CSIRO Plant Industry
Cotton Research Unit
and
CRC for Sustainable Cotton Production

FINAL REPORT

Project title: **Improved pest management for mites and thrips on cotton.**

Project code: **CSP74C**

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A final report prepared for the Cotton Research and Development Corporation

Plain English Summary
Research in this project was conducted over 3 years to investigate a range of issues related to improving the management of pests in cotton, especially through the early season. Experiments investigated

- the efficacy and non-target effects of new insecticides
- the response of cotton to early pest damage from thrips and other pests
- resistance in spider mites to insecticides
- the effects of spider mites on yield of dryland cotton
- plant resistance in cotton to spider mites
- rotation crops and mite overwintering.
- effects of aphids on cotton yield

The aims of the project were largely met and outcomes have been extended to industry. This project has highlighted the importance of early season pest management in 'setting the stage' for integrated pest management (IPM) in cotton. Further, to facilitate the development of IPM the efficacy and effect on predators of a wide range of insecticides was tested. This allowed development of tables that growers / consultants can use to assess the likely impact of insecticides on beneficial insect populations.

A comprehensive risk analysis study for thrips was undertaken and the capacity of plants to recover from thrips damage explained to industry. Further study identified the capacity of cotton to recover from different types of pre-squaring damage and these results reported to industry. These outcomes have contributed significantly to changing attitudes toward thrips control and early damage and have produced a dramatic reduction in the early season use of organophosphate sprays to control thrips.

Resistance in spider mites to acaricides was studied. Resistance was found to older organophosphate compounds, but alarmingly also to the newer pyrethroid, bifenthrin. Early in the project an acaricide resistance management strategy was developed and has been endorsed and accepted by industry. The efficacy of new acaricides was also compared and results reported to industry.

Spider mites are a key pest in irrigated cotton but their significance in dryland cotton was unknown. Our experiments showed that dryland cotton is more tolerant of mite damage than irrigated cotton, with yields much less affected. We also compared the resistance of a range of cotton lines to mites and identified a number which show promising resistance. Notably, the commercial okra leaf varieties consistently conferred a moderate degree of resistance to mites and were high-yielding. We also considered the possible impact of changing rotation crop choices on pests such as mites. Legume crops grown through winter harboured significant mite infestations. These mites could migrate into cotton in the following spring and legume rotations are therefore a potentially important source of infestation of spider mites between crops

Experiments to determine the effects of aphids on cotton growth and yield were hampered by insecticide drift from neighbours. Nevertheless, glasshouse experiments showed that the green peach aphid is far more damaging to cotton than the cotton aphid. This was reflected in changes to thresholds for these pests.

Management of mites and early season sucking pests on transgenic cotton.

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Aims:

- Further define the economic impact of thrips on cotton with emphasis on short season areas.
- Further define the economic impact of early season damage to cotton in terms of yield and maturity for transgenic cotton, considering effects of specific pests (thrips, mirids and *Heliothis*) both alone and in combination, and interactions with plant density.
- Evaluate the effect of new insecticides on non-target insects and on secondary pest outbreaks (mites, aphids and whitefly).
- Investigate the interaction between biotic and abiotic stresses on cotton yield, quality and maturity with specific emphasis on mite damage (biotic) and drought or nutritional stress (abiotic)
- Investigate the effects of aphids on yield of cotton.
- Monitor resistance levels in mites to acaricides and investigate the effects of insecticides on mite reproduction and development.
- Continue research to into plant resistance to mites focussing on new genotypes from the Australian Cotton Breeding Program.
- Investigate overwintering of mites on winter rotation crops.

Summary of Results

A summary of the research, methodology, results and outcomes is given below.

Further define the economic impact of thrips on cotton with emphasis on short season areas.

The economic impact of thrips (*Thrips tabaci* and *Frankliniella schultzei*) on cotton was studied in experiments on commercial cotton farms in the cooler Upper Namoi region during the first two seasons of this project (4 experiments). In all experiments the growth, yield and maturity of cotton protected from thrips using aldicarb (Temik at 3 kg/ha) was compared with unprotected cotton. In some experiments seed treatments such as Semevin or Gaucho were also included. Each experiment was sampled weekly for pest and beneficial abundance for the first six to eight weeks after emergence. Plants were collected from each plot and taken to the laboratory where they were washed to recover thrips, mites, aphids and other pests. After washing we recorded the height, number of nodes, degree of tip or terminal damage, leaf area and dry weight of plants. After squaring began we also recorded the number of squares, bolls and open bolls. A suction sample was also taken from each plot to investigate the impact of the aldicarb or seed treatments on beneficial numbers. Once open bolls were found in the field we did maturity picks in each plot each week until 100% of bolls were open. Yields were obtained from each plot with a commercial pickers and the weight of cotton determined using load cells.

