PLAIN ENGLISH SUMMARY

The Kimberley region of Western Australia is one of the most prospective for a significant expansion of the Australian cotton industry into northern Australia. When developed, northern Australian production is estimated to be worth $750 million annually from a production base exceeding 200,000 ha. However, past failures with agricultural developments in northern Australia have demonstrated the need for in-depth research to identify sustainable cropping and pest management systems to suit the challenge of cotton growing in tropical Australia. The clear lesson from the past is that inadequate understanding of cropping systems and reliance on broad-spectrum insecticides is doomed to failure.

To a large extent, successful industry growth will depend on environmentally acceptable pest management systems based on transgenic varieties. Sustainable cotton production in northern Australia will benefit the existing industry by expanding the production base to make the nation a more reliable and year-round producer of quality lint. The industry will also benefit directly from the IPM developments in northern Australia, which are likely to have applicability to current cotton producers.

Project (AWA.1C) aimed to evaluate the performance of INGARD® varieties grown under several experimental IPM strategies in the Ord River Irrigation Area. Fundamental to all IPM strategies was a shift from summer to winter cropping to avoid peak pest populations and other management problems associated with wet season cropping. To achieve these objectives, paddock-sized plots were replicated on the properties of participating farmers. This large-scale approach to research was necessary to emulate "real" on-farm IPM and was made possible by the establishment of a small gin at Kununurra by Colly Cotton and the Ord River District Cooperative.

The results from the project are very encouraging and have demonstrated the enormous potential for sustainable winter INGARD® production in the Kimberley. The transgenic crops were shown to be efficacious against most lepidopteran pests for a period of around 100 days after planting. In each season fewer than 5 sprays were required for pest control. Yields achieved were around the Australian irrigated average of 7.5 bales/ha. This was a commendable result considering that farmers had no previous cotton growing experience and both agronomic and pest management knowledge at Kununurra was minimal at the commencement of the project.

IPM systems proved to be robust and the use of trap crops such as lucerne and niger increased the number of beneficial insects in adjacent cotton. There was a trend towards higher yield when lucerne strips were deployed alongside cotton as a trap crop. The most important beneficial insect present at Kununurra was the tiny wasp parasitoid Trichogramma, which was responsible for parasitising up to 90% of the key pest's (heliothis) eggs.

It is recommended that these encouraging results for IPM cotton at Kununurra be supported by additional research aimed at further developing environmentally friendly pest management systems whilst improving sustainable crop management techniques. The winter growing philosophy has many benefits for pest management but agronomic and pest control methods need to be adjusted through research to ensure that production efficiency is maximised.

FINAL REPORT – PROJECT AWA.1C

FIELD EVALUATION OF INGARD® COTTON AND INTEGRATED PEST MANAGEMENT (IPM) SYSTEMS IN THE KIMBERLEY

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BACKGROUND

In anticipation of the commercial release of transgenic cotton by 1996, Agriculture Western Australia embarked on small-scale cotton research at Kununurra in 1994. The research project followed a feasibility study undertaken by Strickland, Fitt, Thomson and Constable (1993) which concluded that the Kimberley region would be suitable for cotton industry development with transgenic varieties. However, the report recommended that any future production system needed to be radically different from the insecticide dependent industry that failed in 1974, due largely to insecticide resistance in *Helicoverpa armigera* (Wilson, 1974). Aimed at industry sustainability, features of the novel new system conceptualised for the Kimberley included:

- a winter, rather than summer growing season;
- transgenic varieties;
- a pre-emptive insecticide resistance management strategy;
- a robust integrated pest management (IPM) system.

Agronomic and pest management research, undertaken collaboratively with CSIRO in 1994 and 1995, produced very encouraging results for conventional cotton (Strickland and Constable, 1995). Partly due to the strength of these results, CRDC funded a 3-year project (AWA.1C) to investigate the potential for transgenic cotton grown under IPM strategies in the Ord River Irrigation Area (ORIA).

OBJECTIVES

Project AWA.1C had the stated aims to:

1. evaluate the field efficacy of INGARD® cotton varieties, originating from the CSIRO and Deltapine breeding programs, against lepidopteran pests;
2. develop an integrated pest management (IPM) system for INGARD® cotton to minimise the risk of Bt resistance development.

This report details the development of a successful IPM strategy for the Kimberley and the results from test-farming IPM systems in replicated paddock-scale trials with local farmers.

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 are critical to successful cotton production in the Kimberley, *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 supplied from Dunluce International Pty Ltd. All traps were serviced weekly and moth numbers recorded. The pheromone lures were replaced every 4 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 entomoLOGIC (now 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 entomoLOGIC data, more intensive data collection was used to measure the abundance of beneficial insect species in IPM cotton and supporting trap 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 sucking from 20 m row whilst walking at 1 m/second.

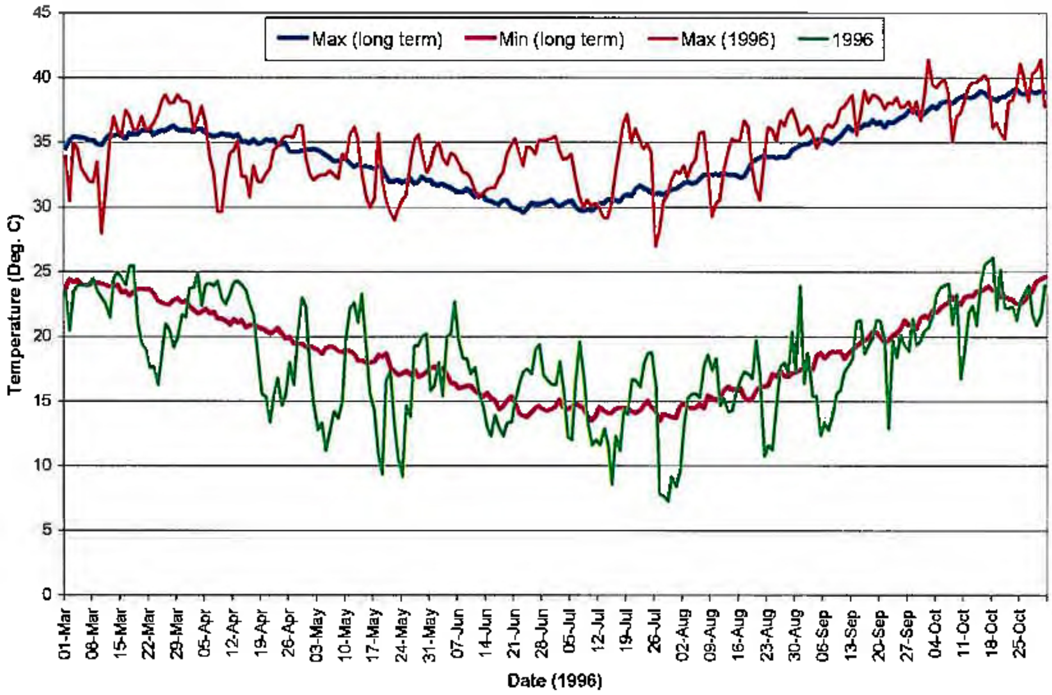
On rare occasions when time permitted, the samples were immediately sorted and the insect fauna identified and numbers recorded. However, generally the samples were sieved to remove extraneous material such as leaves and then frozen until time for processing became available.

1996 SEASON

Climate

Minimum temperatures were generally cooler than the long-term average but this was compensated for, to an extent, by often warmer than expected maximums. However there were a total of 12 'cold shock' nights where temperatures were 11°C or lower. A total of 19 nights were below 12°C. Long-term averages predict 7 cold shock events at Kununurra but a record 30 cold shock nights occurred in 1967. Figure 1 shows the 1996 seasonal temperatures relative to long-term means.

Figure 1. Minimum and maximum temperatures compared to long term averages for the 1996 season at Kununurra.



Late summer rain hampered land preparation and delayed sowing from the target of late March/early April until the end of April. Although this may have slightly limited the yield potential for the season, the trials established well and a total of around 50 ha of experimental cotton (mainly INGARD®) was planted.

Rainfall did not influence picking with 9.2 mm being recorded in September on a single day and 13.1 mm falling in October on 5 days at an average of 2.6 mm per day.

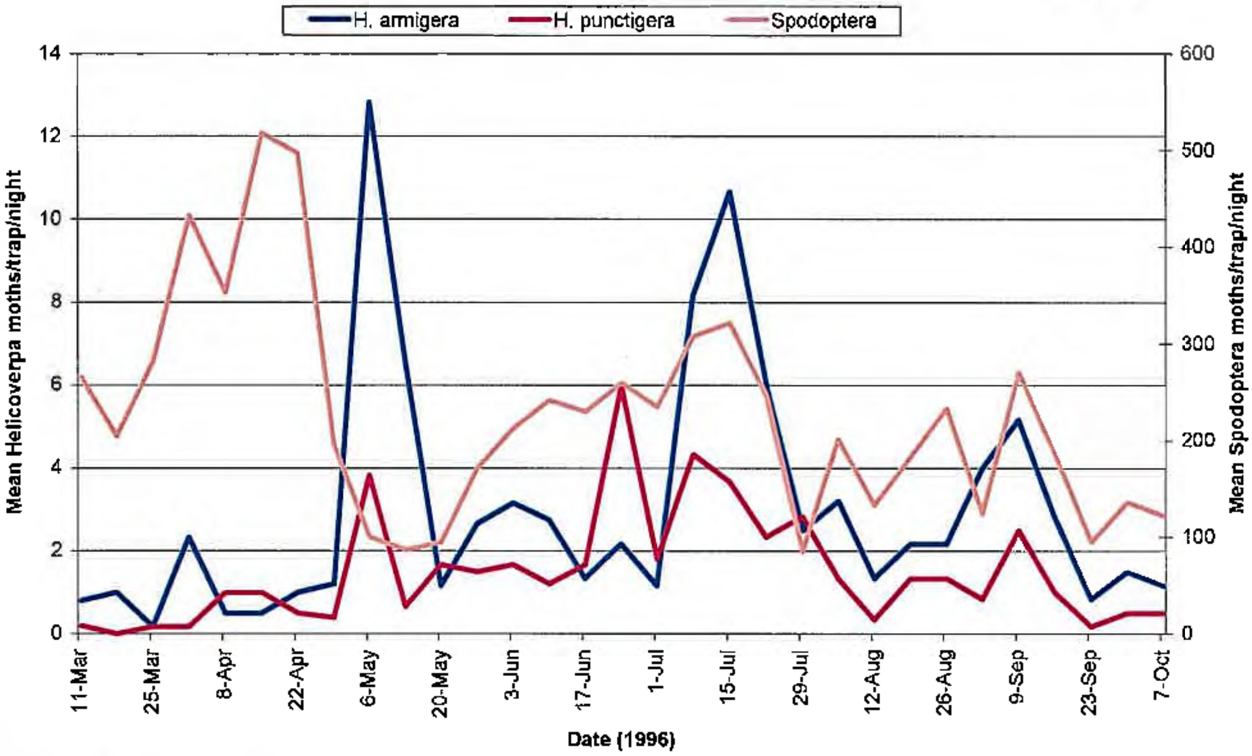
Pest abundance

The seasonal abundance of the key lepidopteran pests, *Helicoverpa* spp. and *Spodoptera litura* is illustrated in Figure 2. *Spodoptera* tended to follow expected trends with a late wet season peak and a general decline though the dry growing season. Trap catches were typically high with up to 500 moths caught per night per trap.

However, 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 in early May and again in July.

H. punctigera followed a similar pattern of abundance to that of *H. armigera*. However, both *Helicoverpa* species recorded quite low nightly trap catches, generally below 10 moths/trap/night.

Figure 2. Seasonal abundance of Helicoverpa armigera, H. punctigera and Spodoptera litura in pheromone traps at Kununurra, 1996.



IPM trial treatments

A range of agronomic as well as pest management studies were conducted on the cotton grown at the Frank Wise Institute in close collaboration with CSIRO and the CRC for Sustainable Cotton Production. However, only the IPM trials are discussed in this report.

Very limited supplies of INGARD® varieties were available for the first INGARD® field trials in the Kimberley. The long-term aim of the research is to develop IPM systems for INGARD® cotton and enable sustainable production of the crop in the Kimberley. In order to achieve the specific objectives of this project, a replicated experiment incorporating four pest management treatments was conducted. The treatments were:

1. INGARD® (Siokra L23*i*) with conventional sprays.
2. INGARD® (Siokra L23*i*) with lucerne trap crop.
3. INGARD® (Siokra L23*i*) with Envirofeast® sprays + lucerne trap crop.
4. Conventional cotton (Siokra L23) with Envirofeast® sprays + lucerne trap crop.

The IPM treatments were selected on the basis of promising results in eastern Australia, especially the use of lucerne as a trap crop combined with Envirofeast® to attract and retain beneficial insects in the transgenic crops. Thus the benefits of IPM, if any, could be assessed in treatments 2 and 3 and compared to normally managed INGARD® in treatment 1. Conventional cotton, grown with IPM systems, was the final treatment and enabled the effect of the INGARD® gene to be compared in the same parent line without the gene.

Methods

All trials were planted on the Frank Wise Institute on four paddocks bringing the total area planted to approximately 50 ha. The cotton was planted as 2 rows (80 cm apart) on 1.8 m beds, which is standard practice for other crops in the area. The variety Siokra L23*i* was the standard in all IPM trials and chosen because of its excellent performance in conventional variety trials in previous seasons. In particular, Siokra L23*i* has demonstrated high yield potential whilst maintaining excellent fibre length in the cool winter growing conditions.

Plot size was approximately 3 ha, depending on paddock layout. Other crops or bulk cotton buffered adjoining treatments from each other. 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. The bulk of the plot areas were planted with a non-commercial line of INGARD® Siokra L23*i* whilst small plots of 'commercial' Siokra L23*i* were sown in the centre of each plot. The inserted sub-plots were used for detailed assessments such as plant mapping and yield estimates whilst the surrounding bulk area was used for general insect abundance measurement purposes.

Standard pest thresholds contained in entomoLOGIC 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 for the normal clearance tractor available. Care was taken to ensure that spray conditions were suitable to avoid drift onto adjoining plots.

Envirofeast® was applied to appropriate plots on a fortnightly basis rather than relying on preliminary predator-prey ratios or other measurements to trigger applications. By maintaining regular sprays of Envirofeast® it was thought that the impact of the product, if any, could be more readily measured in this inaugural season of trials.

Yields were estimated by machine picking small plots (usually 25 m x 2 rows) using a modified two-row John Deere picker. The picked cotton was weighed and sub-samples sent to ACRI to estimate gin turnout. The final yield data was calculated from these estimates. All seed cotton picked from the trials was burned at the season's end. The value of the burned crop was approximately $225,000!

Results and discussion

1. IPM assessments

The overall yield comparisons from the various pest management systems tested are summarised in Table 1. The most important result was that all INGARD® treatments performed well in terms of yield compared to the conventional cotton which yielded lowest. All INGARD® treatments yielded in the 7-8 bales/ha range, which could be considered to reflect likely commercial yields given that yields were calculated from machine picking of plots at least 3 ha in size. By comparison the conventional Siokra L23 had a mean yield of only 6.4 bales/ha.

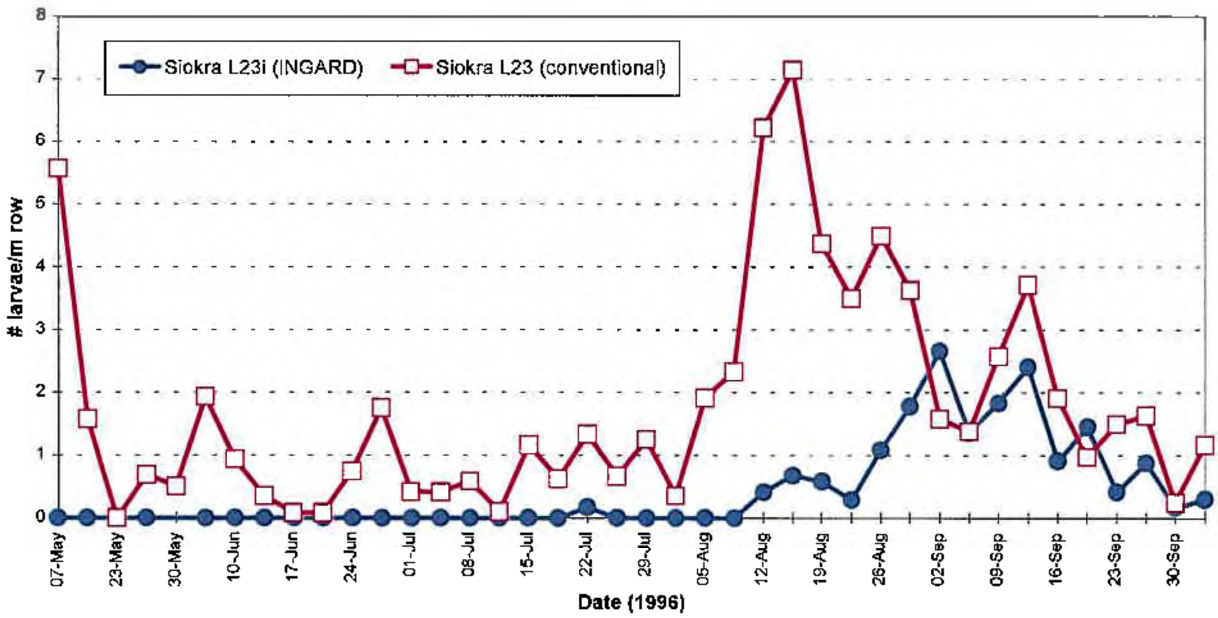
This difference can be largely attributed to the efficacy of INGARD®, which provided excellent control of *Helicoverpa* larvae for about 130 days after planting (see Figure 3).

Table 1. The mean yields obtained from various treatments in the IPM trial at Kununurra, 1996

Treatment[1]	Yield (bales/ha)	Yield 'bulk area*' (bales/ha)
1. Siokra L23*i* + conventional chemicals **(L23*i* Hard)**	6.98	7.22
2. Siokra L23*i* + IPM (soft) chemicals + lucerne **(L23*i* Soft)**	8.22	8.31
3. Siokra L23*i* + Envirofeast® + lucerne **(L23*i* Enviro)**	7.06	6.99
4. Siokra L23 conventional + Envirofeast® + lucerne **(L23 Conventional)**	6.67	6.44

* The bulk area was an experimental INGARD® breeding line of Siokra L23*i* not intended for commercial use.
1 All treatments were sprayed when entomoLOGIC thresholds were reached.

