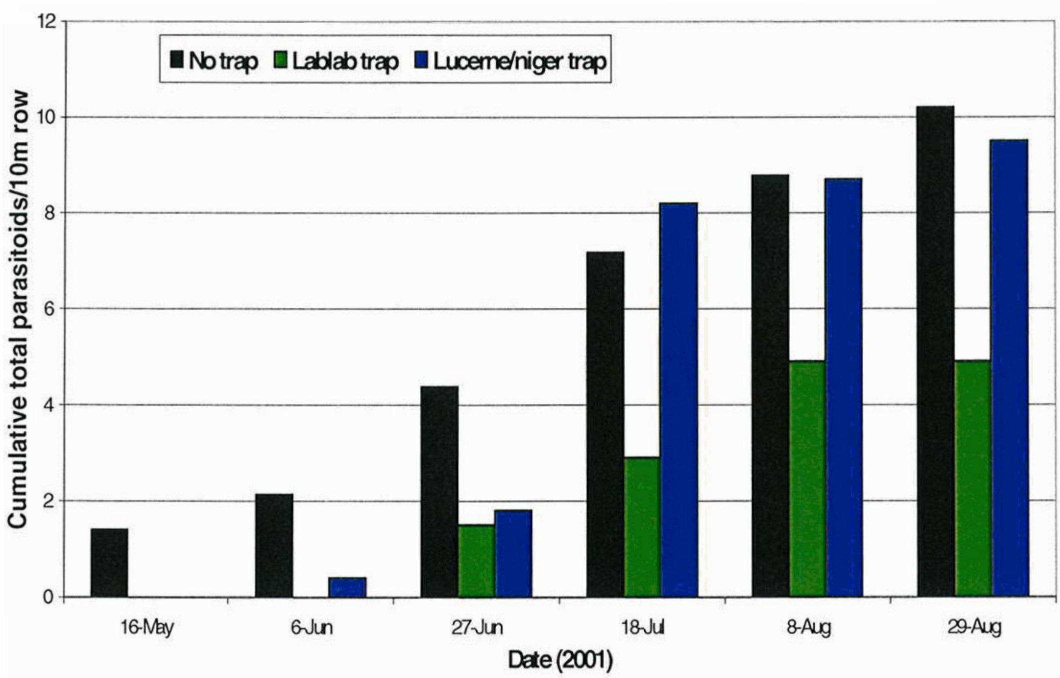


Figure 28. Total cumulative insect parasitoids from suction samples in INGARD® cotton with or without trap costs at Kununurra, 2001.

3. Mirids and companion crops

Companion crops are an important component of IPM systems and have two prime functions:

- to divert some pests, particularly the green mirid, *Creontiades dilutus*, away from cotton.
- to provide a reservoir of beneficial insects that can colonise neighbouring cotton crops.

During the 2001 season, suction samples were taken from INGARD® cotton alone, INGARD® with the companion crops, and from the lablab and lucerne/niger companion crops themselves. The samples were collected every three weeks and the collections sorted in the laboratory and the data recorded. By comparing these data it is possible to determine if the companion crops themselves are attractive to the beneficial and pest insects of concern, and also whether the cotton grown with companion crops accrues more beneficial insects and less pests than would otherwise occur.

Figure 29 shows the cumulative mirid populations in cotton with and without companion crops. The data suggest that cotton with lablab strips may have received a benefit of slightly lower mirid numbers later in the season but the lucerne/niger strips were not effective this season. This poses the question of whether the companion crops themselves were more attractive to mirids than cotton or not.

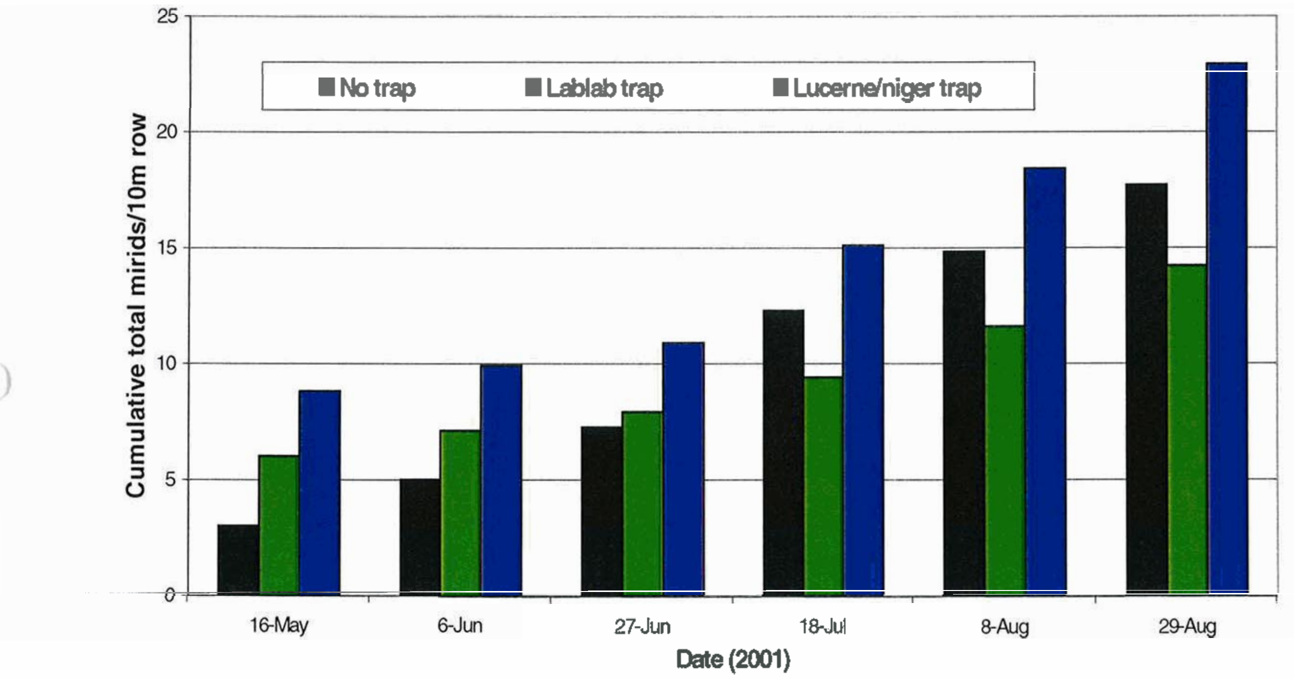


Figure 29. Total cumulative mirids from suction samples in INGARD® cotton with or without trap crops at Kununurra, 2001.

The attractiveness of the companion crops relative to cotton is summarised in the following Figure. Very clearly, both the lablab and the lucerne/niger companion crops were far more attractive to green mirids than INGARD® cotton alone. However, the fact that INGARD® cotton grown with the companion crops did not have lower mirid populations suggests that either the companion crops were ineffective at trapping an adequate proportion of the mirid population or that the companion crops acted as mirid nursery crops and some mirids invaded the cotton from the companion crops. The use of a trap and destroy strategy would help to resolve this uncertainty.