The efficacy of the seed treatments thiodicarb (Semevin) and imidacloprid (Gaucho) for control of thrips was investigated and compared with aldicarb. Semevin provided moderate control of thrips populations for about 2 weeks, but did not result in an increase in yield or earlier crop maturity. Gaucho provided good control of thrips for about 4 weeks and occasionally this translated into a slight gain in yield. Aldicarb provided superior control to either seed treatment.

The results for the cool season areas confirm generally confirm those for the warmer regions. Plant growth analysis showed that thrips caused highly significant reductions in plant dry weight, leaf area and tap root weight, even at relatively low thrips densities (3 – 5 per plant). These effects generally peaked at about 30 to 50 days after sowing, when reductions of 50-60 % in dry weight were common, and resulted in highly visible symptoms which made damaged cotton stand out from protected cotton. However, by about 60-80 days after sowing, the damaged plants had fully recovered and had dry weight, leaf area and tap root size similar to that of undamaged plants. In contrast to the warmer regions, where plants generally recover fully from this early damage, the results from the cool regions showed incomplete recovery, with a slight yield loss in several experiments.

We investigated further this difference between the warm and cool regions in recovery of cotton following thrips damage. We combined the outcomes of all of our experiments with those from replicated experiments done by District Agronomists and by Cotton Seed Distributors (Robert Eveleigh, Adam Kay and Glen Lendon). In each case the trials included Temik at 3 kg/ha and an untreated control (seed treated only with fungicides). The results are summarised below and indicate that in warmer regions there is only about a 1 in 10 chance of thrips damage causing a significant reduction in yield. However, in cooler regions this jumps to 1 chance in 2. This outcome has been extended widely to industry, with the general recommendation that in warmer and hot regions control of thrips is rarely justified, and use of an inexpensive seed treatment such as Semevin will provide adequate risk prevention. In cooler regions the higher risk of loss means that more effective control of thrips is warranted, such as aldicarb, thimet or Gaucho.

The effect of thrips damage on crop maturity date was assessed in 9 experiments. Overall, unprotected cotton matured about 4 days later than protected cotton, with a range from no delay to a maximum of 9 days delay at one site where heavy thrips populations (67 thrips / plant) occurred.

Table 1. Number of sites where protection of crops against early thrips damage significantly improved yield or had no effect on yield.

Type of region	Statistically significant difference between unprotected and protected cotton?	No. sites	Ratio (Significant ÷ non-significant)	Average yield (b / ha)		% difference between treatments
				Unprotected (QAP)	Protected (aldicarb or phorate @ 3 kg/ha)	
Cool	Yes	11	50%	7.5	8.1	8.0%
	No	11		7.7	8.0	3.9%
Warm	Yes	3	13%	7.0	8.1	13.6%
	No	21		8.0	8.1	1.2%

Results of the suction sampling showed a slight effect of aldicarb and no detectible effect of seed treatments on beneficials other than thrips. These products can be considered to be relatively selective with these use patterns.

Further define the economic impact of early season damage to cotton in terms of yield and maturity for transgenic cotton, considering effects of specific pests (thrips, mirids and *Heliothis*) both alone and in combination, and interactions with plant density.

We undertook a series of experiments where we used artificial damage to simulate that caused by different intensities of pests. We used artificial damage to investigate the response of cotton to different types of early season damage including; reduced leaf area (thrips damage), tipping out (thrips, mirids, *Helicoverpa* or tipworm) and early fruit loss (*Helicoverpa* or mirids). Artificial or 'simulated' damage allows us to determine the responses of cotton to specific types, intensities and combinations of damage. We cut out the growing terminal with scissors to simulate tipping out, or cut off a portion of each leaf to simulate the reduced leaf area or defoliation caused by thrips. If we tipped out a plant more than once, we cut out all new growing tips, not just the dominant one. Experiments were all sown in early October, managed similarly to commercial practice with adequate fertilisation and irrigation and. They were protected from other forms of damage using an in-furrow insecticide and insecticide spraying as required. The variety in experiment 1 was Siokra V-15, and in experiments 2 and 3 was Sicala V-2i.