Figure 3. Mean total Heliothis larvae/m row in Siokra L23i (INGARD®) and Siokra L23, 1996.



Further evidence of the importance of INGARD® in controlling *Helicoverpa* can be seen from the insecticide application requirements for the various IPM systems summarised in Table 2. The conventional cotton required an average of 10.5 sprays whilst the three INGARD® treatments required only 3 to 3.5 sprays for the season. For sprays specifically targeting *Helicoverpa*, the INGARD® treatments only required an average of 1.75 sprays compared to 7.5 sprays on the conventional cotton. This represents a 76% reduction in the spray requirement for INGARD® crops.

Table 2. The mean number and purpose of spraying in the IPM trial, Kununurra, 1996

Treatment[1]	Mirid sprays	Heliothis sprays	Total sprays
1. Siokra L23*i* + conventional chemicals **(L23*i* Hard)**	1.75	1.75	3.5
2. Siokra L23*i* + IPM (soft) chemicals + lucerne **(L23*i* Soft)**	1.25	1.75	3.0
3. Siokra L23*i* +Envirofeast® + lucerne **(L23*i* Enviro)**	1.25	1.75	3.0
4. Siokra L23 conventional + Envirofeast® + lucerne **(L23 Conventional)**	3.0*	7.5	10.5

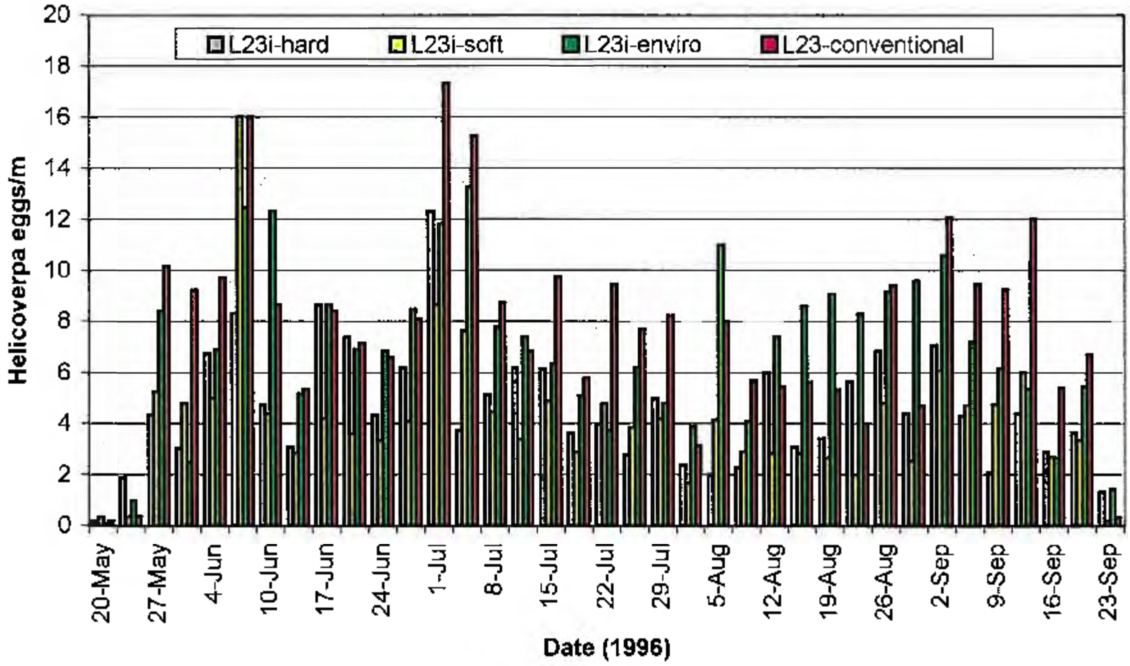
* Includes rough bollworm as a target pest.
[1] All treatments were sprayed when entomoLOGIC thresholds were reached.

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 in general is known to be poorly controlled by INGARD®.

The winter growing strategy was successful in 1996 with no cluster caterpillar or pink bollworm larvae being recorded on any plots, including the conventional cotton.

Helicoverpa pressure for the 1996 season was light, as indicated by both the pheromone trap data shown in Figure 2 and the oviposition rates on the various treatments in Figure 4. The latter data indicate that peak oviposition was 17 eggs/m row and remained below 10 eggs/m for most of the season. Interestingly the highest oviposition occurred on the conventional cotton, which was sprayed with Envirofeast®, and the INGARD® with Envirofeast® treatment. This was contrary to expectations because Envirofeast® is reported to have an oviposition suppression effect.

Figure 4. Mean Helicoverpa oviposition on IPM cotton treatments at Kununurra, 1996.



Helicoverpa larval numbers (Figure 5) were highest in the conventional cotton, as expected, and followed next by the INGARD® 'hard spray' treatment. This is further evidence that the IPM treatments including trap crops and soft sprays are assisting in the control of larvae, especially during the pre-cutout phase. Even the generally higher levels of oviposition in the Envirofeast® treatment did not carry forward into high larval populations. Figure 6, which illustrates the larval populations in all three INGARD® treatments, highlights the lower larval densities in the two IPM treatments relative to the hard spray treatment with no trap crop.

Figure 5. Mean Helicoverpa larvae/m on IPM cotton treatments at Kununurra, 1996.

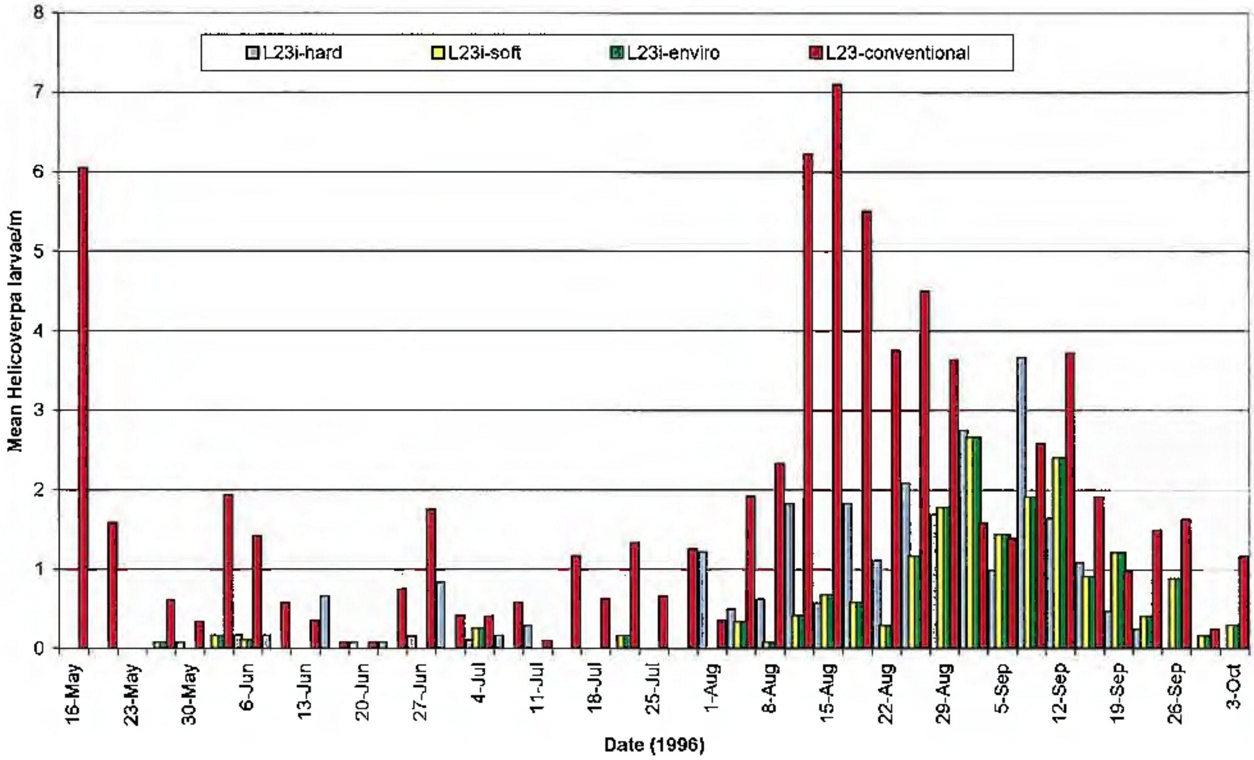
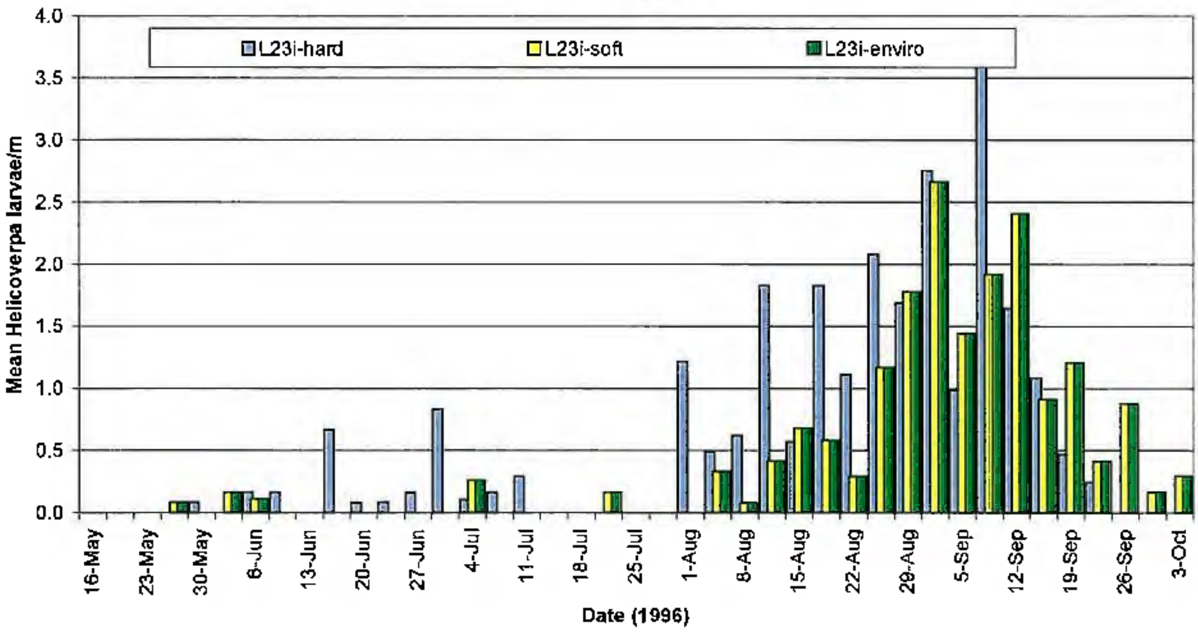


Figure 6. Mean Helicoverpa larvae/m on INGARD cotton treatments at Kununurra, 1996.

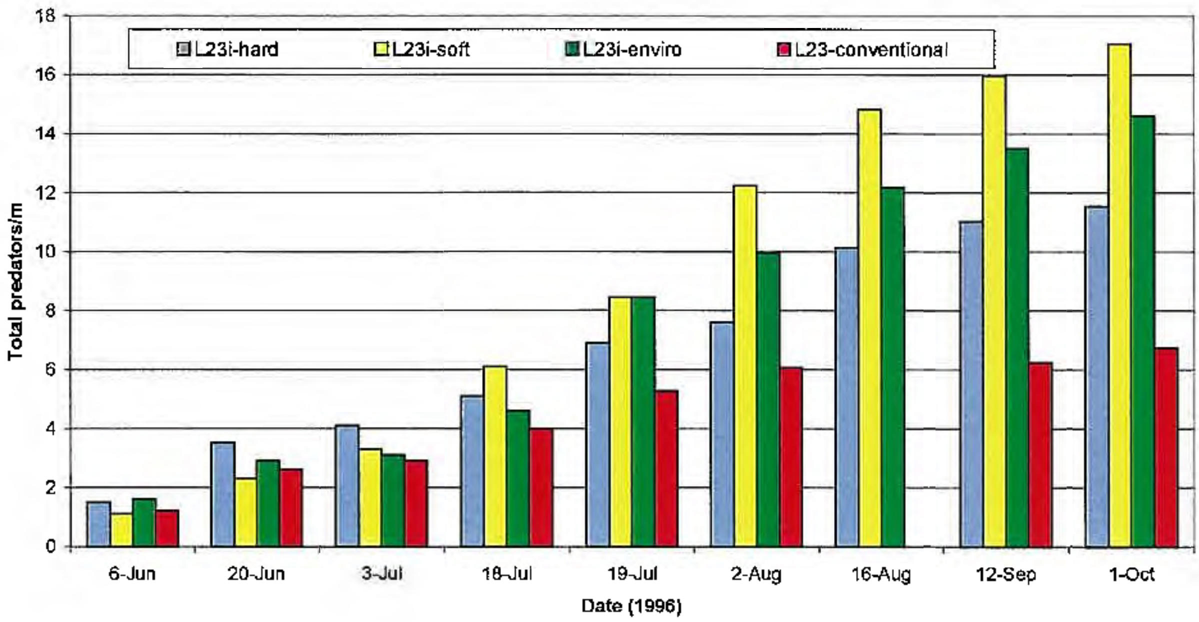


2. Beneficial insect impact

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 7 and 8 respectively.

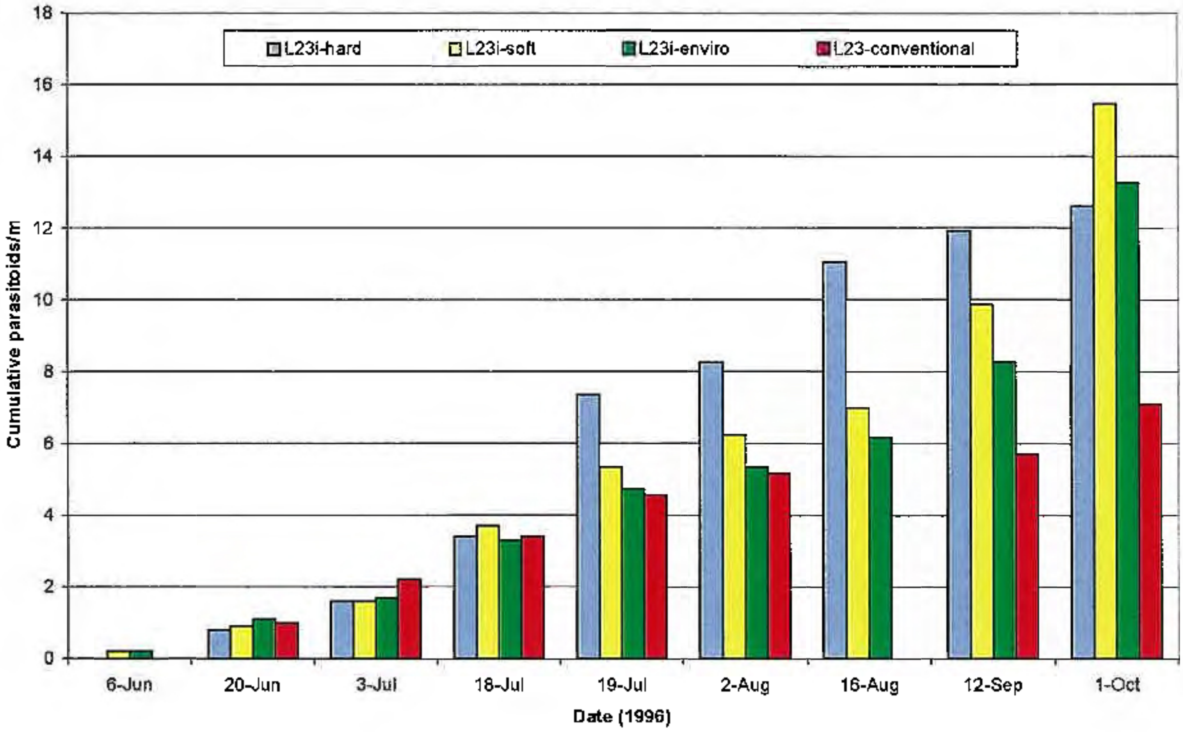
The cumulative predators chart (Figure 7) shows that the number of predators in the 'soft' and 'Envirofeast®' IPM treatments were higher than the other treatments from mid-season onwards. This is to be expected because the other treatments (conventional cotton and 'hard' INGARD®) required broad-spectrum insecticides for their management with a consequent reduction in predator numbers. The two soft IPM systems also recorded the least *Helicoverpa* larval pressure and it can be inferred that predators were linked to this observation.

Figure 7. Total cumulative predators from suction samples in IPM treatments at Kununurra, 1996.