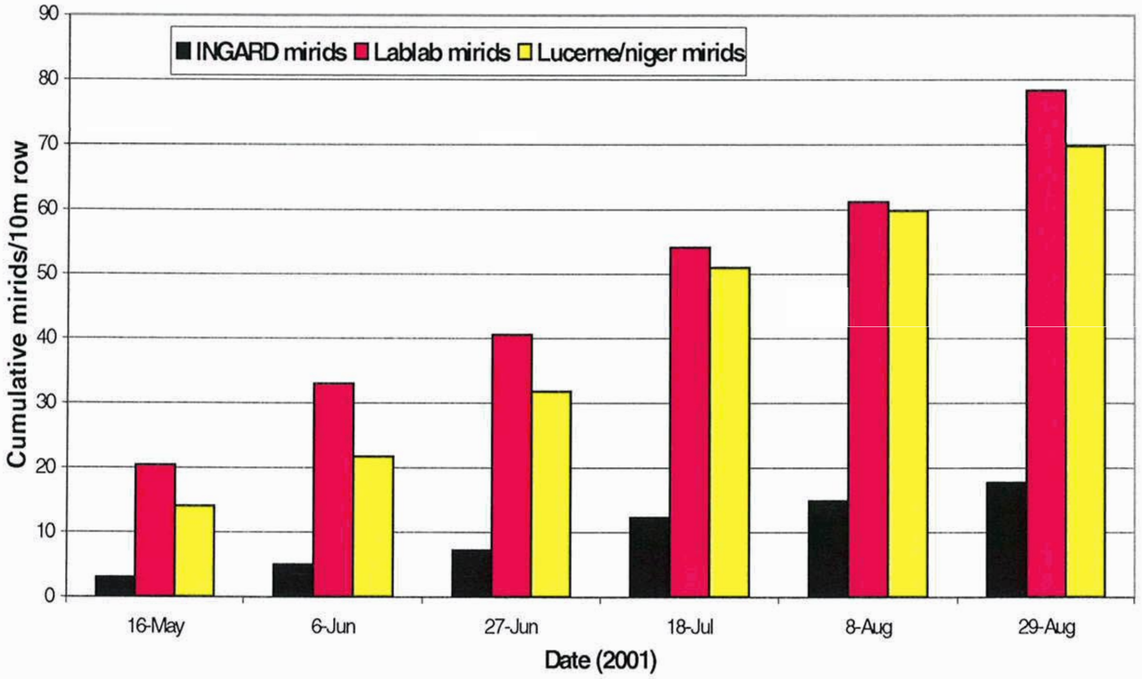


Figure 30. Total cumulative mirid numbers from suction samples in INGARD® and companion crops at Kununurra, 2001.

Apart from trapping and retaining mirids, the other important function of companion crops is the production of beneficial insects including parasitoids such as *Trichogramma*, and predators such as lady beetles, hover flies, lacewings and assassin bugs. The relative performance of the companion crops compared to INGARD® cotton is shown in Figures 31 and 32 for predators and parasitoids (excluding *Trichogramma*) respectively.

Somewhat surprisingly there was little difference between cotton and the companion crops in their attractiveness to predatory insects. The most likely explanation for this is that most of the predators recorded from cotton were aphid feeders, lady beetles and hoverflies. The attractiveness of aphids to these generalist predators probably masks any inherent crop characteristics that may cause one crop to be more attractive than another.

The reverse was the case for parasitoids. Because these insects are very dependent on their hosts for survival, vastly higher numbers were recorded from companion crops compared to cotton. The greater diversity and population size of hosts in the companion crops is clearly important to fostering this group of insects. The companion crops are important reservoirs of parasitoids, which are available to invade the neighbouring cotton crop when pest hosts become available.

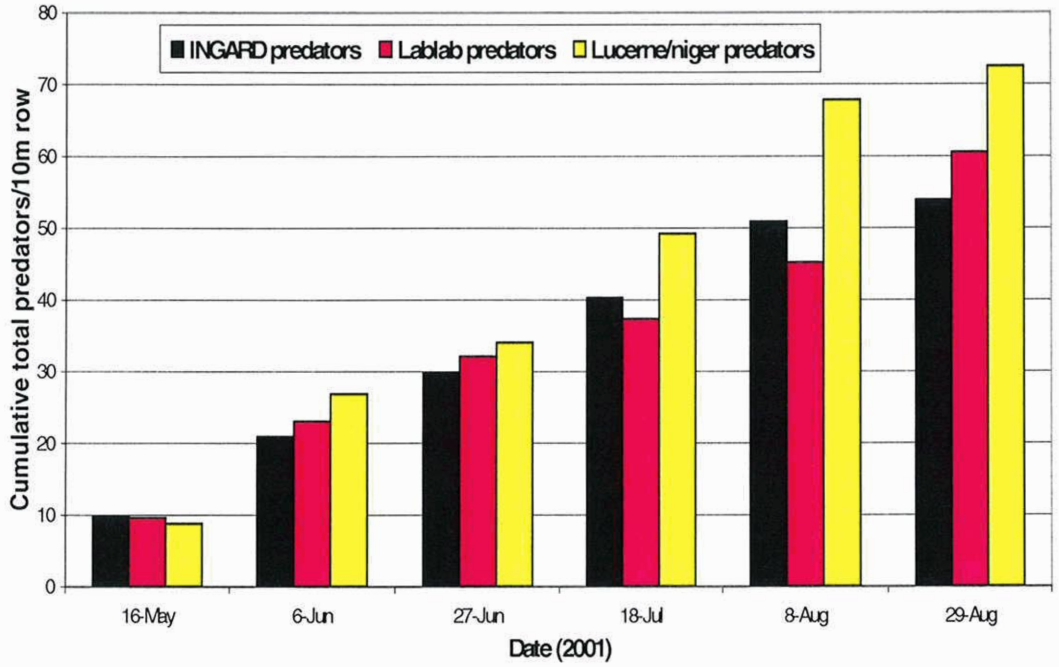


Figure 31. Total cumulative predator numbers from suction samples in INGARD® and companion crops at Kununurra, 2001.

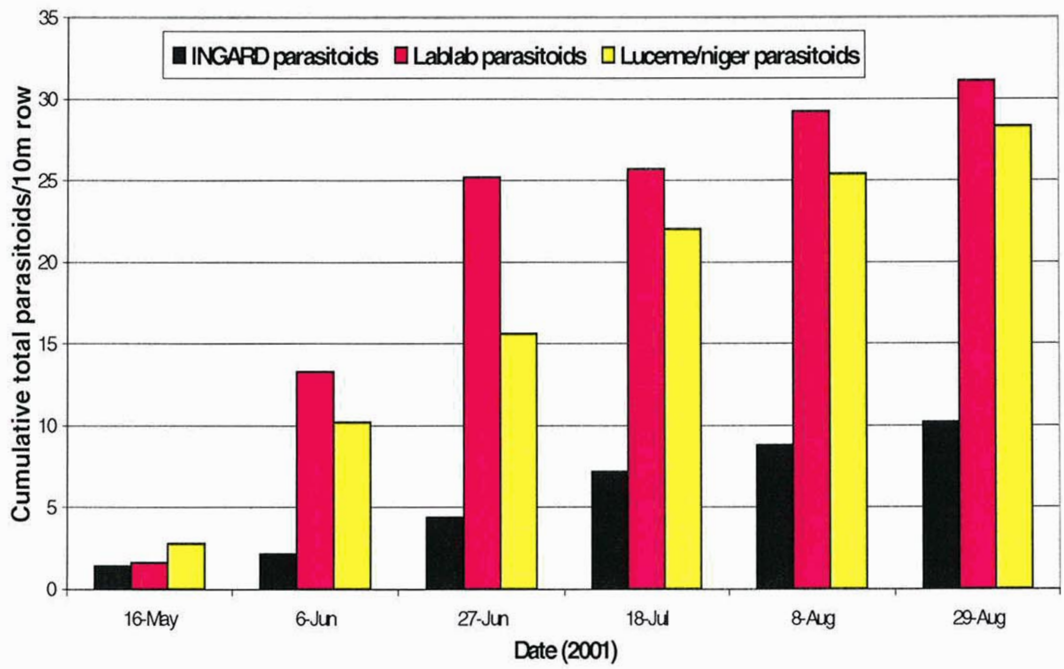


Figure 32. Total cumulative parasitoid numbers from suction samples in INGARD® and companion crops at Kununurra, 2001.

IPM SUMMARY AND CONCLUSIONS

This report details the results of three years of IPM research involving growers at Kununurra test-farming a range of IPM strategies on their properties. Large-scale trials have been made possible by the visionary support of Colly Cotton and the Ord River District Cooperative. More than 1,500 ha of INGARD® cotton was grown in the trials, which were all managed for pests in a uniform way by Department of Agriculture researchers. All crops were scouted according to standard CottonLOGIC thresholds and IPM compatible spray decisions made at all times. In this way comparisons between farms can be made although they are not strictly treatment replications in a statistical sense because the crops were located on different farms with variable times of planting and day to day management.

The research has the long-term aim of developing sustainable pest management systems, linked to an agronomic package, that would enable cotton production to become established on Stage II of the Ord River Irrigation Area, and eventually in other locations in the Kimberley and the NT. The basic elements of the novel production system in tropical Australia include:

- winter, rather that summer cropping, to avoid key pests and high pest pressure;
- INGARD® cotton grown in an IPM system; and
- pre-emptive resistance management.