These experiments were all done in the lower Namoi Valley, which is a warm or 'full season' region. The results have significant implications for early season pest management in full season regions, but to some extent the principles will also apply in cooler 'short season' regions. Across all experiments the damage imposed had striking visual effects in the field, especially the 'heavy' damage treatments with repeated 100% defoliation or repeated tipping out. Several key conclusions can be drawn about the responses of cotton to damage;

1. Pre-squaring cotton was very tolerant of relatively high levels of tip damage, i. e. 100% of plants tipped out up to three times did not affect yield or maturity. This held true even when tip damage was combined with other forms of damage such as defoliation or fruit removal,

2. Heavy early fruit loss (all fruit lost from first four fruiting branches) did not affect yield but did cause a delay in maturity of about seven days,

3. The yield of pre-squaring cotton was unaffected by defoliation, even when 100% of true leaves were removed on three occasions. Pre-squaring cotton is also tolerant of defoliation levels of up to 80% loss of true leaf area without affecting maturity. Defoliation of 100% of true leaf twice was required before there was a significant delay (5 – 13 days).

Implications - Tip damage
Early season tipping out had no significant effect on yield or maturity, which is not surprising given the results of other similar studies. Thrips only cause tip damage if they are present in extremely high numbers (> 30 thrips per plant). Comparisons of the degree of early tip damage in conventional and Ingard cotton show that most tipping out is due to *Helicoverpa* rather than thrips. Often neonate *Helicoverpa* larvae will damage the tip of a plant then die, either due to exposure to unsuitable environmental condition (wind, rain) or predation. When the plant is checked, thrips are present but no *Helicoverpa* larvae found - possibly leading to the conclusion that thrips caused the tipping out.

The tip damage simulated here probably reflects light mirid damage. Research by Moazzem Khan and Robert Mensah at ACRI shows that heavy mirid damage usually completely kills the terminal and young true leaves resulting in significantly delayed plant maturity, though yield is usually unaffected. As well, mirids also inject enzymes known as pectinases when feeding, which may affect the ability of the plant to recover.

A characterising feature of the 1998-99 cotton season was the high abundance of tipworm through the pre-squaring period in many regions. This pest caused very high levels of tip damage, with plants being tipped out repeatedly, often 4 or more times. In fields affected by tipworm it was evident that plants that had been tipped out 1-3 times generally recovered, whereas plants with more tipping out events often remained stunted and cabbage-like in appearance. It is unclear whether the more extremely tip damaged field suffered yield loss, but many were delayed in maturity.

In hindsight this season has confirmed the results of our experiments – plants can tolerate reasonably high levels of tip damage without affecting yield or maturity. However, there is a point beyond which further tip damage will adversely affect either yield or maturity or both. When assessing the likely effects of tip damage the form and source of damage should be considered. If tip-damage occurs as a single event, such as neonate *Helicoverpa* feeding or non-entrenched tipworm then the crop can suffer relatively high levels of tipping out without delay, in the order of 1-2 tip damage events per plant (ie 100- 200%). If the damage is due to extreme thrips populations (>30 per plant) or entrenched tipworm then the tip may be prevented from re-growing for some time. This type of damage is essentially similar to frequent repeated damage and a lower tip-damage threshold should be used, initially plants each damaged once, (i.e. 100%). Light mirid damage often causes damage similar to *Helicoverpa* spp. but the pectinases injected may affect plant recovery so a threshold of 50% of plants tipped-out should be used. Heavier mirid damage, where several nodes are damaged has the potential to significantly delay plant growth and a threshold of 20% of plants tipped out should be used.

The seasonal conditions and crop vigour are also likely to be important. Repeated tip damage is likely to be less of a concern if the conditions are warm and the crop vigorous than if the conditions are cool and the crop slow growing. Under such conditions a lower tip damage threshold may be applicable until the crops growth recovers. Similarly the experiments with thrips damage, described above, suggest that damage may be more of a concern in cooler regions where crops have less time in which to recover. The plant growth matrix developed by Dallas Gibb and Mark Hickman (see ENTOpak Supporting Documents) provides a framework to combine plant damage, pest numbers and plant growth in the pest management decision-making process.