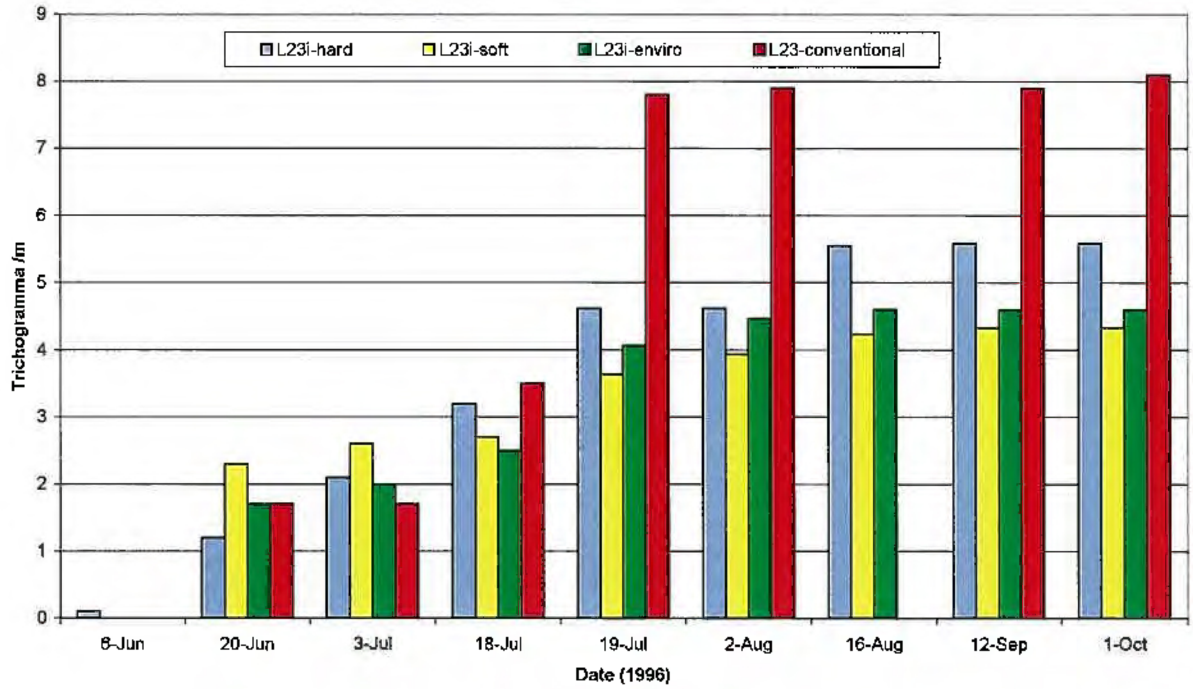
Somewhat surprisingly, the parasitoids (including *Trichogramma*) did not follow the same trend as that seen for predator abundance. In fact the 'hard' INGARD® treatment recorded the highest cumulative number of general parasitoids whilst the conventional cotton treatment had the greatest abundance of *Trichogramma* (Figure 9). A possible explanation for this is that these treatments also recorded the highest *Helicoverpa* oviposition and larval populations during the season. Host availability may have attracted parasitoids more strongly than the predators because of the "tighter" association parasitoids have to their hosts than the more generalist predators. The relatively small plot area to buffer ratio could also have enhanced this effect. Mobile parasitoids would have been able to invade small sprayed areas from the large unsprayed buffers.

Figure 8. Total cumulative parasitoids (excluding Trichogramma) from suction samples in IPM treatments at Kununurra, 1996.



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% and in excess of 90% on some occasions.

Figure 9. Total cumulative Trichogramma in suction samples from IPM treatments at Kununurra, 1996.



3. Mirids and trap crops

An important aspect of IPM systems being developed by 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 in all treatments except the INGARD® 'hard' treatment. The cumulative and seasonal abundance of green mirids is shown in Figures 10 and 11 respectively.

Mirids were not in high abundance during the 1996 season and mean numbers exceeding 1/m were rare. Cumulative counts of mirids were predicably highest in the two 'soft' IPM treatments and lowest in the two 'hard' treatments.

Figure 10. Total cumulative mirids/m collected by suction samples in IPM treatments at Kununurra, 1996.

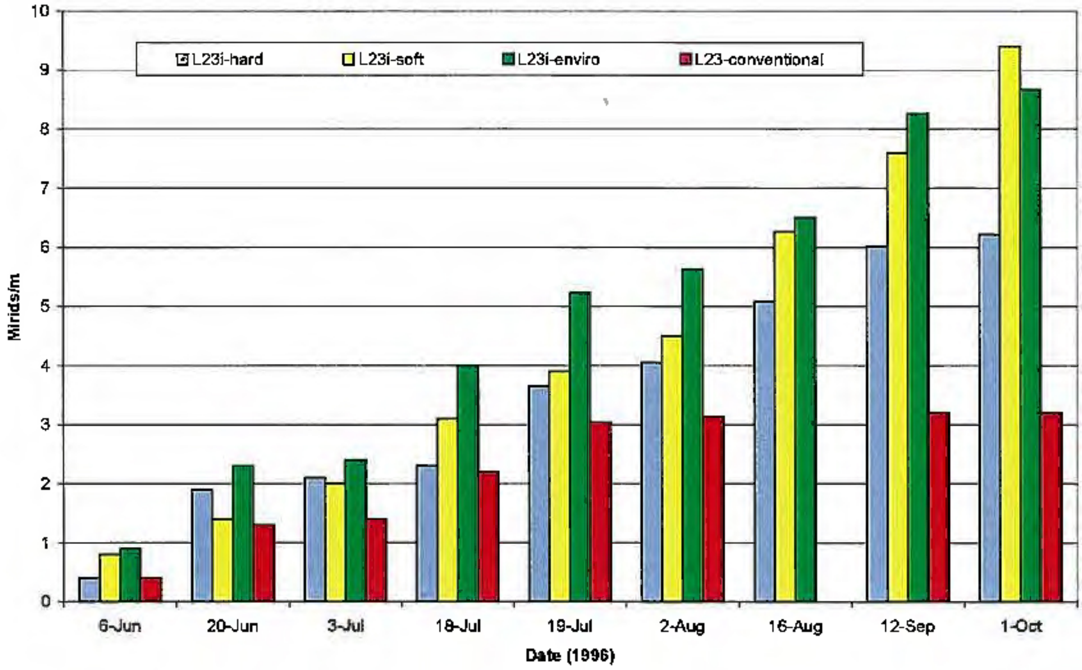
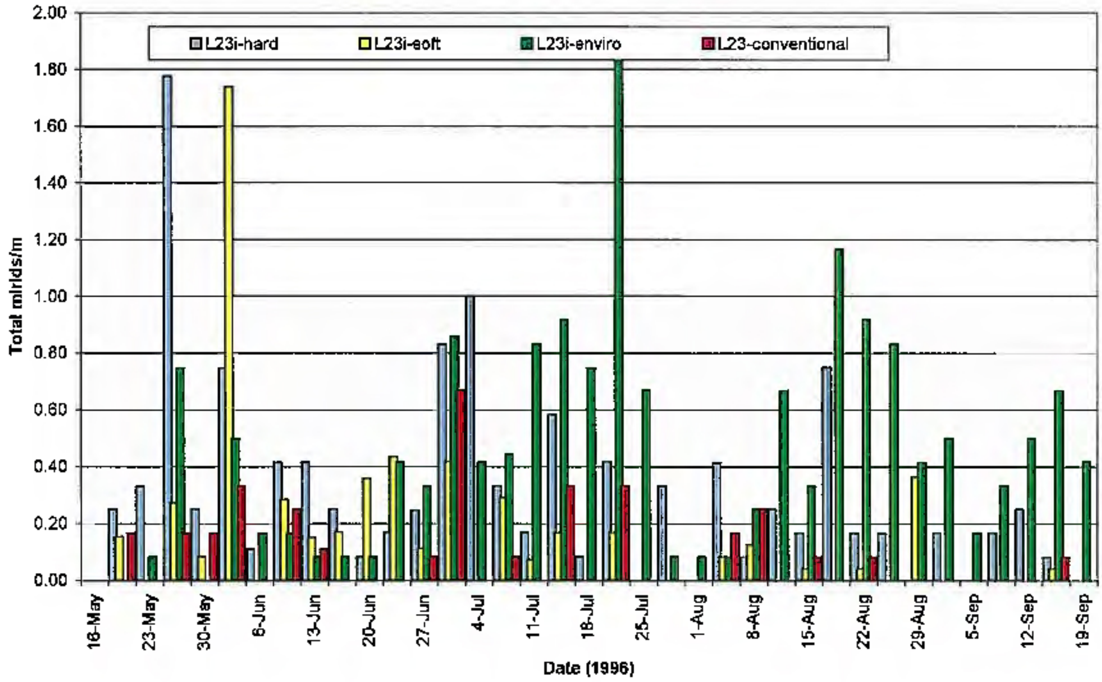


Figure 11. Total mirids (adults+nymphs) recorded in scouting data from IPM treatments at Kununurra, 1996.

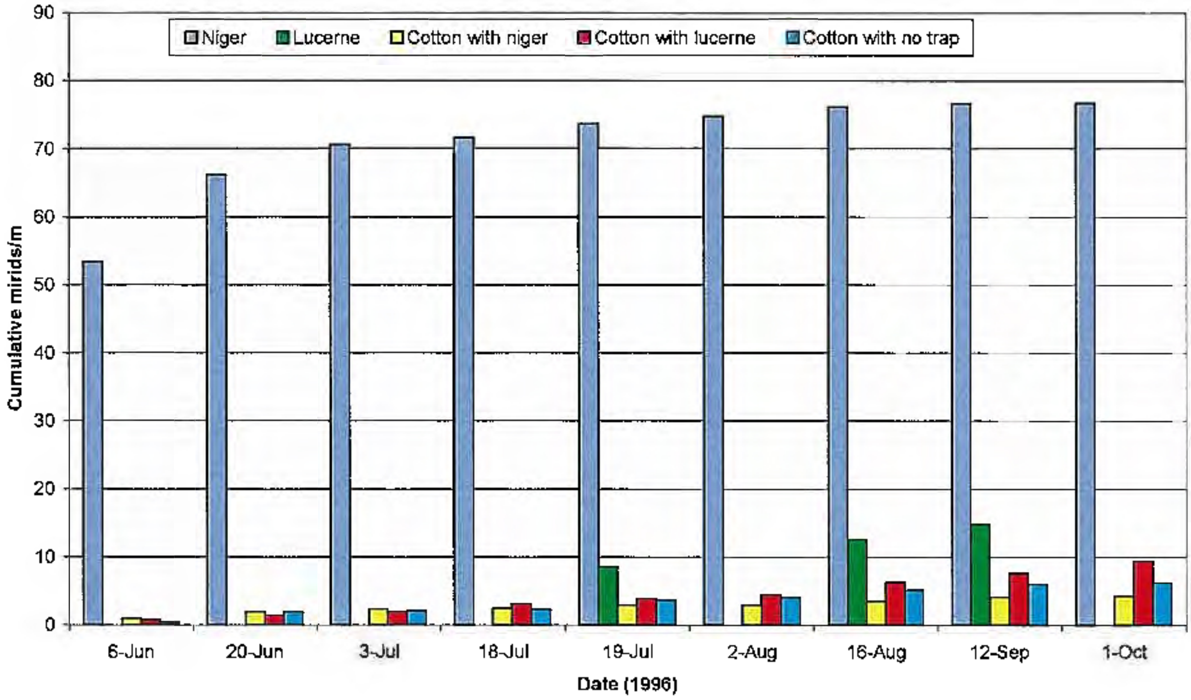


For a trap crop to be useful it must clearly be more attractive to mirids than the alternative cotton crop. Figure 12 summarises the cumulative green mirid numbers collected from suction samples from cotton alone, cotton adjacent to lucerne, cotton adjacent to niger, and from the lucerne and niger trap crops themselves. Niger was not a replicated component of the IPM trial but established as a single observational paddock on the Frank Wise Institute. The crop was selected following observations that it had some excellent attributes to be a trap crop. These included:

- high attractiveness to mirids;
- high attractiveness to *Helicoverpa*;
- high attractiveness to hymenopterous parasites and parasitoids.

The figure also shows that lucerne is more attractive to mirids than cotton but that niger is extremely attractive. Clearly, more detailed evaluations of niger as a potential trap crop for mirids and other pests is warranted.

Figure 12. Total cumulative mirids in lucerne, niger and cotton at Kununurra, 1996.

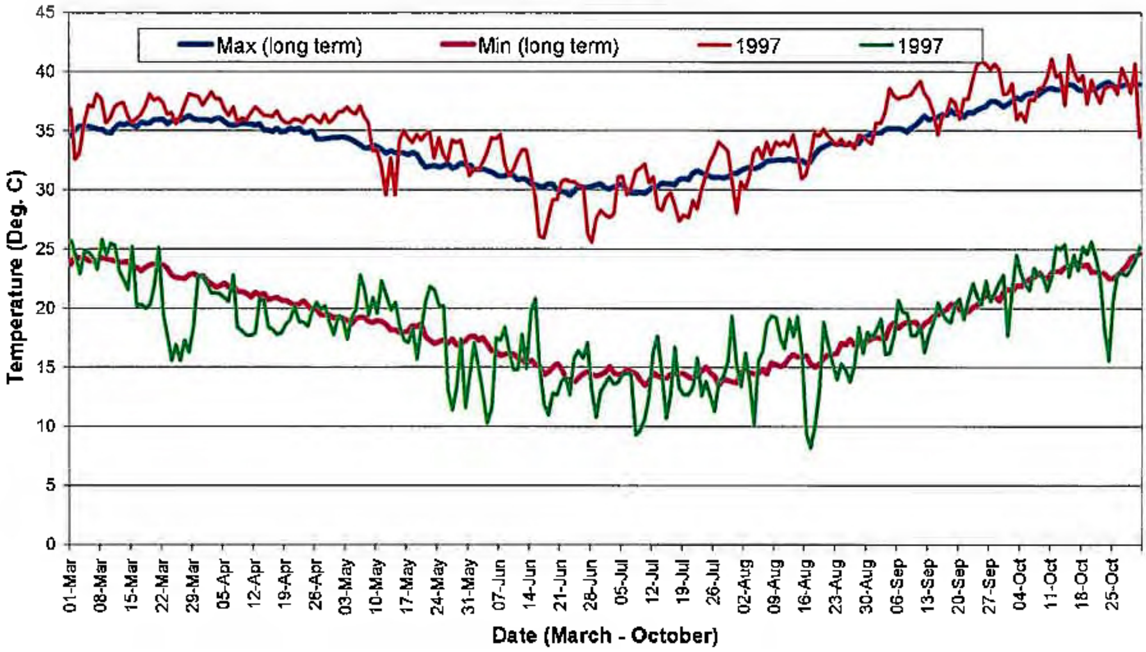


1997 SEASON:

Climate

Minimum and maximum temperatures generally hovered around the long-term averages and the 1997 season could be considered 'average' in that respect. However there were a total of 11 'cold shock' nights where temperatures were 11°C or lower and a total of 16 nights were below 12°C. Long-term averages predict 7 cold shock events at Kununurra. Figure 13 shows the 1997 seasonal temperatures relative to long-term means.

Figure 13. Minimum and maximum temperatures compared to long term averages for the 1997 season at Kununurra.



This was probably the most favourable season for growing cotton since research commenced. Wet season rain terminated in early March and this enabled early sowing. Temperatures during flowering, June and July, were mild and consistent. As mentioned previously, there were 11 cold shock nights (minium below 11°C) compared with 19, 11 and 12 in the 1994, 1995 and 1996 seasons respectively.

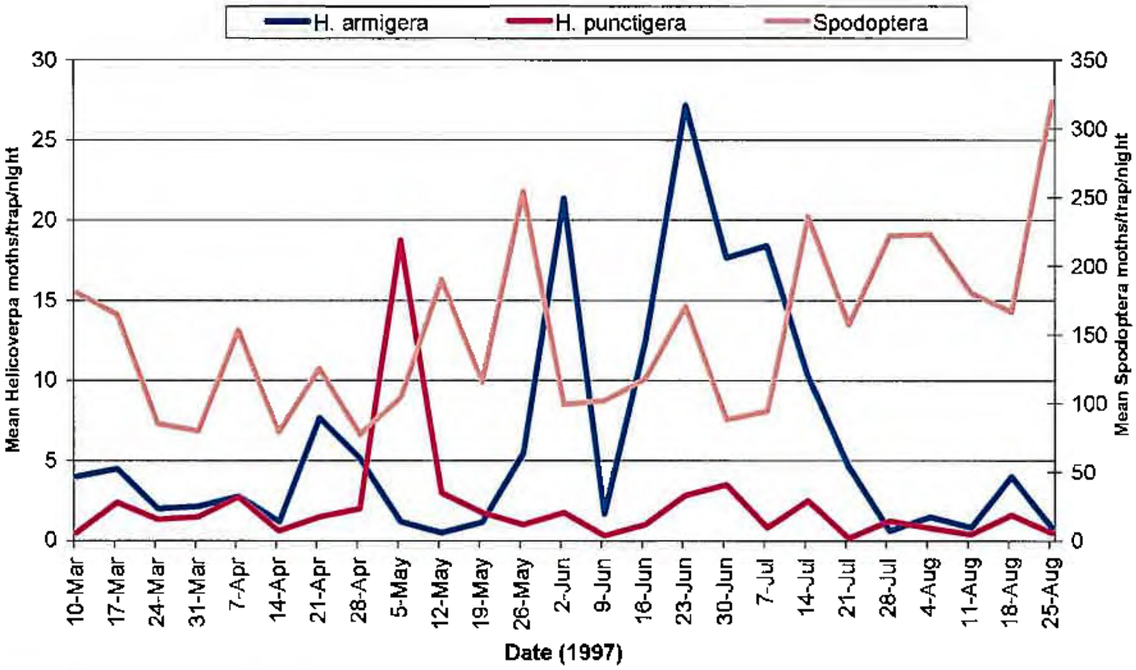
Rainfall was below average during the harvest and stalk pulling period with 7.0 mm being recorded in September in a single day and 10.4 mm falling in October on four days at an average of 2.6 mm per day. This was almost identical to the 1996 season.

Pest abundance

The seasonal abundance of the key lepidopteran pests, *Helicoverpa* spp. and *Spodoptera litura* is illustrated in Figure 14. The pheromone trap data suggests an unusual seasonal activity for all 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 1997.

H. punctigera were generally in low abundance during the season apart from an unusual peak in early May. The sudden peak suggests a migratory flight rather than a local generation as the source of the population. In most seasons *Helicoverpa* spp peak noticeably in August but this did not occur 1997. However, two *H. armigera* peaks were recorded about a month apart in June and again in July.

Figure 14. Seasonal abundance of Helicoverpa armigera, H. punctigera and Spodoptera litura in pheromone traps at Kununurra, 1997.



IPM trial treatments

The 1997 cotton research program was the largest yet undertaken by Agriculture WA, CSIRO and research partners. A total area of 230 ha was planted for an expansion of the INGARD® IPM evaluations commenced the previous year. Three farmers participated in cotton growing for the first time and the commissioning of a ginning facility by Colly Cotton and the Ord River District Cooperative enabled benchmark yields and fibre quality parameters to be assessed.

The involvement of Colly Cotton was an enormous boost to the cotton research and development program. The company brought with it a wealth of knowledge and skills to the district. Gary Coulton, senior agronomist, was based at the research station for the season and assisted local growers and researchers immensely.