The overall summary of the trials in terms of yields and sprays is shown in Table 9, along with similar data from earlier years. A highlight from these data is the ongoing low requirement for insecticides on INGARD® crops grown at Kununurra. Less than five total sprays per crop have been required on INGARD® grown alone and less than four sprays used on INGARD® grown with a companion crop. These numbers compare favourably with those from the traditional growing areas in eastern Australia. It should also be remembered that the former summer cotton industry at Kununurra averaged around 20 sprays per season in its best years (~ 1970) and peaked at 40 sprays per crop in the disastrous final season (1974) when insecticide resistance overwhelmed the industry (Wilson, 1974). If these data are used as a benchmark then the dramatic turnaround with the new IPM and INGARD® system is immediately obvious.

Less impressive are the yield results from the 1999 and 2001 seasons. In early seasons average yields were generally in the 7-8 bales/ha range. This was considered acceptable, given the lack of experience with cotton growing and the occasional very poor crop, which brought the trial average down. However yields of the standard variety Siokra L23*i* trended downward from 1996 to 1999, not only on farms but also in CSIRO variety trials. The reason for the yield decline was not determined conclusively but the increasing prevalence of the leaf disease *Alternaria* was suggested as a possible explanation. The change of variety to Siokra V16*i* and Sicot 289*i* immediately lifted yields in 2000 but further yield slippage occurred in the following season. Of enormous concern in the 2001 season was the fact that unsprayed refuge crops of Siokra 1-4 out-yielded some managed INGARD® paddocks. However, on the positive side, excellent individual paddock yields over 9 bales/ ha were also recorded during the trials. Understanding and reducing yield variability is recommended as a high priority for future research based on Bollgard II® varieties.

Table 9. Summary of yields and sprays comparing IPM and non-IPM cotton at Kununurra, 1996-2001

Year	Treatment	Aphid sprays	Mirid sprays	Heliothis sprays	Total sprays	Average yield
1996	INGARD® Alone	0.00	1.75	1.75	3.50	6.70
	INGARD® + Lucerne	0.00	1.25	1.75	3.00	8.22
	INGARD® + Lucerne + Envirofeast®	0.00	1.25	1.75	3.00	7.06
	Conventional Cotton + Lucerne + Envirofeast®	0.00	3.00	7.50	10.50	6.44
1997	INGARD® Alone	0.50	2.50	2.75	5.75	6.61
	NuCOTN 37 Alone	0.75	2.25	2.25	5.25	7.21
	INGARD® + Lucerne	0.25	1.25	1.75	1.75	6.82
	INGARD® + Lucerne + Envirofeast®	0.30	1.70	2.30	4.30	5.80
	INGARD® + Niger	0.25	1.50	3.00	4.75	7.18
1998	INGARD® Alone	0.25	0.00	3.75	4.00	7.27
	INGARD® + Lucerne	0.08	0.00	3.58	3.68	7.53
1999	INGARD® Alone	0.00	0.33	4.50	4.83	6.11
	INGARD® + Lucerne	0.00	0.17	3.50	3.33	5.45
	INGARD® + Lablab	0.00	0.00	4.50	4.50	6.13
2000	INGARD® Alone	0.00	1.00	4.70	5.66	7.37
	INGARD® + Lucerne	0.00	0.00	5.00	5.00	8.27
	INGARD® + Lablab	1.00	1.50	4.00	6.50	6.98
	INGARD® + Pigeon Pea	0.50	1.50	3.50	6.00	7.87
2001	INGARD® Alone	0.00	0.17	2.00	2.17	4.69
	INGARD® + Lucerne + Niger	0.00	0.25	1.00	1.25	4.44
	INGARD® + Lablab	0.00	0.50	0.75	1.25	4.66
	INGARD® + Pigeon Pea	1.00	2.00	0.00	3.00	6.17
Average INGARD® alone		**0.21**	**1.14**	**3.10**	**4.45**	**6.57**
Average INGARD® + IPM treatments		**0.24**	**0.92**	**2.60**	**3.67**	**6.61**

A possible explanation for disappointing yields is an underestimation of the importance of sucking pests, especially green mirids and the cotton aphid, *Aphis gossypii*. Aphids fluctuate in abundance from year to year but occur in large numbers in some seasons and on some crops. Predators generally control aphids but this can be a slow process with crops maintaining high aphid populations for several weeks. Whilst aphids may not be affecting yield in traditional cotton growing areas, their impact may be greater in the winter season in the Kimberley if the populations occur when plants are under other stresses such as cold weather, short day lengths or Pix™ applications. Circumstantial evidence suggests that yield may be improved when aphids are controlled. For example the INGARD® with pigeon pea companion crop in 2001 received three sprays for aphid/mirid control and yielded much higher than other treatments that had minimal sprays (Table 9).

Key features of IPM system research included the role of companion crops and the encouragement of naturally occurring beneficial insect species. The companion crops assessed in the experiments were lucerne, lablab, pigeon pea and a lucerne/niger mix. Whilst each of the alternatives has merit, lablab has emerged as the companion crop of choice by farmers because it is easy to establish, fast growing and easy to manage. From a research point of view the crop performs well in terms of trapping mirids and attracting *Helicoverpa* oviposition.

Lucerne is too difficult to establish in hot conditions at the beginning of the season. However, some growers have decided to use ground rigs exclusively and have planted their traffic rows permanently to lucerne. A grower who used this system in 2001 achieved an average yield of 8.12 bales/ha with only one insecticide application, testament to the potential of this system (Table 8 - Farm 4).

The overall conclusion from the research is that INGARD® cotton, grown with supporting IPM systems, shows great promise in tropical north-western Australia. Winter cropping avoids many pest and agronomic difficulties imposed by summer cropping in the Kimberley region, but raises its own crop adaptation issues.

RECOMMENDATIONS

The results from this project support the development of a sustainable cotton industry in north-western Australia using transgenic varieties grown in an integrated pest management (IPM) system. The benefits of IPM in dramatically reducing the insecticide requirement of the crop and producing a rich abundance of beneficial insects have also been shown.

However, there is a need for additional pest management and agronomic research to be undertaken in the Kimberley to build on the encouraging results achieved to date and to increase average yields. In terms of pest management research, key areas requiring additional input include:

1. continued development of dynamic *Helicoverpa* and *Spodoptera* thresholds in Bollgard II® cotton;
2. further refinement and improvements to companion crop and beneficial insect management in Bollgard II® IPM systems, including a 'trap and destroy' technique for mirids;
3. assessment of refuge crop options and defining a pre-emptive resistance management strategy for Bollgard II® cotton in Kimberley winter grown cotton;
4. integration of agronomic and pest management research to develop a Bollgard II® production package suitable for commercial production.

REFUGE CROP OPTIONS

Background

Resistance management strategies for GM crops, including INGARD®, Bollgard II® and Roundup Ready® crops, is a requirement of regulatory authorities prior to registration. In the case of Bt cotton in northern Australia, it is recognised that seasonal and cropping system differences mean that strategies developed for eastern Australia can not automatically be transposed to other regions. For this reason, it is important that new cotton growing regions develop appropriate resistance management plans tailored to the specific needs of the area.

One important component of resistance management in Bt cotton is the use of refuge crops, which are grown to ensure an abundance of *Helicoverpa* moths that have not been exposed to Bt toxins. As a first step in developing regional resistance management models, it is important to quantify the production of *Helicoverpa* from a range of potential refuge crops. *H. armigera* is seen as the primary risk and therefore crops, which are both economic and likely to be good hosts for the pest, have been investigated in these trials.

Methods

During the three years of the project, similar methods to assess refuge crops were used. Approximately monthly, between irrigation cycles, the crops were sampled for *Helicoverpa* pupae. At least 15, 0.5 m^2 (1 m x 0.5 m) quadrats were placed in the soil surface under the target crop. The loose dirt was scraped away and the hard ground examined for larval entrance holes. If holes in the soil were found they were carefully dug up with a trowel to expose the pupal chamber. The number of pupal chambers and pupae in each quadrat was recorded. Pupae were removed and returned to the laboratory where they were placed in individual rearing chambers. For each quadrat the fate of the collected pupa (emerged, parasitised, diapausing, diseased) was recorded.