Implications - defoliation (reduced leaf area)

Our leaf removal experiments simulated the equivalent of very light to very heavy thrips pressure. The results confirm those obtained in field experiments with thrips, namely that such levels of damage are often cosmetic despite their dramatic appearance. Plants suffering early defoliation may appear to be growing much worse than protected ones. However, in warm or hot regions, plants are generally able to recover fully from this degree of damage. These findings confirm those of Lane (1959) who found that defoliation levels in excess of 80% were generally required to reduce the yield of seedling and pre-squaring cotton.

Implications - early fruit loss

Heavy early fruit damage can cause a delay in maturity. However the results show that fruit damage does not interact with early defoliation or tip damage, but has an additive effect. This has two key implications for IPM in cotton. Firstly, work by Dallas Gibb shows that yield is maintained provided that early fruit retention levels of about 60% are maintained. Our data shows that even in a worst case scenario when all early fruit is lost yield was unaffected, though maturity was delayed by a week. Secondly, early season fruit loss does not hinder the capacity of the plant to recover from earlier tip damage or defoliation.

Conclusions

Studies of this nature help us to understand the responses of cotton to pest damage. Although, simulated damage is not the same as actual insect damage, the agreement between studies using simulated damage and those using actual insect damage is encouraging. Future research will continue to define responses of cotton to damage in the key pre-squaring period. Development of IPM in cotton depends significantly on avoiding disruption of the early season predator complex in cotton. This requires a balance between preventing early damage and preserving beneficials. In many instances the value of early beneficial populations in helping to manage pests, such as mites, outweighs the value of early pest damage. Given the apparent resilience of young cotton found here and also by Dallas Gibb in his work with *Helicoverpa* thresholds, it is clear that further understanding of the compensatory capacity of cotton will be extremely valuable in reducing early season pesticide use.

- **Evaluate the effect of new insecticides on non-target insects and on secondary pest outbreaks (mites, aphids and whitefly).**

In each year of the project experiments were done to investigate the efficacy and non-target effects of a range of insecticides, with emphasis on newer products. This provides independent information on the performance of insecticides against the target pests for which they have or will have registration and also provides information on their impact on beneficial insects and on outbreaks of secondary pests such as spider mites or aphids. The experiments have all been conducted very successfully and have yielded invaluable data. Though some of the data has yet to be fully analysed and written up, sufficient has been done to facilitate the development of tables (Tables 2 and 3) indicating the target pests and effect on key beneficial groups. This research will continue as a core component of this research project.

Table 2. Impact of insecticides applied as foliar sprays on key beneficial groups in cotton (high= more disruptive)

Insecticides	Main Target Pest(s)						Beneficial group					
	Hel.	Mite	Mir.	Aph.	Th.[10]	Persistence[9]	Overall[13]	Predatory beetles[1]	Predatory bugs[2]	Spiders	Wasps & Ants	Thrips
Abamectin	√[6]	√				medium	**low-moderate**	low	low	moderate	moderate	low
Amitraz	√	√[11]				medium	**moderate**	moderate	low	high	moderate	moderate
Bacillus thuringiensis	√					short	**very low**	v low	v low	v low	v low	v low
Carbaryl						short	**high[3]**	high	high	-	high	high
Chlorfenapyr	√	√				medium	**moderate**	moderate	moderate	low	high	low
Diafenthiuron		√		√		medium	**low-moderate[12]**	-	-	-	-	-
Dicofol		√				long	**low**	low	low	low	low	v low
Endosulfan	√		√	√	√	medium	**moderate**	moderate	moderate	moderate	moderate	moderate
Fipronil			√		√	medium	**moderate**	low	high	moderate	v high	high
Imidacloprid[8]			√	√		medium	**moderate**	high	high	v low	moderate	moderate
Methomyl	√					short	**high**	v high	high	moderate	moderate	high
NP Virus[8]	√					short	**very low**	v low	v low	v low	v low	v low
OP's[5]	√	√	√	√	√	short-medium	**high**	high	high	high	high	high
Pirimicarb				√		short	**low**	low	low	low	low	low
Propargite		√				medium	**low[3]**	-	-	-	-	-
Pyrethroids[4]	√	√[7]				long	**very high**	v high	v high	v high	v high	v high
Spinosad	√					medium	**low**	low	low	low	high	moderate
Thiodicarb	√					medium	**high**	v high	moderate	low	moderate	high