Land preparation progressed well and most areas were planted on schedule around early April. With the exception of two paddocks on the Frank Wise Institute, which suffered establishment losses due to *Fusarium*, all other crops enjoyed excellent germination and crop establishment. The sowing dates for the four research sites were:

- Oasis Farms 27 March
- Frank Wise Institute 1 April
- Bothkamp Farms 10 April
- Sass-Neilsen 26 April

The main aim of the project is to develop IPM strategies for INGARD® cotton production in the Kimberley. In order to advance the objectives of the project, a replicated experiment incorporating five pest management treatments was planted. The treatments were:

1. Siokra L23*i* + selective chemicals;
2. Siokra L23*i* + selective chemicals + lucerne refuge crop + Envirofeast®;
3. Siokra L23*i* + selective chemicals + lucerne refuge crop;
4. Siokra L23*i* + selective chemicals + niger refuge crop;
5. NuCOTN 37+ selective chemicals.

The treatments were selected on the basis of promising results obtained during the previous season, especially the use of niger and lucerne as trap crops. Envirofeast® did not provide outstanding results in 1996 but was retained for further assessment in the 1997 season. Conventional cotton was not grown.

The dominant variety in the trials was Siokra L23*i* due to its excellent track record in the area. However, following representations from Deltapine and Monsanto, the normal leaf variety NuCOTN 37 was also included to enable the impact of the normal leaf type with a different gene event to be evaluated.

Methods

All trials were planted as 2 rows (80 cm apart) on 1.8 m beds, which was standard practice for other crops in the area. The target plant population was 11 plants/m row and this was generally achieved although plant establishment was uneven in some paddocks.

Plot size was approximately 20-30 ha, depending on paddock availability. 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. The only exception to this was the Sass-Neilsen farm where all treatments were restricted to a single 80 ha paddock. However, in this case, the treatments were separated by 2-3 ha of maize, which formed a buffer between the treatments.

Standard pest thresholds contained in entomoLOGIC 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.

Envirofeast® was applied to appropriate plots on a fortnightly basis rather than relying on preliminary predator-prey ratios or other measurements to trigger applications Mensah (1997). By maintaining regular sprays of Envirofeast® it was thought that the impact of the product could be more readily measured. Aerial application of Envirofeast® was common.

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

Average yields from the IPM trial (Table 3) were slightly disappointing given the excellent growing season and high expectations derived from previous small plot yields. Yields were also highly variable due mainly to paddock variability and farmer inexperience (no farmers had previously grown cotton). However, when the highest and lowest yields for each treatment are considered there is considerable reason for optimism. The highest three paddock yields were 9.17, 8.92 and 8.81 bales/ha, all very respectable results from first time cotton farmers.

Low yielding paddocks had clear agronomic problems as the prime cause of poor performance, rather than pest problems. The worst paddock, for example, suffered from lengthy waterlogging due to a drainage problem and other poor paddocks could be similarly explained by poor fertiliser placement and poor watering.

Table 3. The mean and range of yields in the IPM trial, Kununurra, 1997

Treatment	Helicoverpa sprays	Yield - average	Yield - highest	Yield - lowest
1. INGARD® (L23*i*) sprayed **(Hard)**	2.75	6.61	8.81	4.94
2. INGARD® (L23*i*) with Envirofeast® sprays + lucerne trap crop **(Envirofeast)**	2.3	5.72	7.03	3.94
3. INGARD® (L23*i*) with lucerne trap crop **(Lucerne)**	1.75	6.88	7.58	6.40
4. INGARD® (L23*i*) with niger trap crop **(Niger)**	3.0	7.29	9.17	5.97
5. INGARD® (NuCOTN 37) sprayed **(NuCOTN 37)**	2.25	7.21	8.92	6.52

NB: All yields are in bales/ha.

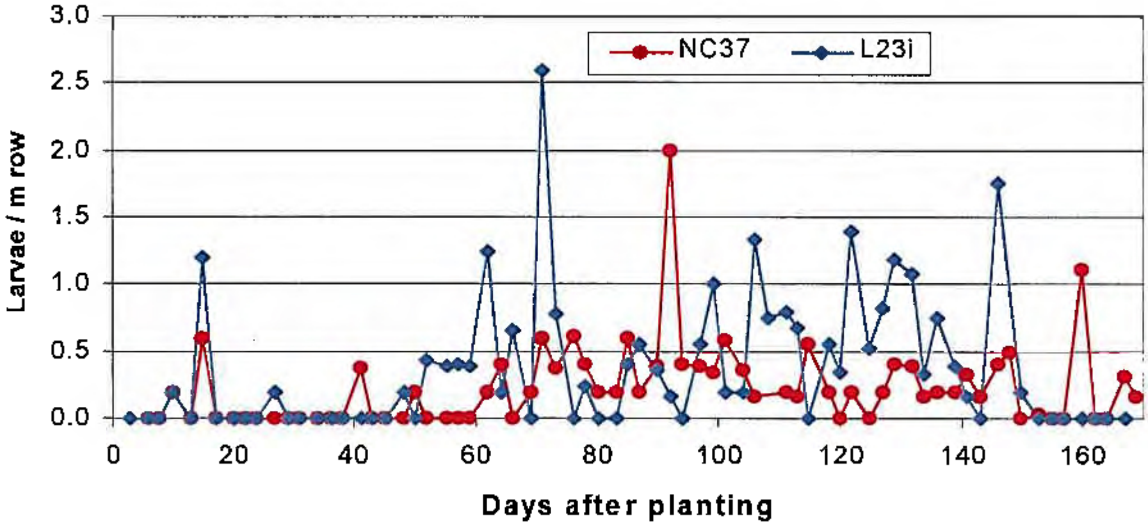
The best of the treatment yields were Siokra L23*i* with a niger trap crop and NuCOTN 37. However, the huge paddock to paddock variability meant that statistical significance could not be attached to this result.

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

The efficacy of INGARD® was generally excellent with no *Helicoverpa* sprays required on any plots until around cut-out. **Two of the twenty blocks in the trial did not reach threshold and did not require any insecticide applications for *Helicoverpa* control for the duration of the season.**

An example of efficacy against *Helicoverpa* is shown in Figure 15 for the varieties Siokra L23*i* and NuCOTN 37 grown of the Frank Wise Institute (research station). Excellent control of larvae was provided by INGARD® for most of the season with an indication of superior performance of NuCOTN 37 relative to Siokra L23*i*.

Figure 15. Helicoverpa larvae on INGARD® cotton (Siokra L23i and NuCOTN 37) on FWI, 1997.



NB: Very small larvae (not included in thresholds) are included in Figure 15.

Further evidence of INGARD® efficacy can be seen from the frequency of spraying on the various treatments as summarised in Table 4. An average of less than 3 sprays for *Helicoverpa* control was required across all treatments. As in 1996, no other lepidopteran pests required control. Several experimental insecticides were used for *Helicoverpa* control. These included Tracer®, Intrepid®, Dimilin® and Insegar®. Supplies of these products were limited and, when exhausted, conventional insecticides, including bifenthrin and methomyl, were used.

Table 4. The mean number and purpose of spraying in the IPM trial, Kununurra, 1997

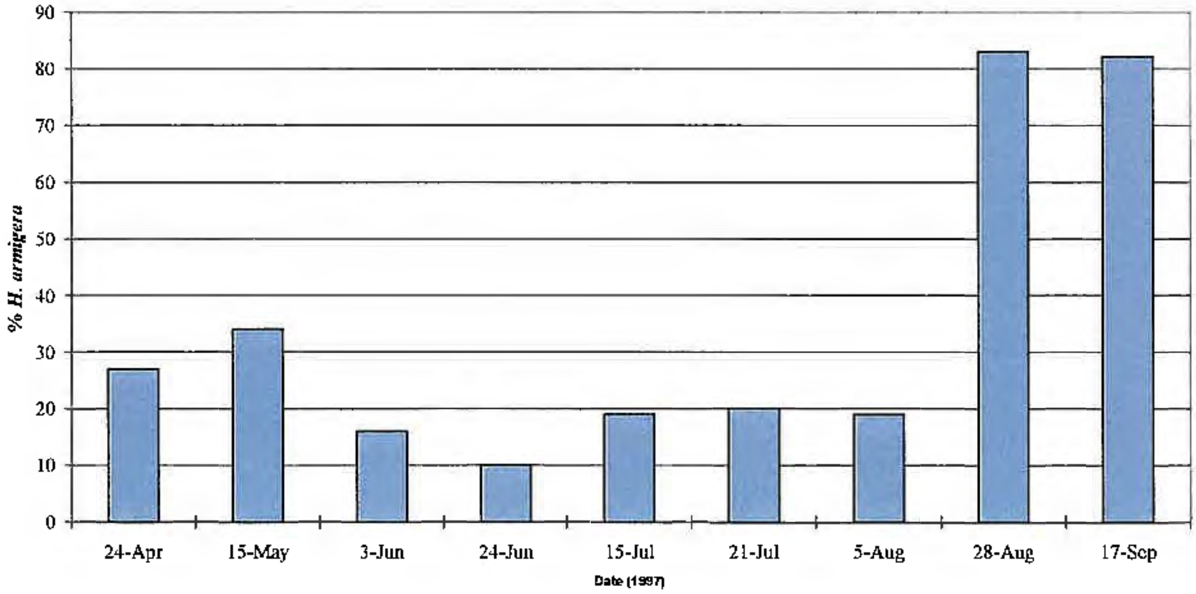
Treatment[1]	Mirid sprays	Aphid sprays	Helicoverpa sprays	Total sprays
1. INGARD® (Siokra L23*i*) sprayed (**Hard**)	2.5	0.5	2.75	5.75
2. INGARD® (Siokra L23*i*) with Envirofeast® sprays + lucerne trap crop (**Envirofeast**)	1.7	0.3	2.3	4.3
3. INGARD® (Siokra L23*i*) with lucerne trap crop (**Lucerne**)	1.25	0.25	1.75	3.25
4. INGARD® (Siokra L23*i*) with niger trap crop (**Niger**)	1.5	0.25	3.0	4.75
5. INGARD® (NuCOTN 37) sprayed (**NuCOTN 37**)	2.25	0.75	2.25	5.25

[1] All treatments were sprayed when entomoLOGIC thresholds were reached.

Apart from agronomic problems on some farms, pest management also had an impact on yield. *Helicoverpa armigera* was very difficult to control late in the season when insecticide resistance levels were high and Bt expression levels had declined to sublethal doses. Late fruit are often important contributors to yield in the ORIA. Timing and efficacy of sprays was also sub-optimal at times due to poor efficacy of some experimental insecticides and difficulties in booking aerial sprays.

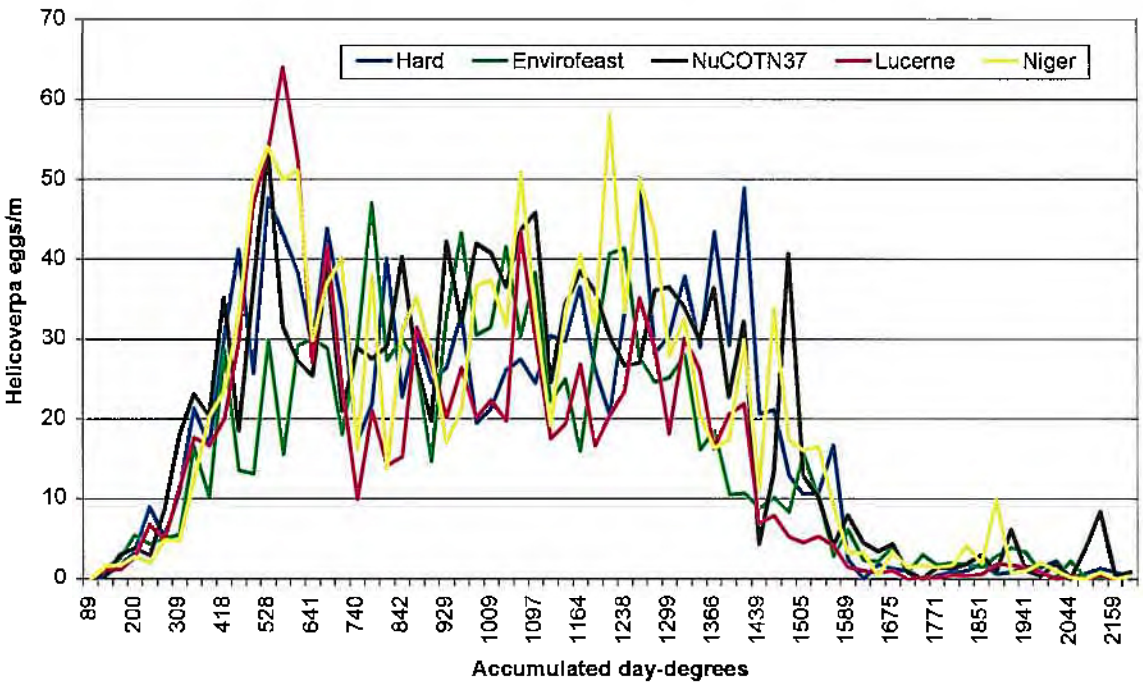
The range of planting times from 27 March to 26 April illustrated the importance of planting early in terms of pest management, as well as for agronomic reasons. The main advantage of earliness to pest management is the avoidance of highly insecticide resistant *Helicoverpa armigera*, which emerge from other crops (mainly maize) in about mid-August. The change in species composition from *H. punctigera* to *H. armigera* is shown in Figure 16.

Figure 16. The percentage of eggs confirmed as Helicoverpa armigera (from LepTon® tests) on INGARD® cotton on FWI, 1997.



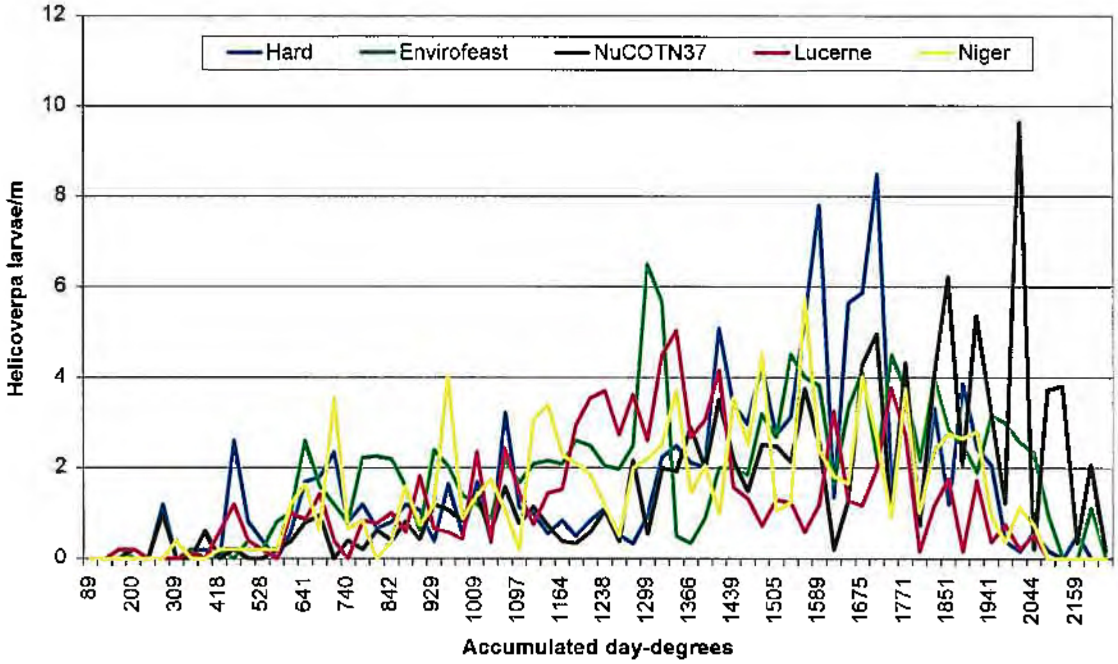
Consistent with higher pheromone trap catches in 1997, *Helicoverpa* spp. oviposition on all treatments was also higher. Figure 17 shows that egg pressure was in the range of 30-40 eggs/m for most of the season with fewer eggs early and, of course, later in the season when the crops become less attractive after cutout. The plots in the Envirofeast® treatment had lower levels of oviposition early in the season but plots with lucerne trap crops tended towards lower oviposition levels for the remainder of the season.

Figure 17. Mean Helicoverpa oviposition on IPM cotton at Kununurra, 1997.



Helicoverpa larval populations (including 'very smalls') tended to be much higher than in 1996 and this was to be expected given the much higher rate of oviposition on all crops. Several trends differentiating the 'hard' treatments (Hard and NuCOTN 37) from the IPM treatments were apparent. Firstly, the hard treatments tended to carry fewer larvae during the mid-season (between 1,100 and 1,350 accumulated day-degrees) than the IPM treatments. This was probably due to the residual activity of insecticides (pyrethroids and carbamates) relative to the soft chemicals (Insegar®, Dimilin®, Tracer®) used in the IPM treatments. However, this trend was reversed later in the season from around 1,650 day-degrees onwards. Despite insecticide applications, the 'hard' treatments carried relatively high larval populations, especially the NuCOTN 37. In NuCOTN 37's case, larval control may have been exacerbated by its vigorous normal leaf growth, which may have limited insecticide penetration through the canopy. In contrast the IPM crops, especially those with lucerne traps, faired much better late in the season and supported fewer *Helicoverpa* larvae. These trends can be seen in Figure 18 following.

Figure 18. Mean Helicoverpa larvae/m in IPM cotton treatments at Kununurra, 1997.