Suitable crops for sampling were selected from the research station and from commercial farms. To this extent the sampling was opportunistic and crops were sometimes sprayed and not true 'refuges'. However, even sprayed crops provide important information on the generation of *Helicoverpa*, because they reflect commercial crop production.

Results and discussion

The numbers of viable *H. armigera* pupae produced from various crops throughout the cropping season are summarised in the following three Figures for 1999, 2000 and 2001. Maize and sweetcorn were the outstanding *H. armigera* nurseries in each of the seasons and produced between 20,000 to 30,000 viable pupae per hectare. Larger numbers of pupae were sometimes recorded from other crops but these were often parasitised or diseased and therefore did not produce viable pupae that would lead to moths. It is thought that maize and sweetcorn cobs provide an excellent environment for larval development and the tight cob sheaths protect larvae from parasites and predators. In addition, maize is rarely sprayed and, although sweetcorn is often heavily sprayed, the cob sheath prevents contact by insecticides and larvae are able to develop unaffected by sprays.

These data are preliminary and give information on sources of *H. armigera* from commercial cropping situations. Future assessments will be made with a range of candidate refuge crops planted in the same paddock with Bollgard II® and unsprayed. The data generated from these trials will then be more closely matched to the phenology of the target crop to be protected (Bollgard II®) and reflect a true refuge crop which is not sprayed with products that may control *Helicoverpa*.

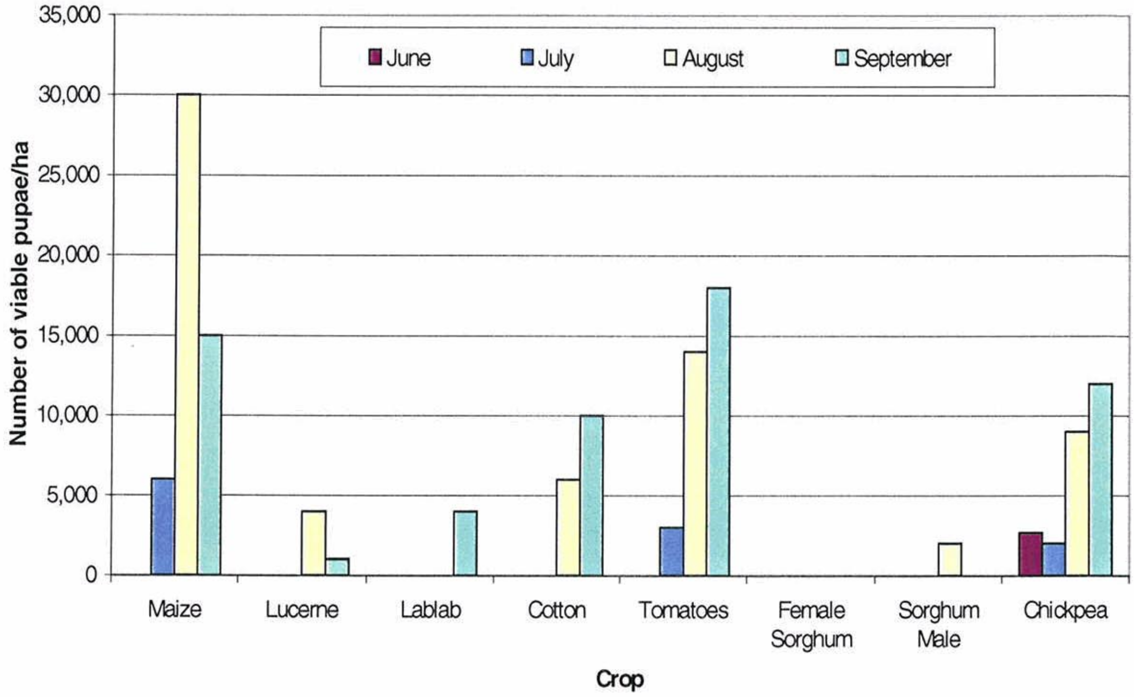


Figure 33. Estimated number of viable *Helicoverpa armigera* pupae from refuge crops, Kununurra, 1999.

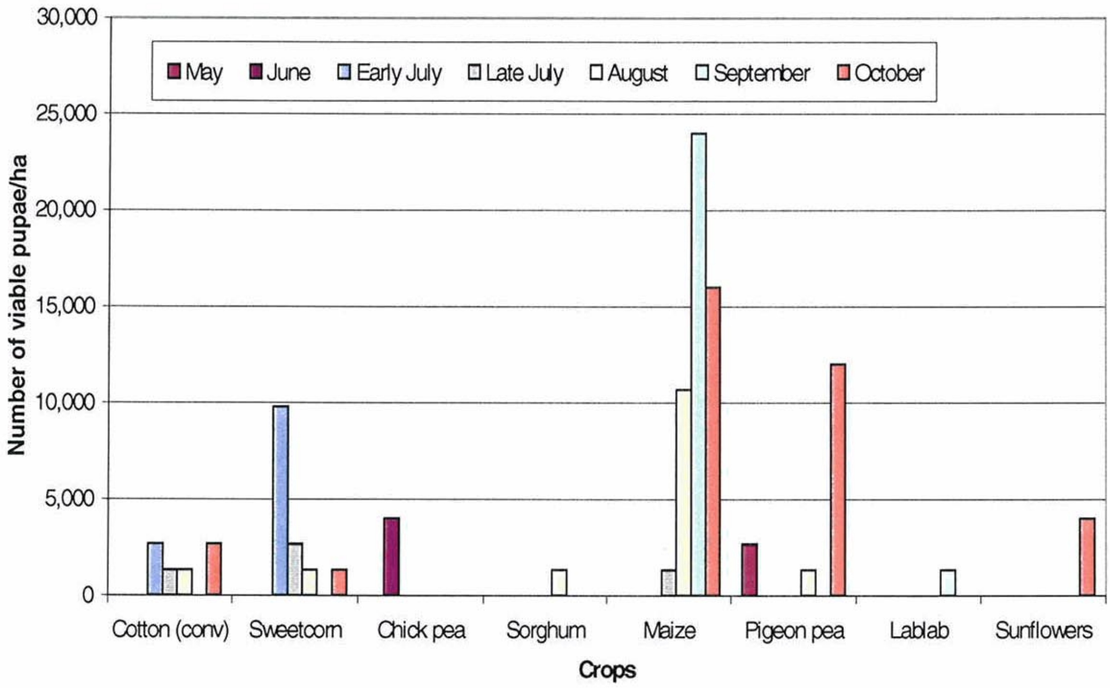


Figure 34. Estimated number of viable *Helicoverpa armigera* pupae from refuge crops, Kununurra, 2000.

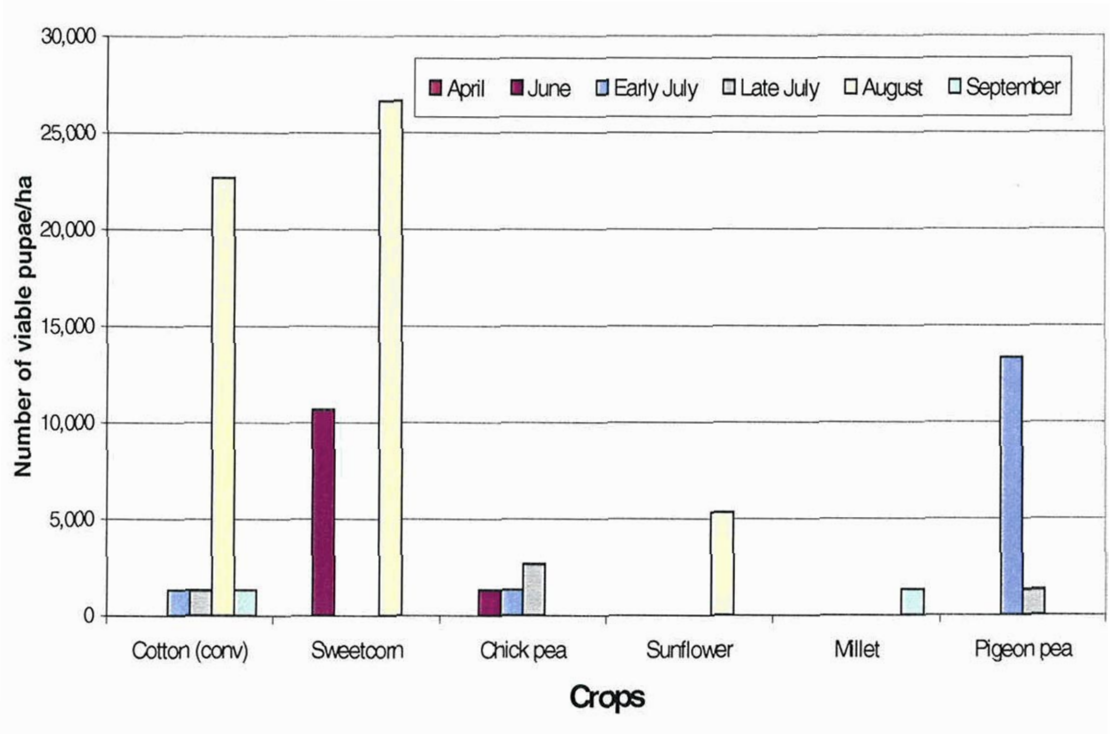


Figure 35. Estimated number of viable *Helicoverpa armigera* pupae from refuge crops, Kununurra, 2001.

MIRID THRESHOLDS

The green mirid, *Creontiades* spp, is a recognised pest of cotton that destroys terminals and small squares. Damage occurs during feeding when the insect inserts its needle-like mouthparts into the plant tissue and injects salivary enzymes that cause desiccation and death of the surrounding plant cells. The green mirid is a major pest of INGARD® cotton. Previously, on conventional cotton, chemicals used to control *Helicoverpa* often controlled green mirids simultaneously.

Field cage studies carried out in NSW indicated that up to four adult green mirids could be tolerated per metre in cotton prior to flowering before maturity is significantly delayed or yield threatened. However, green mirids are very mobile pests and are easily disturbed during sampling, making accurate estimates of the population in the field very difficult to achieve. It is common therefore for commercial thresholds to be well below four per metre and often less than one per metre.

For the past three years the cotton project in the ORIA has relied upon the standard green mirid thresholds which were developed for the eastern States cotton industry (Table 10). These are rather complicated and consist of three separate thresholds; - one for green mirid nymphs, one for green mirid adults and one for sucking pests. The sucking pest threshold combines the damage levels of green mirid nymphs (3.5 times the damage of adult mirids) and adults with apple dimpling bug (one-fifth the damage of adult mirids).

Table 10. Green mirid thresholds on INGARD® cotton grown in eastern Australia

	[a] Phase I	[b] Phase II	[c] Phase III
Green Mirid nymphs	-	-	-
Green Mirid adults	0.5/m	0.5/m	0.5/m
Sucking pests	0.16 to 0.33/m	2.00 to 4.00/m	-

[a] Phase I - crop emergence till 50 per cent plants with first square.
[b] Phase II - 50 per cent plants with first square to 1 per cent open bolls.
[c] Phase III - 1 per cent open bolls to harvest.

The current mirid thresholds are possibly unsuitable for the ORIA environment, which offers a vastly different growing season to that in the east. For this reason it was decided to validate thresholds for *Creontiades* spp. on INGARD® cotton. The purpose of mirid studies in the 1999, 2000 and 2001 seasons was to evaluate the existing mirid thresholds for their applicability to the winter growing conditions at Kununurra.

1999 SEASON

Aim

To validate standard mirid thresholds in winter grown cotton at Kununurra.

Methods

The trial was planted into Field 10C at FWI as a randomised block design with four blocks of each of four treatments. For ease of applying insecticide treatments and for harvesting purposes, plots ran the entire length of the field. The four treatments were spray thresholds for sucking pests as shown below:

1. Control (unsprayed)
2. Temik® (at planting)
3. 0.5 total sucking pests/metre
4. 4.0 total sucking pests/metre

Plots of 27 m (15 beds) x 219 m were sown with Siokra L23*i* at 12 seeds per metre to establish eight plants per metre. Temik® was applied in the planting furrow at 7 kg/ha, for sucking pest control, in the appropriate plots of the experiment.

Scouting and insect measurements

From planting until harvest the whole field was scouted as one management unit for *Helicoverpa* control purposes. Thirty plants in the field were checked using the protocol outlined by CottonLOGIC. The presence/absence method of sampling insects was used. Standard CottonLOGIC thresholds were used and the entire field was treated if these were exceeded. Selective insecticides with no impact on mirids were used through the mirid trial period to control *Helicoverpa* if necessary.

Specific mirid sampling

From first square until first flower specific mirid scouting was conducted. Thirty plants in each plot were checked using the protocol outlined by CottonLOGIC. Only sucking pests were counted. During the scouting the whole plant was examined and the total number of sucking pests counted.

D-vac sampling

D-vac samples were taken twice weekly immediately following the visual scouting on the cotton. Five samples, each covering a 5 m transect were taken from each plot. Sampling commenced when the cotton plants reached first square and continued until first flower. The number of sucking pests found in the D-vacs were counted. This was used as a check to determine if mirids were not seen during visual scouting.

Yield measurements

At first flower, when the intensive scouting stage of the trial was concluded, the number of squares per plant and the percentage of tipped plants was scored. Ten 1 m transects were taken from each plot and the total number of fruit on each plant counted. The number of plants that were tipped out, the node of tipping and the total number of plants present in the sample were recorded.

The cotton was harvested using a John Deere cotton picker, which had been modified to pick small trials. Six 20 m transects were picked from the middle beds of each plot and the cotton collected into hessian bags. The samples were weighed and a small sub-sample (300-600 grams) taken for ginning. The sub-sample was hand ginned and a turnout and lint yield in Stat-bales/ha calculated.

Five whole untipped cotton plants were collected from the row next to each plot that was picked (a total of 30 plants per treatment plot). Bolls on these plants were mapped using the plant mapping system in CottonLOGIC.

BUFFER	4.0 total sucking pests/m	Temik®	0.5 total sucking pests/m	Control	0.5 total sucking pests/m	Control	4.0 total sucking pests/m	Temik®	4.0 total sucking pests/m	Control	0.5 total sucking pests/m	Temik®	Control	4.0 total sucking pests/m	Temik®	0.5 total sucking pests/m
3 beds	15 beds	15 beds	15 beds	15 beds	15 beds	15 beds	15 beds	15 beds	15 beds	15 beds	15 beds	15 beds	15 beds	15 beds	15 beds	15 beds
	Replicate 1				Replicate 2				Replicate 3				Replicate 4			

Figure 36. The experimental design for the sucking pest threshold trial in 1999.

Results

Despite planting the trial in a paddock with a history of mirid attack, scouting showed that mirids were in very low abundance throughout the season. This was the case for all crops in the valley and other sucking pest such as aphids were also in very low abundance. Not surprisingly, none of the treatment thresholds were reached and therefore no spray applications were made to control mirids. The following table shows that there were no significant yield differences between any of the treatments, including the Temik® applied at planting.

Table 11. Yield summary from mirid control trial at Kununurra, 1999

Treatment	Yield (bales/ha)	Number of mirid sprays
Control	5.867	0
Temik® at planting	5.804	0
0.5 sucking pests/m	6.042	0
4.0 sucking pests/m	5.796	0

LSD = 0.3426, $P < 0.05$

2000 season

Aim

To determine the most effective methods of sucking pest control for early season sucking pests on INGARD® cotton in the ORIA.

Treatments

The trial was planted as a randomised complete block design with four blocks of each of five treatments (Figure 37). The data were analysed using GenStat® for Windows (Sixth Edition).

For ease of applying treatments and harvest, plots ran the entire length of the field. The treatments were spray thresholds for sucking pests and application timing of Temik®. There were five treatments:

1. Control (untreated)
2. Temik® at 5 kg/ha at planting
3. 0.5 total sucking pest/metre
4. 4.0 total sucking pests/metre
5. Temik® at 8 kg/ha side-dressed at first square

Control action was taken when the mean number of pests from four plots in a treatment reached the prescribed threshold. Sprays were applied by ground rig or with an aircraft.

Methods

Plots of 21.6 m (12 beds) x 149 m were planned to be sown with an experimental 2-gene line of cotton nicknamed 'DEVIL' at 10 seeds per metre to establish 8 plants per metre.

However, approval to use the line was not given by GMAC and a last minute variety change to Siokra V16*i* was made to enable the trial to proceed.