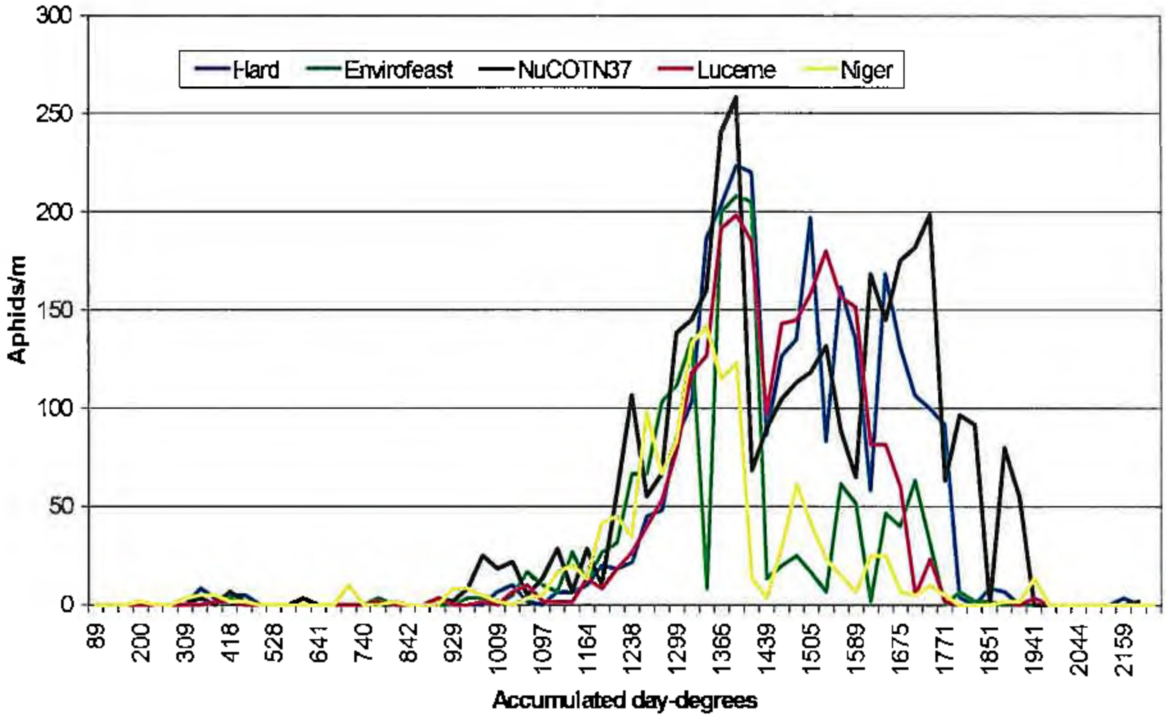


Cotton aphid, *Aphis gossypii*, is an increasing problem on low spray cotton. It has particular importance in Kununurra where the cucurbit industry is vulnerable to several serious viruses (especially zucchini yellow mosaic virus - ZYMV), which are transmitted by *A. gossypii*. The interaction between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

Figure 19 shows the seasonal abundance of *A. gossypii* on cotton IPM treatments. Populations peaked in the mid to late season (July-August) with most plants infested. It was apparent that crops grown with either a niger trap crop or a lucerne + Envirofeast® trap crop were less troubled by aphids. This fact is also reflected in the spray data shown in Table 4 where these two treatments received an average of 0.25 and 0.3 aphid sprays respectively. In contrast, the Siokra L23*i* and NuCOTN 37 without IPM required more than twice the average number of sprays with 0.5 and 0.75 sprays required respectively.

Predators are the main aphid controlling mechanism at Kununurra and no parasitoids have been recorded. This contrasts with eastern Australia where hymenopterous parasitoids are often highly abundant and exert a strong controlling influence on aphid populations. A further contrast is that the other common aphid found on cotton in eastern Australia, *Myzus persicae*, has not been recorded on cotton at Kununurra although the species is found rarely on solanaceaeous hosts such as capsicum.

Figure 19. Mean aphids/m in IPM cotton treatments at Kununurra, 1997.



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 20 and 21 respectively.

The cumulative predators chart (Figure 20) 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 lucerne. These results are consistent with suction sample data from the 1996 season. There was also a trend to slightly higher predator numbers in Envirofeast® treated cotton but this was not as great as for the lucerne association.

Figure 20. Total cumulative predators from suction samples in IPM treatments at Kununurra, 1997.

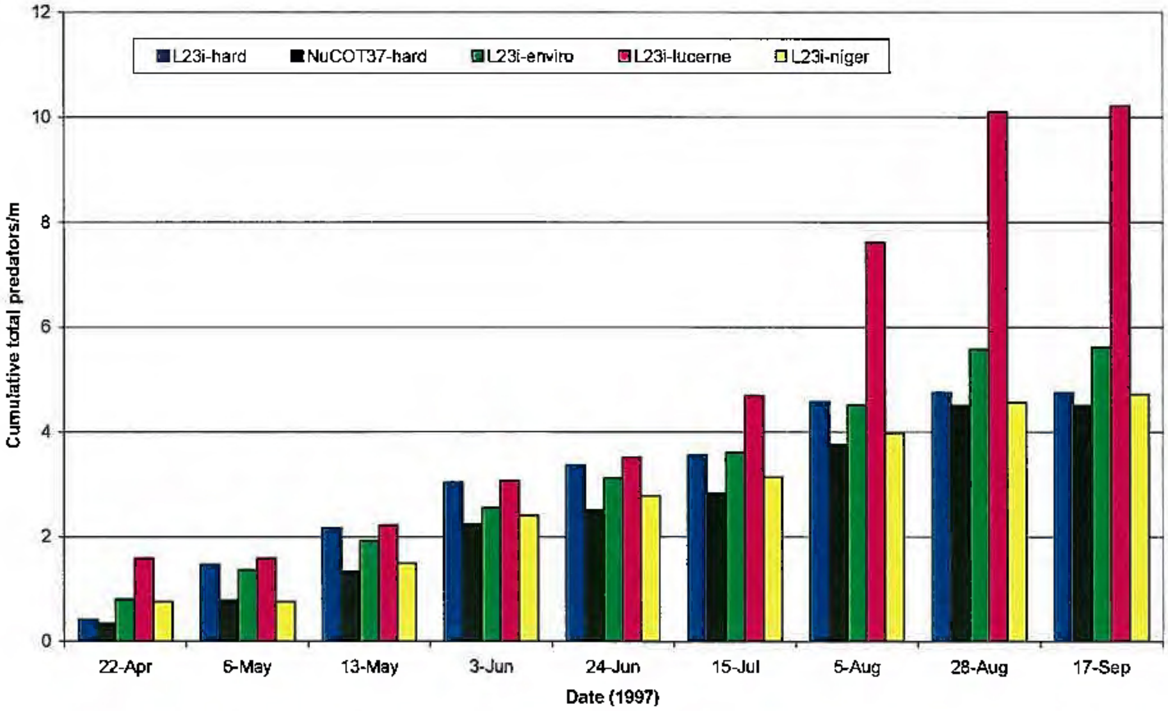
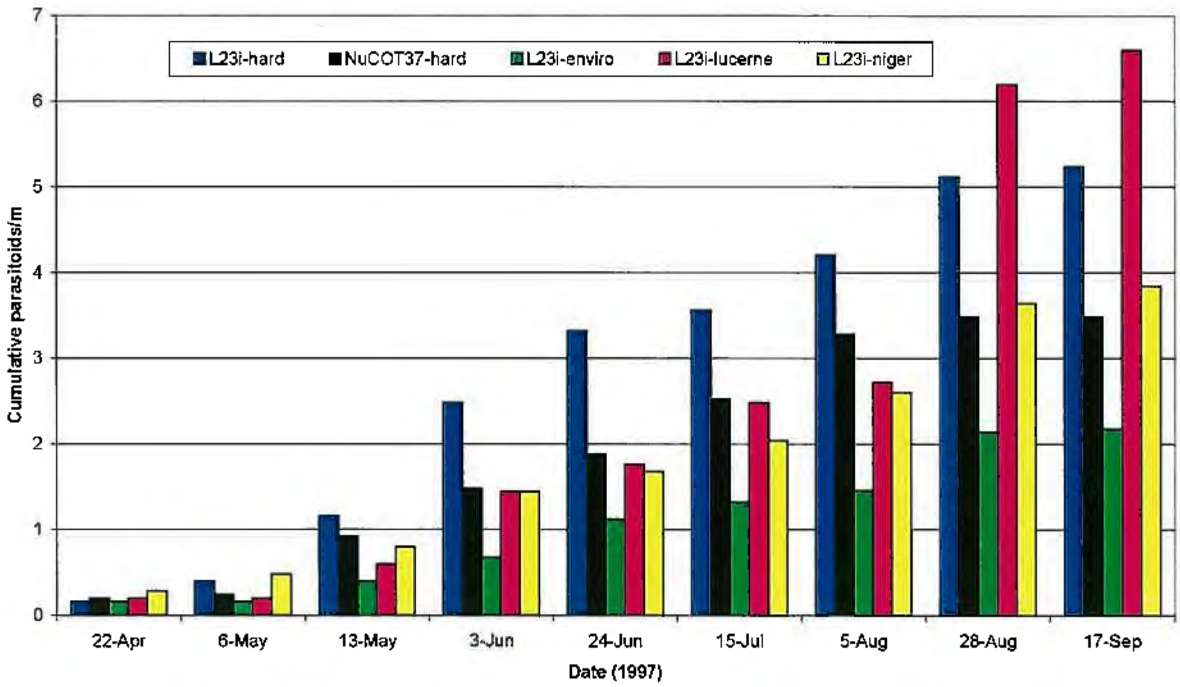


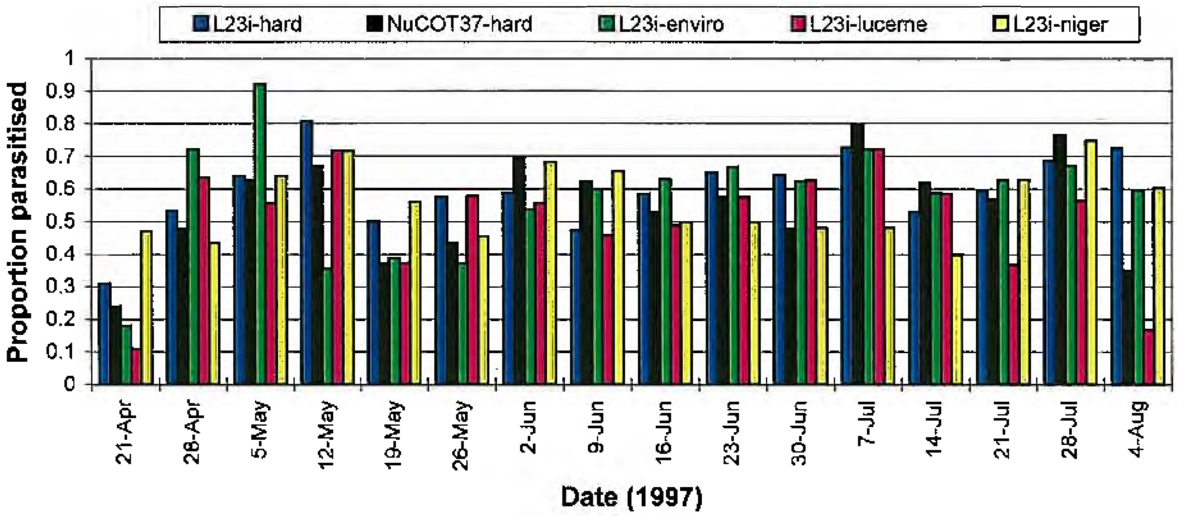
Figure 21. Total cumulative parasitoids in IPM treatments at Kununurra, 1997.



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% 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.

Figure 22 summarises the *Trichogramma* activity in all the IPM systems under evaluation. There were no treatments with consistently higher levels of egg parasitism relative to any others but levels of 60% or higher were frequently recorded during the season.

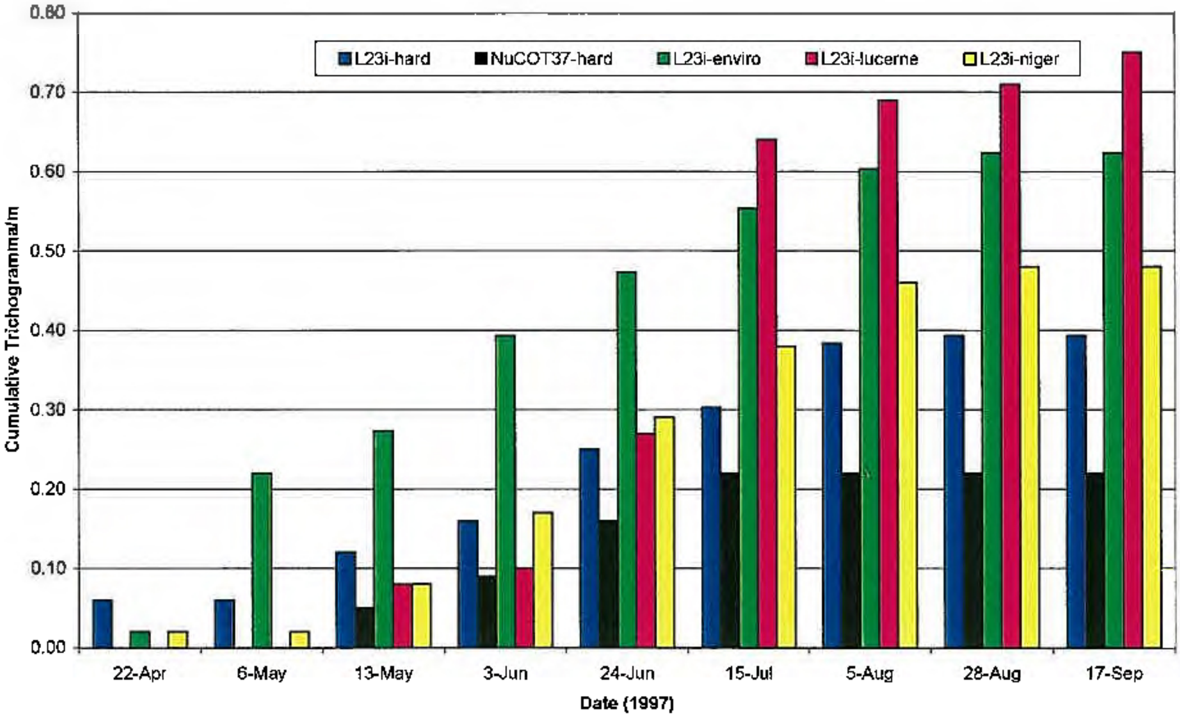
Figure 22. The percentage of Helicoverpa eggs parasitised by Trichogramma in INGARD® cotton crops during 1997.



Suction sampling data (Figure 23) shows that *Trichogramma* abundance was greater in the cotton with a lucerne trap crop and/or Envirofeast®. Envirofeast® early in the season appears to have been attractive to *Trichogramma* and this is reflected in Figure 22 showing high levels of egg parasitism in Envirofeast® treatments early in the season. However, the suction sampling data suggest higher *Trichogramma* abundance in lucerne later in the season but this is not reflected in the parasitism data. The reasons for these inconsistencies are not understood.

The 'hard' treatments, without trap crops, have fewer *Trichogramma* collected in suction samples. This could be attributed to the use of broad-spectrum insecticides in these treatments. However, it is interesting to note that egg parasitism levels did not suffer from the apparently lower abundance of *Trichogramma*. This probably reflects the ability of the parasitoid to rapidly reinvade sprayed crops from surrounding areas.

Figure 23. Total cumulative Trichogramma in suction samples from IPM treatments at Kununurra, 1997.



3. Mirids and trap crops

The purpose of developing IPM systems is to minimise the survival of pests through the combined effects of Bt expression in INGARD™ plants and the impact of beneficial predators and parasitoids. To maximise the benefits of this approach, it is also important to use selective chemicals that have the least disruptive effect on beneficial insects.

The use of insect food sprays and trap crops may also generate useful numbers of beneficial insects, which could invade adjoining cotton crops and assist in pest control. During 1996, preliminary evaluations of lucerne and niger as trap crops, and of Envirofeast® as a food spray, were undertaken. Both crops were useful in different ways, niger was extraordinarily attractive to mirids, whilst lucerne contributed superior numbers of beneficial insects to neighbouring cotton.

Suction samples were taken from cotton and trap 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 trap crop to mirids is one of its most important functions. In addition to being attractive to the pest it is equally important that the trap 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 trap crop some insights into this relationship can be developed.

Figure 24 confirms the outstanding attractiveness of niger to green mirids and confirms the same observation from the 1996 trials. The figure also shows also that Envirofeast® enhances the attractiveness of lucerne to mirids. The attractiveness of these trap crops is confirmed early in the season by Figure 25 showing fewer mirids in cotton grown with a trap crop relative to the non-IPM Siokra L23*i* and NuCOTN 37 without trap crops. However, later in the season the impact of the trap crops diminishes and cumulative mirid numbers in all treatments become the same. This suggests that while the trap crops are initially attractive to mirids, they do not retain them throughout the duration of the season. Indeed, the abundance of mirids increases in cotton sprayed with Envirofeast® later in the season relative to other treatments. This may be explained by the Envirofeast® effectively masking the differences between lucerne and cotton with the consequence that the mirids are less beholden to the trap crop.

Figure 24. Total cumulative mirids in suction samples from trap crops adjacent to cotton at Kununurra, 1997.

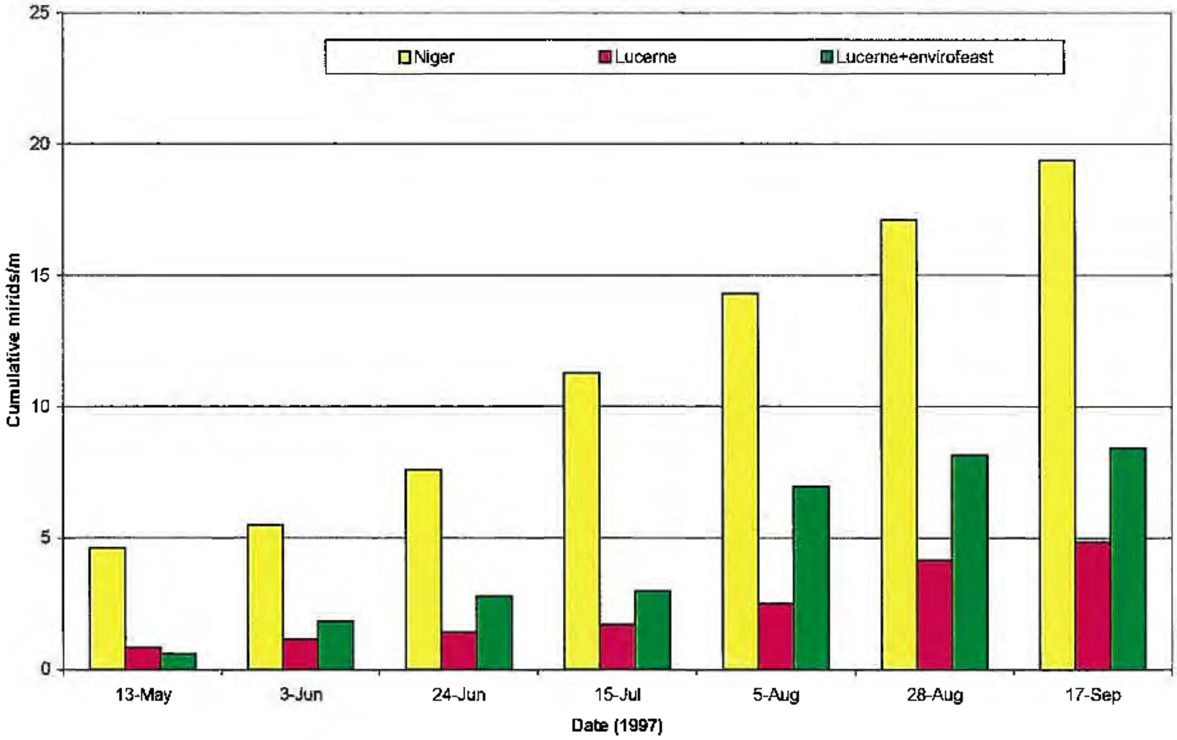
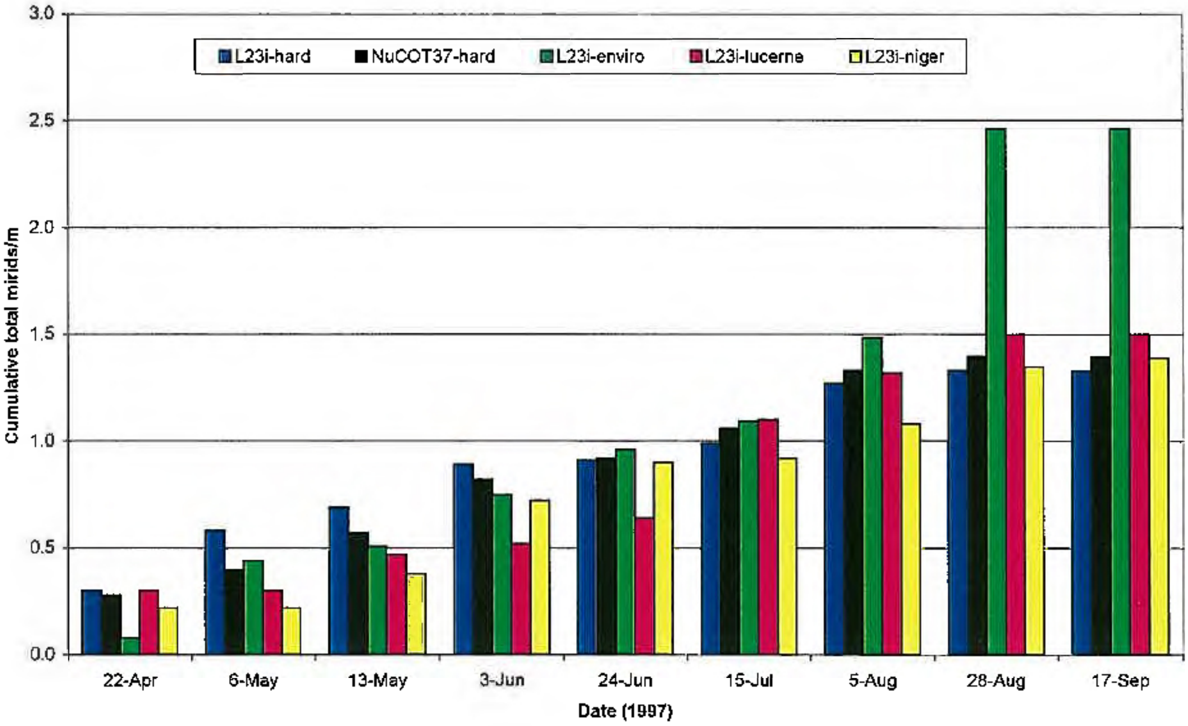


Figure 25. Total cumulative mirids from suction samples in IPM treatments at Kununurra, 1997.



Apart from trapping and retaining mirids, the other important function of trap 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 trap crop options in terms of total predator abundance throughout the season is shown in Figure 26. The lucerne + Envirofeast® trap crops were consistently higher in predatory insect populations than either the lucerne alone or niger. This contrasts with the data in 1996 that did not reveal a consistent benefit from Envirofeast® applications.

In terms of insect parasitoid populations, the lucerne + Envirofeast® trap crop was again outstanding with consistently higher populations recorded, as shown in Figure 27. The parasitoids included wasps (not *Trichogramma*) and tachinid flies. However, *Trichogramma* was very abundant in lucerne trap crops and much less so if Envirofeast® was applied (Figure 28). Again this could be explained by the Envirofeast® masking the differences in attractiveness between cotton and lucerne for *Trichogramma*, thus causing the wasp to move freely between the trap and cotton crops.

Figure 26. Total cumulative predators in suction samples from trap crops adjacent to cotton at Kununurra, 1997.

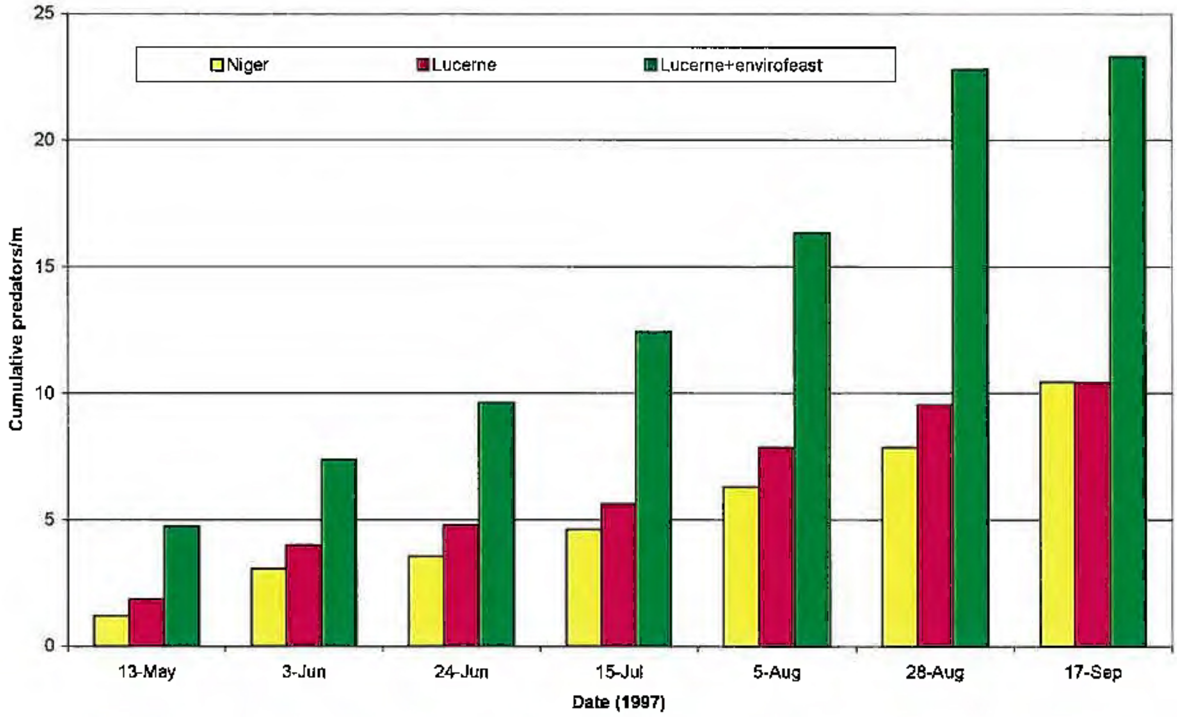


Figure 27. Total cumulative parasitoids in suction samples from trap crops adjacent to cotton at Kununurra, 1997

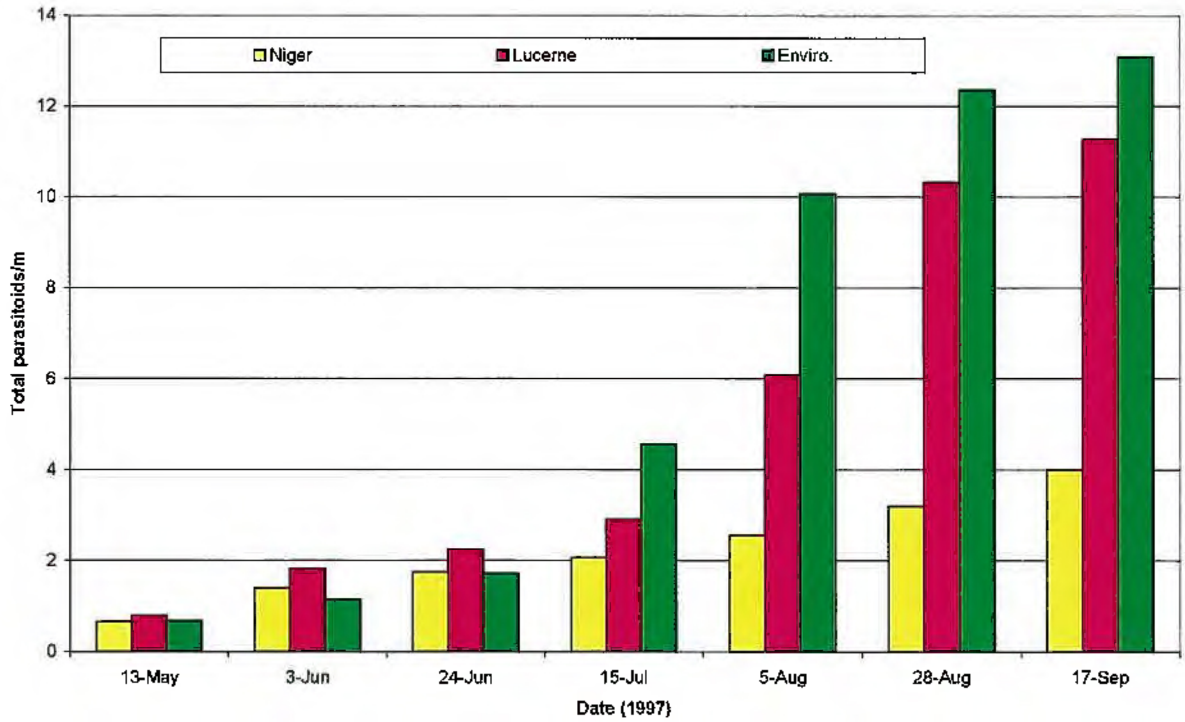
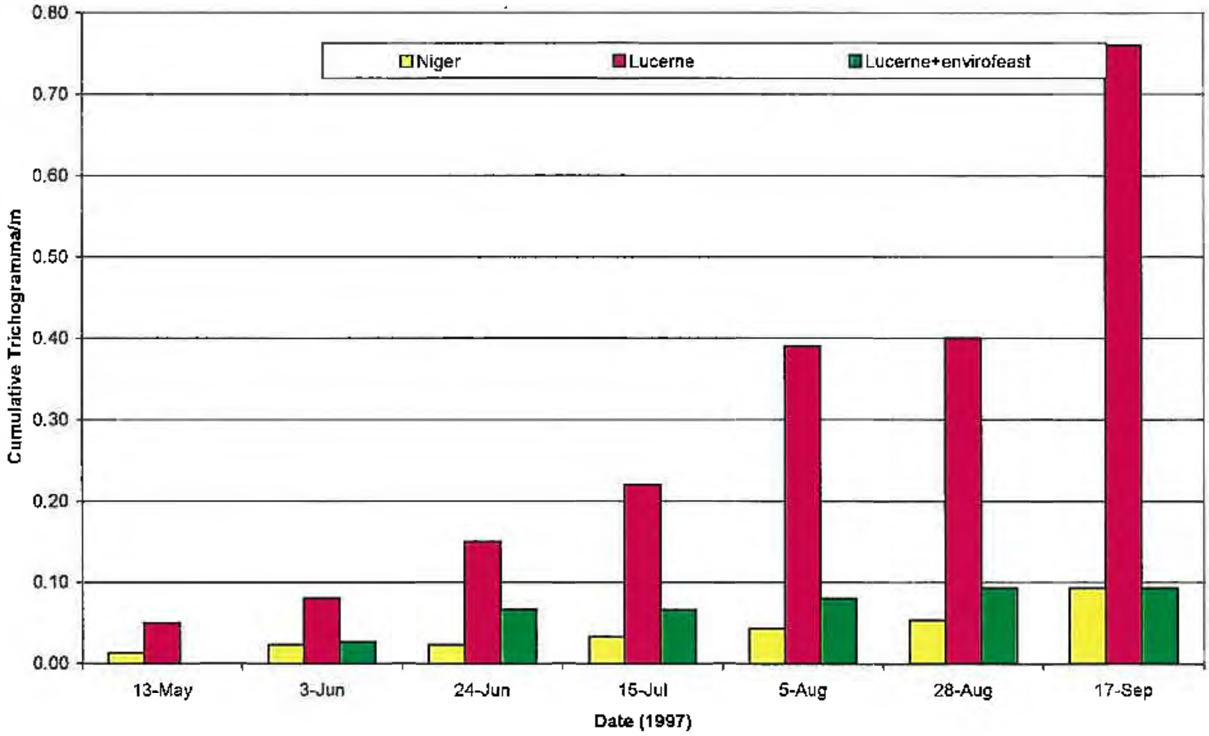


Figure 28. Total cumulative Trichogramma in suction samples from trap crops adjacent to cotton at Kununurra, 1997.



Clearly the various trap crops under consideration have their individual advantages in terms of pest management attributes. However, their adoption by farmers will depend largely on how readily they can be incorporated into the farming system. In this respect both lucerne and niger present practical difficulties to farmers. Lucerne for example is difficult to establish early in the season, especially if the wet season has been prolonged and seed beds are lumpy. Weed control is also difficult in these circumstances. However, once established, lucerne requires little maintenance apart from occasional slashing. On the other hand, niger is far more difficult for farmers to manage. In the Kununurra dry season the crop is difficult to establish and flowers soon after reaching canopy closure. This is an excellent trap crop attribute but means that the crop soon becomes unattractive and needs to be replanted two or three times per season. This requirement ensures excellent attractiveness to insects because the crop is flowering almost continuously but poses significant operational problems to farmers. It is unlikely that farmers will readily accept the high management costs of niger as a trap crop.

1998 SEASON:

Climate

1998 was a hot season with both minimums and maximums generally well above average (Figure 29). This was also reflected in day-degree accumulations summarised in Figure 30.

There were only 3 cold shock nights (minium below 11°C) compared with 19, 11, 12 and 11 in the 1994, 1995, 1996 and 1997 seasons respectively. Despite the hot conditions and lack of cold shock nights, most crops seemed to lack vigour and were reluctant to hold late fruit.

Rainfall was well above average during the harvest and stalk pulling period with 15.2 mm being recorded in September in a single day and 49.6 mm falling in October on eight days compared to long term averages of 3 mm and 22 mm respectively.

Figure 29. Minimum and maximum temperatures compared to long term averages for the 1998 season at Kununurra.

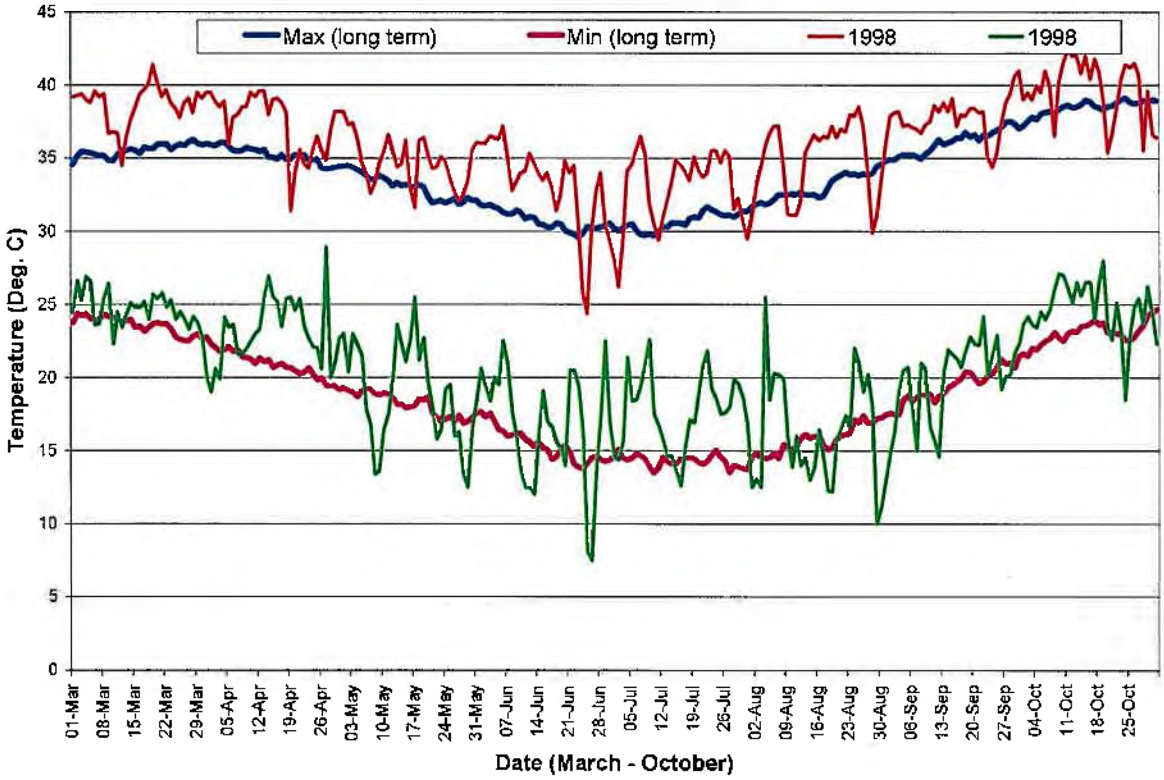
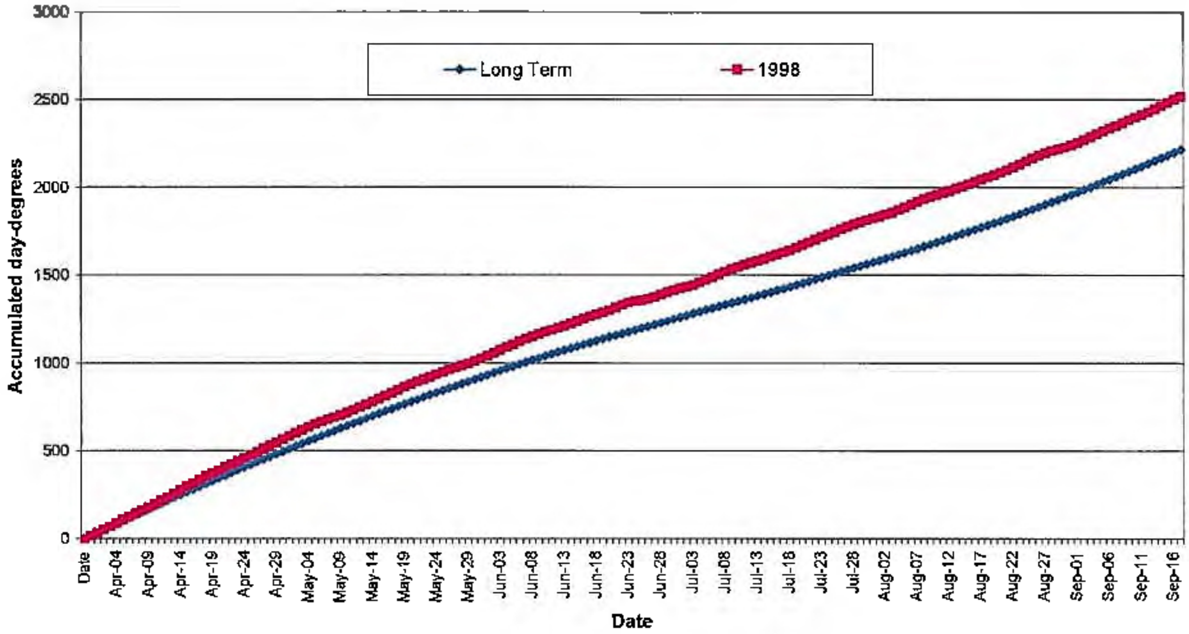


Figure 30. Day-degree accumulation for 1998 versus the long term average.