Temik® was applied at planting in the seed furrow at 5 kg/ha, for early sucking pest control, in the appropriate plots of the experiment. Temik® (8 kg/ha) was side-banded just prior to first square, in the appropriate treatment plots.

Scouting and insect measurements

From planting until harvest the whole field was scouted as one management unit for *Helicoverpa* control purposes. Thirty plants in the field were checked using the protocol outlined by CottonLOGIC. The presence/absence method of sampling insects was used. Standard CottonLOGIC thresholds were used and the entire field was treated if this was exceeded. Selective insecticides with no impact on mirids were used throughout the mirid trial period for *Helicoverpa* control.

Specific mirid sampling

From first square until first flower, specific mirid scouting was conducted. Thirty plants in each plot were checked using the protocol outlined by CottonLOGIC. Only sucking pests were counted. During the scouting the whole plant was examined and the total number of sucking pests counted.

D-vac sampling

D-vac samples were taken twice weekly immediately following the visual scouting on the cotton. Five samples, each covering a 5 m transect were taken from each plot. Sampling commenced when the cotton plants reached first square and continued until first flower. The number of sucking pests found in the D-vacs were counted. This was used as a check to determine if mirids may not have been seen during visual scouting.

Leaf samples

Leaf samples were collected from the Temik® applied in furrow at 5 kg/ha. Samples were collected at two weeks, four weeks, six weeks, eight weeks, and 10 weeks after application. The samples were frozen and forwarded to Aventis™ for aldicarb residue analysis.

Yield measurements

At first flower, when the intensive scouting stage of the trial was concluded, the number of squares per plant and the percentage of tipped plants was scored. Ten 1 m transects were taken from each plot and the total number of fruit on each plant counted. The number of plants that were tipped out, the node of tipping and the total number of plants present in the sample were recorded.

The cotton was harvested using a John Deere cotton picker, which had been modified to pick small trials. Six 15 m transects were picked from the middle beds of each plot and the cotton collected into hessian bags. The samples were weighed and a small sub-sample (300-600 grams) taken for ginning. The sub-sample was hand ginned and a turnout and lint yield in Stat-bales/ha calculated.

Five whole untipped cotton plants were collected from the row next to each plot that was picked (a total of 30 plants per treatment plot). Bolls on these plants were mapped using the plant mapping system in CottonLOGIC.

Head channel

Replicate	Treatment	Beds
Replicate 1	4.0 total sucking pests/m	12 beds
	Temik® in furrow	12 beds
	0.5 total sucking pests/m	12 beds
	Control	12 beds
	Temik® side-dressed	12 beds
Replicate 2	0.5 total sucking pests/m	12 beds
	Temik® side-dressed	12 beds
	4.0 total sucking pests/m	12 beds
	Temik® in furrow	12 beds
	Control	12 beds
Replicate 3	4.0 total sucking pests/m	12 beds
	Control	12 beds
	0.5 total sucking pests/m	12 beds
	Temik® side-dressed	12 beds
	Temik® in furrow	12 beds
Replicate 4	Control	12 beds
	Temik® in furrow	12 beds
	4.0 total sucking pests/m	12 beds
	Temik® side-dressed	12 beds
	0.5 total sucking pests/m	12 beds

Tail drain

Figure 37. The experimental design for the sucking pest threshold trial in 2000.

Results

The results from the mirid threshold trial are summarised in Table 12. Due to an equipment failure it was not possible to side-dress the Temik® so that the side-dress treatment became additional control plots. Similarly the 4 mirids/m threshold treatment did not reach a spray threshold and therefore was considered to be additional control plots for yield estimation purposes.

Neither the Temik® at planting nor the standard threshold of 0.5 mirids/m treatments gave a yield improvement compared to the unsprayed control. This was surprising because the 0.5 mirid/m threshold was breached on two occasions and insecticides applied for control. In fact the yield of the sprayed treatment trends lower than the other treatments and is significantly lower than the Temik® applied at planting which gave the best yield.

Table 12. Yield summary from mirid control trial at Kununurra, 2000

Treatment	Yield (bales/ha)	Number of mirid sprays
Control	9.027	0
Temik® at planting	9.150	0
0.5 sucking pests/m	8.697	2
4.0 sucking pests/m	Merged with 'control'	0
Temik® side-dressed	Merged with 'control'	0

LSD = 0.3381, $P < 0.05$

2001 season

Aim

To determine the most effective methods of sucking pest control for early season sucking pests on INGARD® cotton in the ORIA.

Methods

The trial was planted on Cununurra clay formed into 1.8 m beds, on 11 April 2001. Seed was planted in two rows per bed. Beds were 16 cm in height. Plots of 22 m (12 beds) x 149 m were sown with Siokra V16*i* at 10 seeds per metre to establish eight plants per metre. Temik® was applied at planting in the seed furrow at 5 kg/ha, for sucking pest control, in the appropriate plots of the experiment. Temik® (8 kg/ha) was also side-banded into the furrow side of the bed just before first square, in the appropriate treatment plots.

The trial was planted as a randomised complete block design with four blocks of each of five treatments (Figure 38). The data were analysed using GenStat® for Windows (Sixth Edition).

Block 1	4.0 total sucking pests/m	Temik® in furrow	0.5 total sucking pests/m	Control	Temik® side-dressed
Block 2	0.5 total sucking pests/m	Temik® side-dressed	4.0 total sucking pests/m	Temik® in furrow	Control
Block 3	4.0 total sucking pests/m	Control	0.5 total sucking pests/m	Temik® side-dressed	Temik® in furrow
Block 4	Control	Temik® in furrow	4.0 total sucking pests/m	Temik® side-dressed	0.5 total sucking pests/m

Figure 38. The experimental design for the sucking pest trial in 2001.

Treatments

For ease of applying treatments and harvest, plots ran the entire length of the field. The treatments were spray thresholds for sucking pests and application timing of Temik®. There were five treatments:

1. Control (Untreated)
2. Temik® at 5 kg/ha at planting
3. 0.5 total sucking pest/metre
4. 4.0 total sucking pests/metre
5. Temik® at 8 kg/ha side-dressed at first square

Control action was taken when the mean number of pests from four plots in a treatment reached the prescribed threshold. Sprays were applied by ground rig or with an aircraft.

Scouting and insect measurements

From planting until harvest the whole field was scouted as one management unit for *Helicoverpa* control purposes. Thirty plants in the field were checked using the protocol outlined by CottonLOGIC. The presence/absence method of sampling insects was used. Standard CottonLOGIC thresholds were used and the entire field was treated if this was exceeded. Selective insecticides with no impact on mirids were used through the trial period for *Helicoverpa* control.

Specific mirid sampling

From first square until first flower specific mirid scouting was conducted. Thirty plants in each plot were checked using the protocol outlined by CottonLOGIC. Only sucking pests were counted. During the scouting the whole plant was examined and total number of sucking pests counted.

D-vac sampling

D-vac samples were taken twice weekly immediately following the visual scouting on the cotton. Five samples, each covering a 5 m transect were taken from each plot. Sampling commenced when the cotton plants reached first square and continued until first flower. The numbers of sucking pests found in the D-vacs were counted. This was used as a check to determine if mirids were not seen during visual scouting.

Leaf samples

Leaf samples were collected from the Temik® applied in furrow at 5 kg/ha and Temik® applied as a side-dressing at 8 kg/ha. Samples were collected at two weeks, four weeks, six weeks, eight weeks, and 10 weeks after application. The samples were frozen and forwarded to Aventis™ for aldicarb residue analysis.

Yield measurements

At first flower, when the intensive scouting stage of the trial was concluded, the number of squares per plant and the percentage of tipped plants was scored. Ten 1 m transects were taken from each plot and the total number of fruit on each plant counted. The number of plants that were tipped out, the node of tipping and the total number of plants present in the sample were recorded.

The cotton was harvested using a John Deere cotton picker, which has been modified to pick small trials. Six 15 m transects were picked from the middle beds of each plot and the cotton collected into hessian bags. The samples were weighed and a small sub-sample (300-600 grams) taken for ginning. The sub-sample was hand ginned and a turnout and lint yield in Stat-bales/ha calculated.