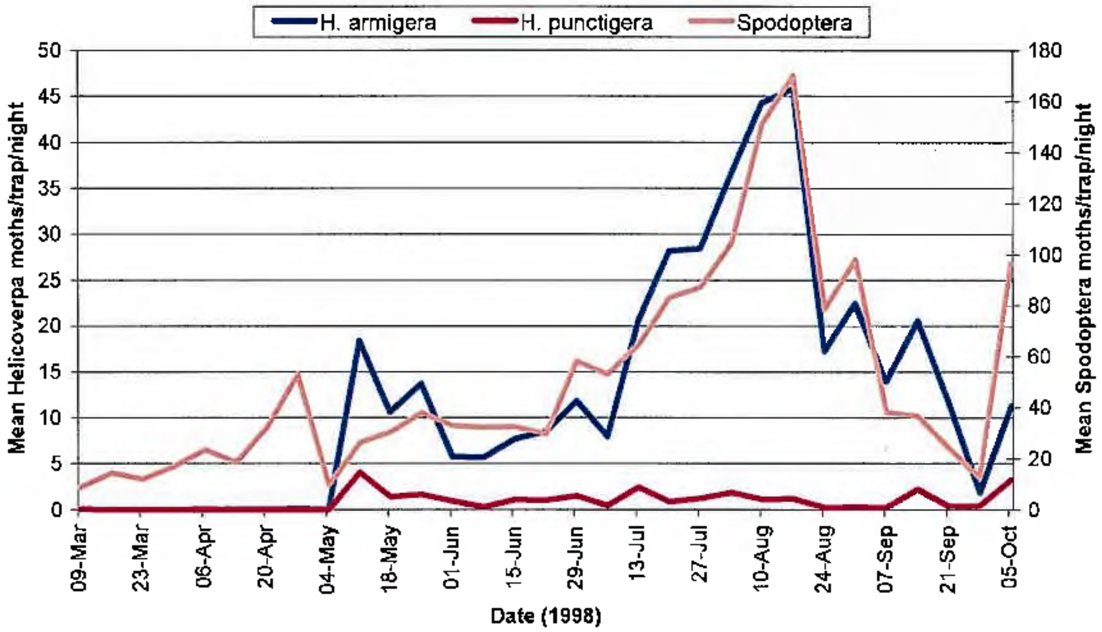


Pest abundance

The seasonal abundance of the key lepidopteran pests, *Helicoverpa* spp. and *Spodoptera litura* is illustrated in Figure 31. The pheromone trap data suggests another year of unusual seasonal activity for all pests, in a similar pattern as 1997. 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 1998.

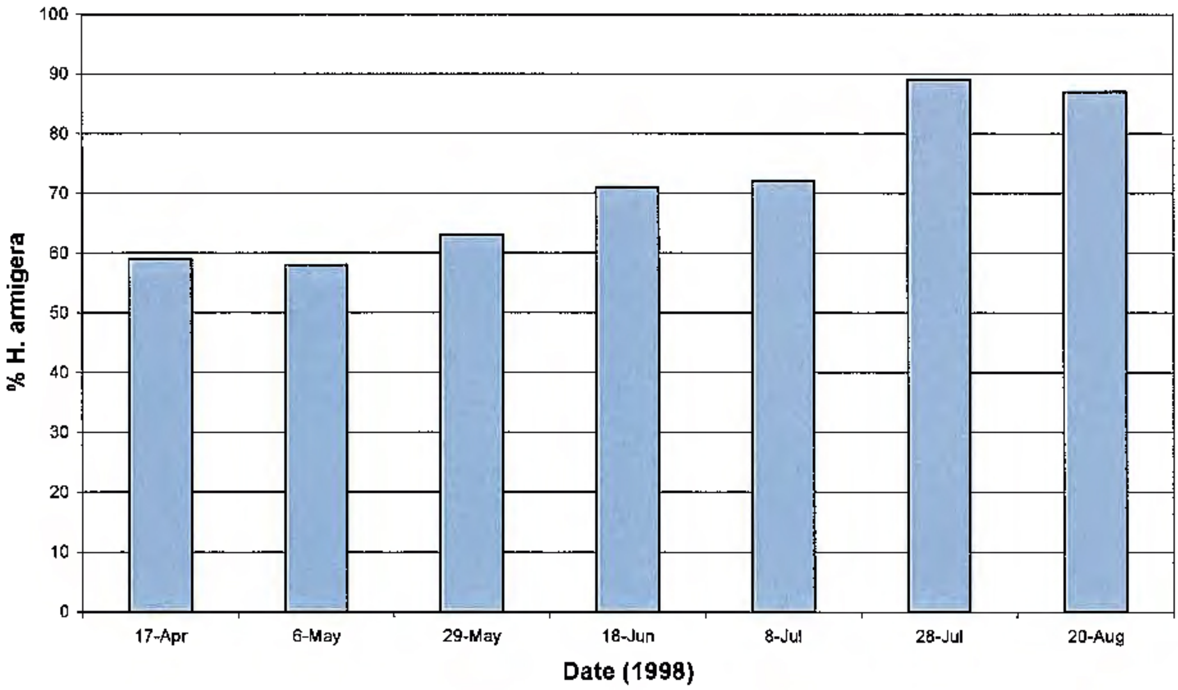
H. punctigera was generally in low abundance throughout the whole season. In most seasons both species of *Helicoverpa* peak noticeably in August but, as in 1997, this did not occur for *H. punctigera* although *H. armigera* did show a modest peak.

Figure 31. Seasonal abundance of Helicoverpa armigera, H. punctigera and Spodoptera litura in pheromone traps at Kununurra, 1998.



The continuously low numbers of *H. punctigera* relative to *H. armigera* were reflected in the LepTon® test results for the season (Figure 32), which showed *H. armigera* comprising 60-90% of the population throughout the cotton season.

Figure 32. The percentage of eggs confirmed as Helicoverpa armigera (from LepTon® tests) on INGARD® cotton on FWI, 1998.



IPM trial treatments

The 1998 cotton research program was the largest yet undertaken by Agriculture WA, CSIRO and research partners. A total area of 380 ha was planted for an expansion of the INGARD® IPM evaluations with four farmers participating in the collaborative trials.

The main aim of the project is to develop IPM strategies for INGARD® cotton production in the Kimberley. In this season, each of the farmers grew crops according to three different management systems with pests controlled according to Agriculture WA protocols. The systems were:

1. INGARD® (Siokra L23*i*) alone;
2. INGARD® (Siokra L23*i*) with lucerne strips;
3. INGARD® (Siokra L23*i*) with lucerne strips + Temik®.

The aim of the IPM field trial was to evaluate the performance of INGARD® alone compared with trap crops and 'soft chemicals'. The third treatment was an attempt to control mirids through a 'trap and destroy' technique by banding Temik® into the lucerne strips. This treatment evolved from observations in previous years, which suggested that mirids were not always well retained in trap crops. The idea of 'trap and destroy' was considered to be worthy of assessment.

In all cases, Agriculture WA maintained responsibility for crop scouting and insecticide recommendations. EntomoLOGIC thresholds were utilised as a basis for all spray decisions. As in previous seasons, the variety Siokra L23*i* was utilised to minimise variation across the experiments and due to its excellent track record in the area.

Methods

All trials were planted as 2 rows (80 cm apart) on 1.8 m beds, which is standard practice for other crops in the area. The target plant population was 11 plants/m row and this generally achieved although plant establishment was uneven in some paddocks.

Plot size ranged from 14 to 43 ha, depending on paddock availability. 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 entomoLOGIC 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

Some conclusions from the paddock-scale IPM studies have been drawn from the previous 2-year's research, despite the difficulties in statistical analysis caused by pseudo-replication on a range of farms. INGARD®, grown in association with a trap crop (lucerne or niger) has tended to produce a yield higher and require fewer sprays than INGARD® grown in the absence of trap crops. Unfortunately, in 1998, the IPM treatments were effectively reduced to two treatments due to difficulties with the 'trap and destroy' treatment, which required Temik® applications. Chemical applications were initially delayed by the non-appearance of mirids. Later, the granular application equipment on loan from Pacific Seeds was unavailable and this prevented timely Temik® applications to the trap crop as initially planned.

There were no significant differences in yield or number of sprays between the crops grown alone or in association with a trap crop this season. A summary of yields from the farms with replicated IPM plots follows in Table 5.

Table 5. Yields and sprays required in the IPM trials at Kununurra, 1998

Treatment	Average yield (bales/ha)	Average number of sprays
INGARD® alone	7.27	3.75
INGARD® + lucerne trap crop	7.36	3.58

Farmers participating in the research have generally been first-time cotton farmers and restricted in the choice of chemicals for insect control by the research protocols. Nevertheless, yields and fibre quality have been encouraging. Farmer performance, including Frank Wise Institute and seed crops, is summarised in the following table. The Kununurra valley average of 7.4 bales/ha is close to the average Australian irrigated cotton yield. This was an excellent achievement by local farmers given the very hot growing conditions and high levels of *Helicoverpa armigera* (see LepTon test results). A valley **average of 3.8 total insecticide sprays per crop was required to control all pests.**

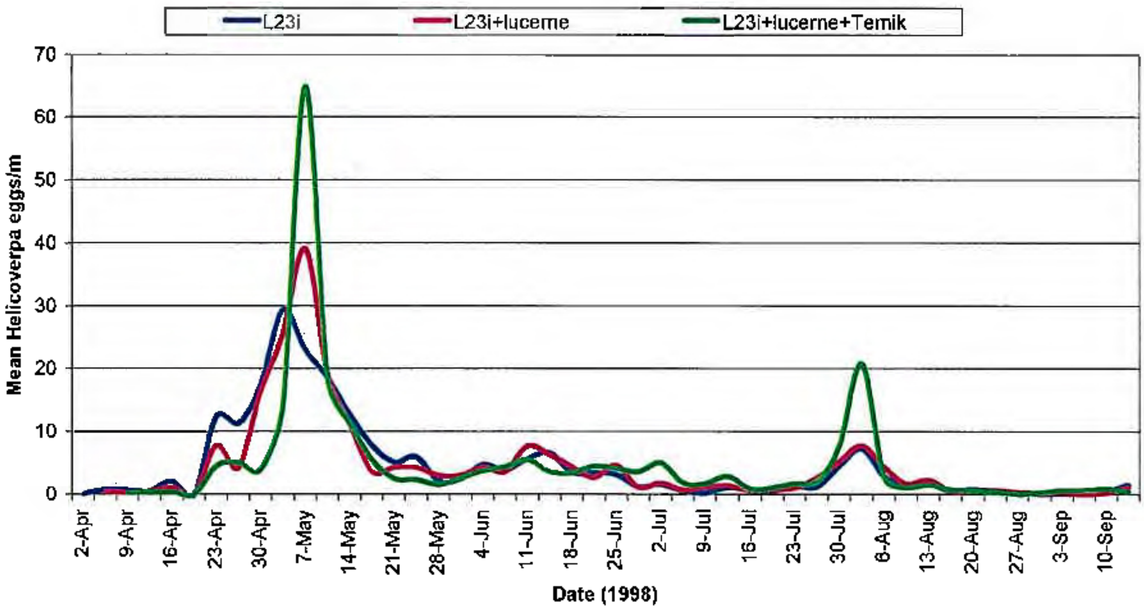
Farm #	Average sprays	Average yield (bales/ha)	Total bales
1* (FWI)	NA	7.44	412
2*	NA	9.33	197
3	4.0	6.96	775
4	4.2	7.68	941
5	1.67	6.65	350
6	2.5	7.74	279
Valley	**3.8**	**7.40 bales/ha**	**2,954**

* Farms without all IPM replications.

INGARD® crops performed reliably with good lepidopteran pest control for much of the season. However, with the increased number of farmers involved, variability in INGARD® efficacy from paddock to paddock was again apparent. In addition, *Spodoptera litura* appeared on some crops and was a minor but, at times a persistent pest. The winter growing strategy was developed in part to avoid this pest because it is known to be poorly controlled by INGARD®.

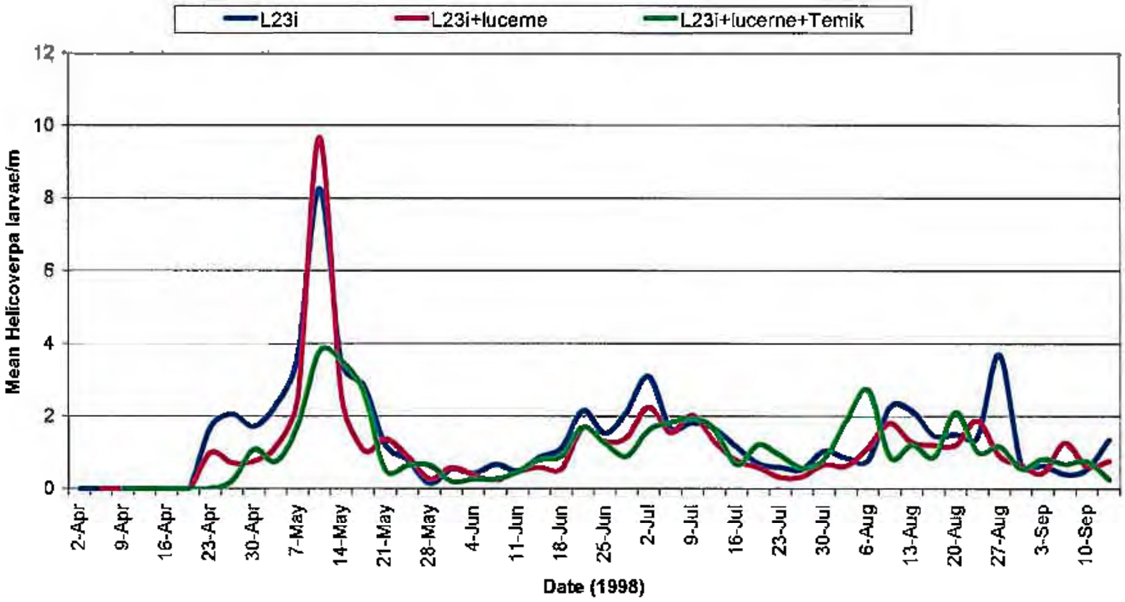
The hot seasonal conditions were expected to encourage *Helicoverpa* activity but this did not eventuate and *Helicoverpa* pest pressure was remarkably low, as summarised in Figures 33 and 34. Figure 33 shows a period between mid-April and May when oviposition was high at between 20-60 eggs/m. However, after this peak oviposition remained at below 10 eggs/m for the remainder of the season, apart from a small and unsustained peak on some crops in early August. This activity was in stark contrast to the previous season when oviposition of 30-40 eggs/m was sustained from seedling emergence through to cutout.

Figure 33. Mean Helicoverpa oviposition on IPM cotton treatments at Kununurra, 1998.



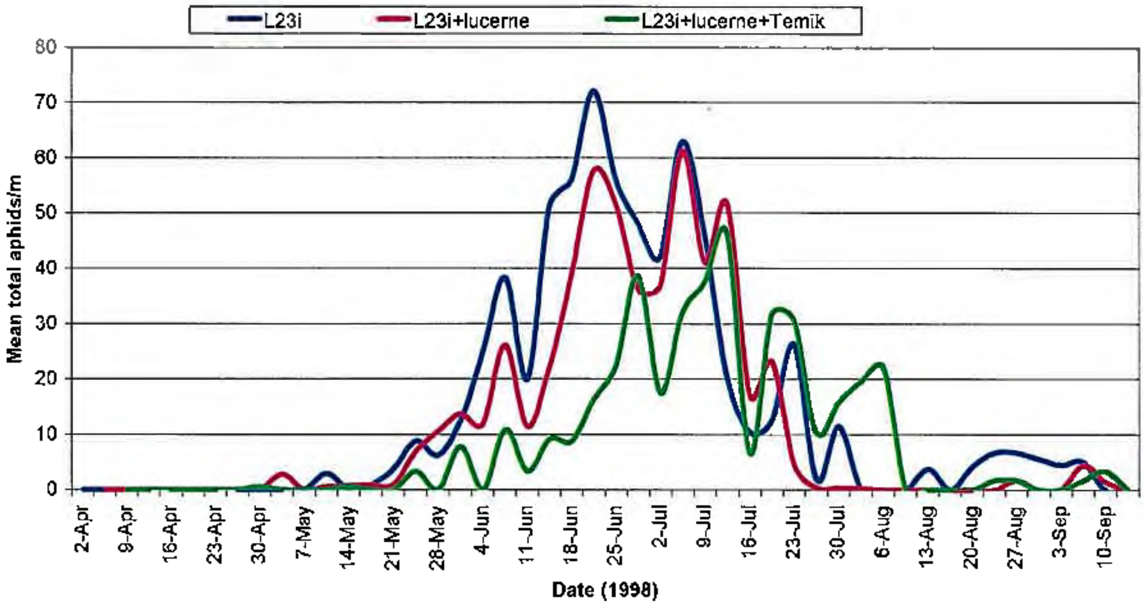
Helicoverpa larval populations in all crops followed the oviposition pattern. Larval numbers (mostly neonates) peaked early in the season and remained sub-threshold for most of the season. As discussed previously, these low pressure conditions resulted in less than four sprays being required to control pests.