Five whole untipped cotton plants were collected from the row next to each plot that was picked (a total of 30 plants per treatment plot). Bolls on these plants were mapped using the plant mapping system in CottonLOGIC.

Results

The trial received low pest pressure from all pests, including mirids, throughout the season. No control of any pests was required except in the 0.5 mirid/m threshold treatment, which was sprayed on one occasion with Regent 200SC™ at 60 ml/ha. Excellent mirid control was achieved and no additional sprays were necessary.

Yield data shown in Table 13 indicate that the 0.5 mirid/m threshold treatment gave a superior yield to all other treatments. The yield increase of about 1 bale/ha relative to the control represents a yield increase of about 16 per cent. This is consistent with data from Katherine in the Northern Territory (Andrew Ward, pers. com.) and confirms that relatively low numbers of mirids can causse serious yield declines. However, in the 2000 season at Kununurra there was no yield improvement from the 0.5 mirid/m treatment, despite two sprays being applied. That seemingly anomalous result may be explained by compensation. The 2000 season yields were over 9 bales/ha and this suggests excellent growing conditions that favour compensation for early pest damage. Contrasting with that, the current season produced yields of around 6.5 bales/ha, suggesting that seasonal conditions may have limited the potential for recovery from early pest attack. Thus the prevention of early fruit loss in the low mirid threshold treatment may have had a significant influence on yield this season.

The application of Temik®, either pre-plant or side-banded, did not increase yield compared to the untreated control this season.

Table 13. Yield summary from the mirid threshold trial at Kununurra, 2001

Treatment	Yield (bales/ha)	Number of mirid sprays
Control	6.608	0
Temik® in furrow	6.636	0
0.5 sucking pests/m	7.658*	Regent 200SC™ at 60 ml/ha
4.0 sucking pests/m	6.909	0
Temik® side-dressed	6.983	0

* LSD = 0.4257, $P < 0.05$

HELICOVERPA THRESHOLDS

Background

Helicoverpa spp are considered the most damaging insect pests of cotton in Australia and consequently have attracted considerable research attention. Problems with insecticide resistance and possible environmental damage associated with excessive insecticide use has led to concerted efforts to reduce spraying in cotton. Integrated Pest Management (IPM) methods and area wide management have emerged as new tactics and are underpinned by decision support systems, including CottonLOGIC. However, despite the myriad of factors to be taken into consideration before spraying, the most important remains the 'pest threshold', as measured by crop scouting. In the case of INGARD® cotton, the established threshold for *Helicoverpa* is a total of 2 larvae/m row in all crop growth phases (Anon. 2002).

Early experiments with INGARD® at Kununurra raised concerns that the fixed threshold of 2 larvae/m may not be appropriate for the unusual winter growing environment in the Kimberley. The concerns were twofold, firstly because the 'reverse' growing season meant that cotton growth was rapid in high temperatures at the beginning and end of the season but slow during boll development in mid-season, and secondly, that extensive periods of 'sub-threshold' damage were often observed.

A preliminary trial conducted in 1998 compared the standard threshold of 2.0 larvae/m to two lower thresholds, 1.0 larva/m and 0.5 larva/m. The results in Table 14 were not accepted at face value, which would be to recommend lower thresholds, but rather as a challenge to develop dynamic thresholds that took into account protracted periods of sub-threshold *Helicoverpa* damage.

Table 14. The influence of *Helicoverpa* thresholds on yield of Siokra L23*i* grown at Kununurra, 1998.

Treatment	Yield (bales/ha)	% yield of two larvae/m	Number of pre-cutout sprays
0.5 larva/m	10.48 ± 0.21*	110%	2
1.0 larva/m	9.75 ± 0.19	102%	0
2.0 larvae/m	9.52 ± 0.17	100%	0

LSD = 0.53, $P < 0.05$

Aims

The objective of the threshold experiments was to test the validity of established *Helicoverpa* thresholds in the winter system with the aim of developing a more dynamic and responsive threshold to better reflect the growth stage of the crop and the impact of insect damage.

Methods

Methodology was similar for each year of the experiments. Plots were large, 21.6 m (12 beds) or 27 m (15 beds) X paddock length (150-250 m). The standard variety sown was Siokra L23*i* in 1999, and Siokra V16*i* was the variety in 2000 and 2001. Cotton seed was sown at 13 seeds per metre to establish 9-12 plants/m. Seed was sown at a depth of 2 cm into moisture using a precision air seeder. Temik® was applied in the planting furrow at 7 kg/ha for sucking pest control. Fertiliser and irrigation schedules were as per standard practice for the area.

The trials were planted as randomised complete block designs with four replications of each treatment. For ease of applying treatments and for machine picking, plots ran the entire length of the field. The treatments were spray thresholds for *Helicoverpa* larvae. There were four treatments in each of the seasons, as summarised in Table 15.

Table 15. *Helicoverpa spp* thresholds evaluated in field experiments at Kununurra, 1999-2001

1999	2000	2001
0.5 larva/m	Fixed Threshold (2 larvae/m)	Fixed Threshold (2 larvae/m)
1.0 larva/m	Cumulative 5 larvae/m	Cumulative 10 larvae/m
2.0 larvae/m	Cumulative 10 larvae/m	Cumulative 10 larvae/m + Retention Factor
Untreated control	Cumulative 15 larvae/m	Untreated control

All larval stages, excluding very small larvae (< 3 mm), were included in the threshold calculations in 2001 but not in the previous seasons. Control action was always taken on the first check rather than the second consecutive check. Control action was taken when the mean number of larvae of four plots in the treatment reached the prescribed threshold. Sprays were applied either with a spray coupe, when soil conditions permitted, or with an aircraft fitted with micronaires.

Scouting of all plots in all years used the presence/absence method as described in CottonLOGIC. Similarly the thresholds from the CottonLOGIC program were used in all cases for fixed thresholds set at either 0.5, 1.0 or 2.0 larvae/m. However, for cumulative thresholds a new calculation was used. In essence, the cumulative threshold calculation uses typical scouting data but also sums some past scouting data to give a cumulative output. The developmental stage of the *Helicoverpa* counted is also taken into consideration by applying a damage rating for larval size. The damage rating ensures that when medium and large larvae are encountered, the cumulative larvae threshold accelerates, compared for example, to when only eggs and small larvae are present.

In 2001 the additional factor of fruit retention was included so that high retention crops did not reach threshold as quickly as low retention crops at the same levels of pest pressure.

The trials were harvested using a John Deere cotton picker, which was modified to pick small trials. One of the picking heads was removed so that only one row was picked at a time and the chutes were extended into the cage. Bags were attached to the chutes to collect the seed cotton. Six 15 m strips were picked from the middle bed of each plot and the cotton collected into hessian bags. The samples were weighed and a small sub-sample (300-600 grams) was taken for ginning. The sub-sample was hand ginned and a turnout and lint yield in bales/ha calculated. Yield measurements were statistically analysed using GenStat for Windows (5th Edition).

Results

1999 season

In 1999 the threshold trial of the previous season was repeated but included an unsprayed control to better benchmark the yield potential of the crop in that particular season. The data shown in Table 16 show that all the *Helicoverpa* thresholds tested gave a significantly higher yield compared to the unsprayed control. In addition, the 1 larva/m threshold also resulted in a significantly higher yield than the standard threshold of 2 larvae/m. However, as in the previous season, an additional insecticide application was required to achieve a modest yield increase of 8 per cent. In contrast, two additional sprays were used for the lowest threshold of 0.5 larvae/m but no significant yield improvement over the 2 larvae/m treatment was observed.

Table 16. The influence of *Helicoverpa* thresholds on yield of Siokra L23*i* grown at Kununurra, 1999

Treatment	Yield (bales/ha)	% yield of 2 larvae/m	Number of pre-cutout sprays
0.5 larvae/m	6.36 ± 0.54	104%	5
1.0 larvae/m	6.60 ± 0.80	108%	4
2.0 larvae/m	6.11 ± 0.68	100%	3
Control	4.76 ± 0.65	78%	0

LSD = 0.38, $P < 0.05$

2000 season

The trial in 2000 evaluated three 'cumulative' thresholds with the standard fixed threshold of 2 larvae/m. This was the first attempt at developing a more dynamic threshold, which took into calculation the numbers of sub-threshold larvae from previous checks (see 'Methods' for details).

The results in Table 17 are inconclusive, with the cumulative 10 larvae/m threshold giving a significantly lower yield than each of the other thresholds. However there was no significant yield difference between the fixed 2 larvae/m, cumulative 5 larvae/m and cumulative 15 larvae/m threshold treatments.

In terms of insecticide requirements, the lowest of the cumulative thresholds (5 larvae/m) had four sprays compared to two sprays for the other treatments. There was no yield improvement attributable to the extra sprays in the cumulative 5 larvae/m. The other threshold treatments required two sprays each but the timing of the sprays was different due to the different threshold calculations. Despite different spray timings, no significant yield differences occurred between the fixed 2 larvae/m threshold and the cumulative 5 or 15 larvae/m treatments.

Table 17. The influence of *Helicoverpa* thresholds on yield of Siokra V16*i* grown at Kununurra, 2000.

Threshold treatment	Yield (bales/ha)	% yield of 2 larvae/m	Number of pre-cutout sprays
Fixed threshold (2 larvae/m)	7.17 ± 0.13	100%	2
Cumulative 5 larvae/m	7.23 ± 0.16	101%	4
Cumulative 10 larvae/m	6.68 ± 0.16	93%	2
Cumulative 15 larvae/m	7.31 ± 0.20	102%	2

LSD = 0.46, $P < 0.05$

2001 season

The 2001 threshold trial again aimed to refine the cumulative larval threshold concept and include the additional variable of retention in the calculations. Thus the cumulative 10 larvae/m threshold was compared to the standard 2 larvae/m, an untreated control and a cumulative 10 larvae/m + retention factor threshold. A summary of results is shown in Table 18.

Yields in 2001 were very poor but interestingly, the fixed 2 larvae/m threshold did not out-yield the unsprayed control despite two insecticide applications. The highest yield was achieved using the cumulative 10 larvae/m threshold, which required only one insecticide application. The addition of a retention factor to the cumulative threshold triggered an additional spray but did not increase yield.

Table 18. The influence of *Helicoverpa* thresholds on yield of Siokra V16*i* grown at Kununurra 2001

Threshold treatment	Yield (bales/ha)	% yield of 2 larvae/m	Number of pre-cutout sprays
Fixed threshold (2 larvae/m)	5.00 ± 0.09	100%	2
Cumulative 10 larvae/m	5.65 ± 0.19	113%	1
Cumulative 10 larvae/m + retention factor	5.28 ± 0.08	106%	2
Unsprayed	4.86 ± 0.15	97%	0

LSD = 0.38, $P < 0.05$

Discussion

Field trials in 1998 and 1999 explored the impact of different fixed thresholds for *Helicoverpa* on yield of INGARD® cotton at Kununurra. The standard threshold of 2 larvae/m was compared to lower thresholds and to unsprayed controls in large experiments. In both years either the 0.5 larva/m or the 1 larva/m threshold gave a significant yield improvement over the standard threshold. These results were important because they demonstrated that significant yield was being lost by adhering to the standard threshold of 2 larvae/m. Moreover the lower thresholds did not lead to excessive insecticide use, one extra spray was used in 1999 and two more sprays in 1998. Nevertheless the imposition of any additional sprays was considered undesirable and counter productive to the goal of sustainable IPM production systems for the Kimberley (Strickland *et al.* 1998).

An observation from the early trials was that the timing of sprays in the lower threshold treatments was noticeably different to the standard treatment. It was perceived that the lower thresholds had the effect of early intervention in prolonged sub-threshold damage common in INGARD® crops. Thus it was considered important to investigate a new approach to *Helicoverpa* thresholds in a way that responded to sub-threshold damage rather than waiting for a predetermined 2 larvae/m threshold to be reached. Therefore, in 2000 and 2001, **cumulative larval thresholds** were evaluated in field trials at the Frank Wise Institute. The cumulative thresholds utilise normal scouting data but include counts from previous scouting events. In the 2001 trial, a **retention factor** was also built into the formula so that crops with poor retention would have earlier spray intervention than crops with high retention, and visa versa.

The cumulative larval thresholds have given variable results but have included some encouraging yields, especially in an inherently low yielding season as experienced in 2001. In that season the cumulative 10 larvae/m treatment produced a significantly higher yield than the other thresholds and required one less spray. This highlights the important fact that cumulative thresholds have the capacity to change the **timing** of insecticide applications rather than the **number** of sprays. At least in some cases this results in a significantly higher crop yield with the same or fewer sprays than in crops utilising the standard fixed threshold of 2 larvae/m. More research is required to fully test and further refine the concept of cumulative larval thresholds.

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PUBLICATIONS

Publications directly relating to the research conducted in this project are listed below.

1. Strickland, G.R., Yeates, S.J., Fitt, G.P., Constable, G.A. and Addison, S.J. (1998). Prospects for a sustainable cotton industry in tropical Australia using novel crop and pest management. Proceedings of the World Cotton Research Conference-11, Athens, Greece, September 1998.

2. Strickland, G.R. and Annells A.J. (2002). Towards dynamic thresholds for Helicoverpa on transgenic cotton in the Kimberley. Proceedings of The 11th Australian Cotton Conference, Brisbane, Qld, August 2002.

3. Stephen Yeates, Geoff Strickland, Shiw Murti, Blair Wood and Ivan Mcleod (2002). Is There a Future for Cotton in Northern Australia? Proceedings of The 11th Australian Cotton Conference, Brisbane, Qld, August 2002.

4. Annells A.J. and Strickland, G.R (2002). Evaluation of companion crops as part of an integrated pest management package for GM cotton in the Kimberley. Proceedings of The 11th Australian Cotton Conference, Brisbane, Qld, August 2002.

PLAIN ENGLISH SUMMARY

Northern Australia possesses the natural land and water resources that could enable substantial irrigated cropping to be developed. If cotton became an important base crop in the north, from a production area exceeding 200,000 ha, it would have an estimated worth of $750 million annually. The north is the only realistic growth region for the Australian cotton industry and has the potential to provide a buffer against erratic production levels, caused mainly by water shortages, and make Australia a reliable year-round producer.

The Kimberley region has excellent prospects for cotton production but there is also a demonstrated need for in-depth research to identify sustainable cropping and pest management systems to suit the challenge of cotton growing in tropical Australia. To a large extent, successful industry growth will depend on environmentally acceptable pest management systems based on transgenic varieties. The existing industry will also benefit directly from the IPM developments in northern Australia, which are likely to have applicability to current cotton producers.

Project (AWA.2C) aimed to involve local farmers at Kununurra in large-scale trials by test-farming IPM systems developed by research. Other objectives were to develop pest thresholds for mirids and *Helicoverpa* in the winter cropping system and to commence research to develop a resistance management strategy for INGARD® cotton in the Kimberley.

The results from the project are very encouraging and have demonstrated the enormous potential for sustainable winter INGARD® production in the Kimberley using IPM principles. Lablab has emerged as an excellent companion crop to fill the role of lucerne used in eastern Australia. Lablab is easy to establish and manage, is attractive to mirids and *Helicoverpa*, and is a good source of beneficial insects. The use of companion crops as strips within cotton paddocks, and selective insecticides early in the season, has led to higher yields and less insecticide applications over several years of large-scale trials.

Mirids have proved elusive and defining reliable thresholds was not possible during the project. However, excellent progress towards the development of dynamic thresholds for *Helicoverpa* was achieved. The new thresholds include an 'accumulated larval-day' component to overcome the problem of long periods of sub-threshold damage in INGARD® crops. The formula also includes a damage trigger based on fruit retention. The dynamic thresholds have the capacity to improve yields by changing the timing of sprays rather than increasing the frequency of spraying.

Despite the excellent progress detailed in this report, there remain important issues to be resolved before a cotton industry could be recommended in the Kimberley. Yield variability between seasons and between farms within seasons is high and not understood. Circumstantial evidence suggests that aphid infestations, combined with other stresses, may be causing unexpected and serious yield losses. Aphid populations are increasing and their influence on yield and crop growth requires immediate research. Similarly the availability of Bollgard II® cotton requires that agronomic and pest management systems developed for INGARD® be validated and refined into a cotton production package suitable for commercial production. Clearly a Bollgard II® resistance management strategy will be an important component of a sustainable system tailored for the east Kimberley and is a priority area for future research.