Figure 34. Mean Helicoverpa total larvae on IPM cotton treatments at Kununurra, 1998.



Populations of *Aphis gossypii* were also low relative to previous seasons, perhaps in response to the hot season. Figure 35 shows aphids generally below 60/m whilst in 1997 the population exceeded 100/m for the mid to late season.

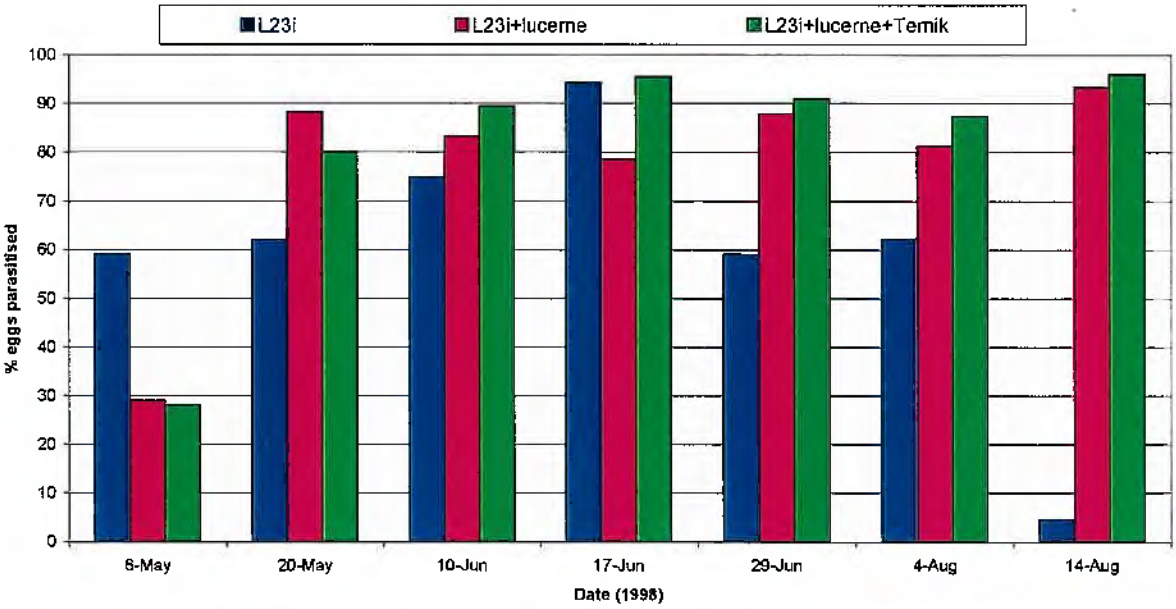
Figure 35. Mean aphids on IPM cotton treatments at Kununurra, 1998.



2. Beneficial insect impact

As in previous seasons, *Trichogramma pretiosum* was a very significant parasitoid and maintained high levels of *Helicoverpa* egg parasitism. Figure 36 shows that all crop management areas had egg parasitism levels of > 70% for most of the season with peak levels of > 90% at several sampling times.

Figure 36. Percentage Helicoverpa eggs parasitised by Trichogramma in IPM crops at Kununurra, 1998.



Other beneficial insects will be discussed in the next section of this report.

3. Mirids and trap crops

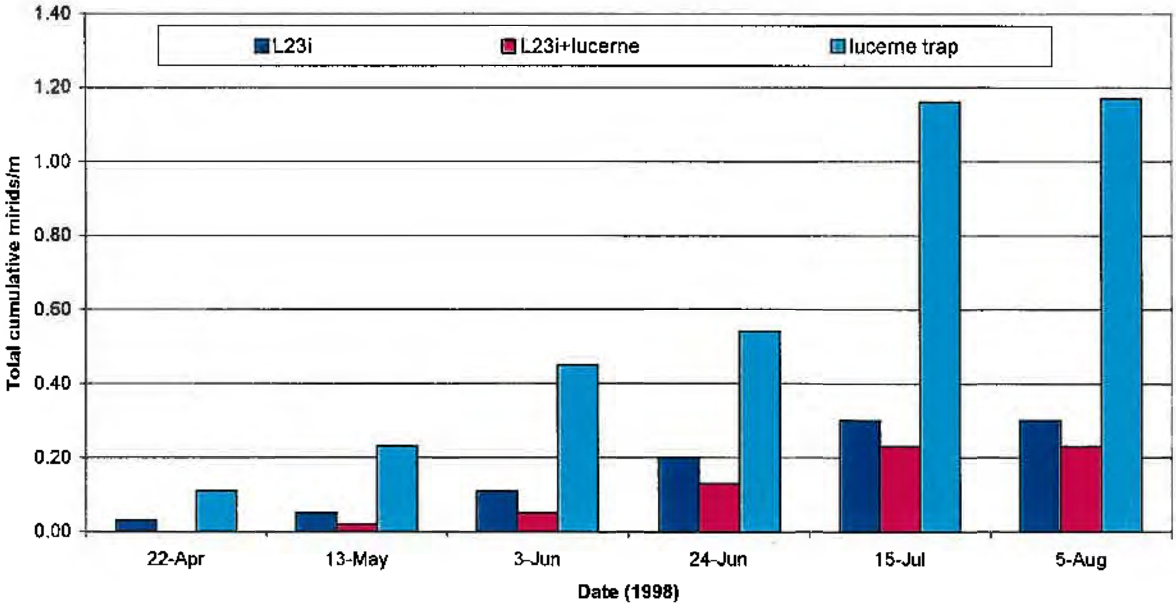
Trap crops are an important component of IPM systems and have two prime functions:

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

During the 1998 season, suction samples were taken from Siokra L23*i*, Siokra L23*i* with a lucerne trap crop and from within the lucerne trap crop itself. The samples were collected every 3 weeks and the collections sorted in the laboratory and the data recorded.

The cumulative mirid data, shown in Figure 37, clearly demonstrates the attractiveness of lucerne to mirids compared to cotton. The mirid population was 400% higher in lucerne than in cotton, with or without a lucerne trap crop. The data also show that mirids tended to remain in the lucerne because cotton with the lucerne trap crop had lower mirid populations than cotton without a trap crop. However, it must be remembered that the mirid population was generally very low in 1998 and this may have influenced the effectiveness of the trap crops. Certainly in previous seasons when mirid numbers were higher, the effectiveness of the lucerne trap was not as clear.

Figure 37. Total cumulative mirids in IPM treatments and the lucerne trap crop at Kununurra, 1998.



Apart from trapping and retaining mirids, the other important function of trap 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 lucerne trap crop compared to cotton, with and without the trap crop, is shown in Figures 38 and 39.

The data for 1998 was consistent with previous seasons in showing the superiority of lucerne over cotton as a source of beneficial insects generally. However the extent to which lucerne produced beneficial insects relative to cotton was not as great as in previous seasons. This was true for both predators and parasitoids.

The data also suggest that although the lucerne contained higher numbers of beneficial insects, they were not necessarily contributed to the neighbouring cotton crop. The data show that fewer beneficial insects were present in cotton when a trap crop was nearby. This result conflicts with the results from previous seasons.

Figure 38. Total cumulative predators in IPM treatments and lucerne trap crops at Kununurra, 1998.

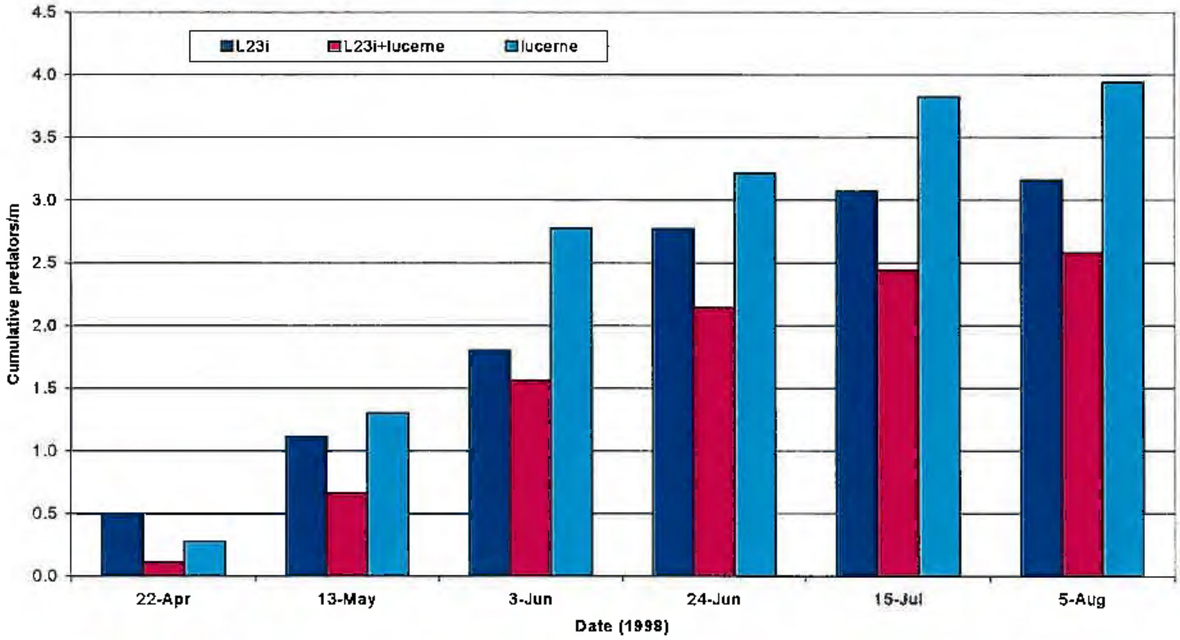
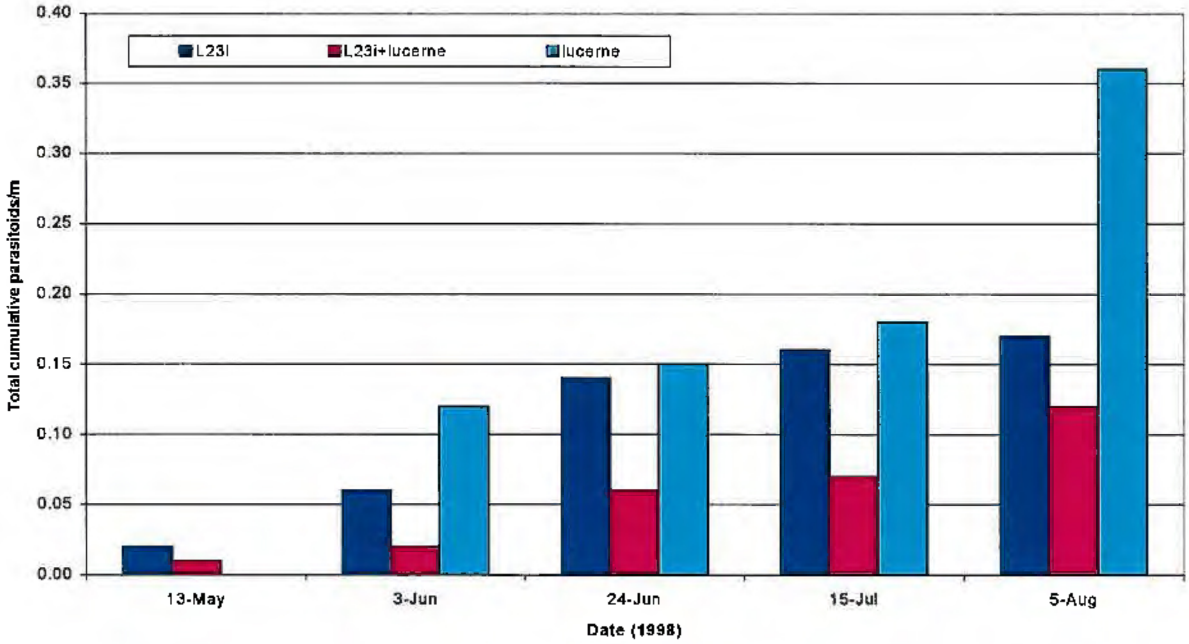


Figure 39. Total cumulative parasitoids in IPM treatments and lucerne trap crops at Kununurra, 1998.



SUMMARY AND CONCLUSIONS

This report details the first three years of pest management research aimed at identifying preliminary integrated pest management (IPM) options for INGARD® cotton grown in the Ord River Irrigation Area. Pest management is seen as a key to future sustainable cotton production in the Kimberley and is a major component of assessing the viability of a new production technology for the Kimberley based on:

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

A feature of the project has been the early involvement of elite local farmers who have committed to growing IPM cotton under the direction of Agriculture WA. This was made possible by the foresight of Colly Cotton and the Ord River District Cooperative, which jointly invested in the construction of a small gin at Kununurra in 1997 and enabled research to be conducted on a realistic scale. The area of cotton included in the trials grew annually from an initial 50 ha in 1996, to 240 ha and 380 ha in the following two seasons.

The farm-scale experiments produced encouraging yields with low insecticide spray requirements as summarised in Table 6. Yields were generally over 7 bales/ha and these were considered acceptable given farmer inexperience, novel IPM systems and the use of unconventional selective chemicals. Average yields were depressed by some extremely poor yields on individual paddocks which had serious agronomic problems, such as waterlogging, during the season. However, on the positive side, excellent individual paddock yields over 9 bales/ ha were also recorded during the trials.

The low number of total insecticide sprays was also a highlight of the trials with an overall average of about 4 sprays being required per crop. This compares very favourably with the former summer cotton industry at Kununurra, which averaged around 20 sprays per season in its best year (1970), and peaked at 40 sprays per crop in the disastrous final season (1974) when insecticide resistance overwhelmed the industry. Four sprays per INGARD® crop also compares favourably with current practices in the established industry in eastern Australia.

Table 6. Summary of yields and sprays comparing IPM and non-IPM cotton at Kununurra, 1996-98

Year	Yield SiokraL23*i*	Number sprays	Yield SiokraL23*i* + *IPM*	Number sprays
1996	6.98	3.50	7.64	3.00
1997	6.61	5.75	6.63	4.10
1998	7.27	3.75	7.36	3.58
Overall means	6.95	4.33	7.21	3.56

Key features of IPM system research included the role of trap crops and the encouragement of naturally occurring beneficial insect species. The trap crops assessed in the experiments were lucerne and niger and both showed their attractiveness to mirids. Niger was far more attractive to mirids than lucerne but needs to be sown three times during the season because it flowers and matures rapidly in the Kimberley winter. This poses logistical problems to the farmer and is likely to render the crop impractical. Cotton grown with niger and lucerne strips generally had fewer mirids that cotton grown alone. However there did appear to be movement from the trap crops to cotton and a 'trap and destroy' strategy would be worth further consideration.

Trap crops also demonstrated a capacity to produce relatively large populations of beneficial insects, including predators and parasitoids. Cotton grown with strips of lucerne and niger had a trend towards lower *Helicoverpa* larval populations and higher numbers of beneficial insects. The *Helicoverpa* egg parasitoid, *Trichogramma pretiosum*, is the most important beneficial insect in the cotton ecosystem at Kununurra. The parasitoid frequently accounts for more than 70% of *Helicoverpa* eggs oviposited on cotton with parasitism levels greater than 90% on some occasions. *Trichogramma* were more abundant in lucerne than cotton but higher parasitism levels did not occur in cotton with trap crops grown in association. The ecology of *Trichogramma* is poorly understood.

The overall conclusion from the research is that transgenic cotton varieties, containing the INGARD® (Bt) gene, show great promise in tropical north-western Australia. Lepidopteran pests are effectively controlled for much of the season and the use of trap crops as components of an integrated pest management (IPM) system assist in control. The *Helicoverpa spp* egg parasitoid, *Trichogramma pretiosum*, is the most important beneficial insect in the cotton ecosystem but its ecology is not fully understood.

Winter cropping avoids many pest and agronomic difficulties imposed by summer cropping in the Kimberley region. Transgenic varieties, grown with supporting IPM systems, offer the opportunity for sustainable cotton industry development in this region.

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 efficacy of INGARD® varieties in controlling lepidopteran pests has been clearly demonstrated in the winter growing conditions of the Kimberley. The benefits of IPM in reducing the insecticide requirement of the crop and producing a rich abundance of beneficial insects have also been shown. First-time cotton farmers have achieved satisfactory commercial-scale yields and there is clear scope to increase yields as improved varieties, farmer experience and crop management practices are developed.

There is also a need for additional pest management and agronomic research to be undertaken in the Kimberley to build on the encouraging preliminary results. In terms of pest management research, key areas requiring additional input include:

1. validation of *Helicoverpa* thresholds in INGARD® cotton, particularly with respect to high levels of sustained neonate damage to pin-squares;
2. validation of mirid thresholds in Kimberley growing conditions;
3. further refinement and improvements to trap crop and beneficial insect management in IPM systems, including a 'trap and destroy' technique for mirids;
4. assessment of refuge trap options and defining a pre-emptive resistance management strategy for transgenic cotton in Kimberley winter grown cotton.

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2. Strickland, G.R. and Lacey, I.B. (1996). The seasonal abundance of *Trichogramma pretiosum* in cotton grown with different pest management strategies in the Ord River Irrigation Area (ORIA). pp. 273 - 277. In Proceedings of The Eighth Australian Cotton Conference, Gold Coast, Queensland.

3. Yeates, S.J., Constable, G.A., Strickland, G.R. and Fitt, G.P. (1996). Development of agronomic and varietal options for dry season cotton production in NW Australia. pp. 577-584. In Proceedings of The Eighth Australian Cotton Conference, Gold Coast, Queensland.

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5. Strickland, G.R., Addison, S.J. and Annells, A.J. (1998). IPM and INGARD® in the Ord. The Australian Cottongrower, March-April 1998.

6. 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 (in press).

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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 Bloeker and Torben Sass-Neilsen have been involved every season and strong support from Rob Boshammer / Fritz Bolten, Darryl Smith, Lindsay Innes, Kane Younghusband, Michael Eppler, Barry Lerch, Pacific Seeds and Dave Menzel is also gratefully acknowledged.

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