1. Predatory beetles – ladybeetles, red and blue beetles, other predatory beetles
2. Predatory bugs – big-eyed bugs, minute pirate bugs,brown smudge bugs, glossy shield bug, predatory shield bug, damsel bug, assassin bug, apple dimpling bug
3. Information sources; Citrus pests and their natural enemies, edited by Dan Smith and University of California Statewide IPM project, Cotton, Selectivity and persistence of key cotton insecticides and miticides.
4. Pyrethroids; alpha-cypermethrin, cypermethrin,betacyfluthrin, bifenthrin, fenvalerate, esfenvalerate, deltamethrin, lambda-cyhalothrin,
5. Organophosphates; dimethoate, omethoate, monocrotophos, profenofos, chlorpyrifos, azinophos ethyl, methidathion, parathion-methyl, thiometon
6. Helicoverpa punctigera only.
7. Bifenthrin only.
8. Registration pending.
9. Persistence; short, less than 3 days; medium, 3-7 days, long, greater than 10 days.
10. Hel., Helicoverpa; Mir, mirids; aph, aphids; th., thrips
11. Suppression of mites only.
12. Based on information supplied by Novartis.
13. Impact rating (% reduction in beneficials following application); very low, less than 10%; low, 10-20%; moderate, 20-40%; high, 40-60%; very high, > 60%

Table 3. Impact of insecticides applied at planting or as seed treatments on key beneficial groups in cotton (high = more disruptive)

Insecticides	Main Target Pest(s)					Persistence	Beneficial group					
	WW	Mite	Mir.	Aph.	Th.[5]		Overall	Predatory beetles[1]	Predatory bugs[2]	Spiders	Wasps & Ants	Thrips
At planting												
Aldicarb	√	√	√	√	√	medium-long	**very low[3]**	v low	v low	v low	v low	v high
Phorate	√	√	√	√	√	medium-long	**very low[3, 4]**	No data	No data	No data	No data	v high
Carbosulfan	√		√		√	medium-long	**very low[3, 4]**	No data	No data	No data	No data	v high
Chlorpyrifos	√					medium	**very low[4]**	No data	No data	No data	No data	No data
Seed treatments												
Thiodicarb					√	short	**very low[3]**	v low	v low	v low	v low	high
Thiodicarb + Fipro	√				√	short	**very low[3, 4]**	No data	No data	No data	No data	high
Imidacloprid	√				√	short - medium	**very low[3]**	v low	v low	v low	v low	v high

1. Predatory beetles – ladybeetles, red and blue beetles, other predatory beetles
2. Predatory bugs – Big-eyed bugs, minute pirate bugs,brown smudge bugs, glossy shield bug, predatory shield bug, damsel bug, assassin bug, apple dimpling bug
3. Except for effects on thrips which are predators of mites. Note that aldicarb and phorate will also control mites.
4. Based on observations with other soil or seed applied insecticides.
5. WW., wireworm; Mir, mirids; aph, aphids; th., thrips
6. Persistence; short, 2- 3 weeks; medium, 3-4weeks, long, 4-6 weeks
7. Impact rating (% reduction in beneficials following application); very low, less than 10%; low, 10-20%; moderate, 20-40%; high, 40-60%; very high, > 60%

Investigate the interaction between biotic and abiotic stresses on cotton yield, quality and maturity with specific emphasis on mite damage (biotic) and drought or nutritional stress (abiotic).

Two experiments were undertaken and were highly successful. The results of the first have been published. Both experiments showed that there was a very strong interaction between water stress and the capacity of cotton to tolerate mites. The first experiment had two treatments, irrigation (+ or - water) and mites (+ or - mites).The second experiments had irrigation (+ or - water) and mites (infested with mites in January, in February or uninfested). Large differences in water stress between treatments developed in both experiments from early January. Mite populations developed to similar levels on both irrigated and dry cotton, as indicated by conventional counts of adults at leaf 3 below the terminal. However, when leaves were collected from the 3rd, 6th and 8th mainstem node below the terminal and all mite stages counted it was found that on the lower leaves the numbers of mite eggs, nymphs and adults was far less on the dryland cotton than the irrigated cotton. In the first experiment the lint yield in the unstressed crops (+ water, -mites) was 1750 kg/ha, water stress reduced this by 30%, mite infestation by 92% and the combination of mites and water stress by 72%. However, in the second experiment, where mite populations were less severe, mite damage caused a significant decline in the yield of irrigated cotton, with the earlier infestation having the greatest effect (Fig. 1). In contrast, water stress alone caused a significant reduction in yield compared with irrigated cotton, but mite damage caused no additional loss.

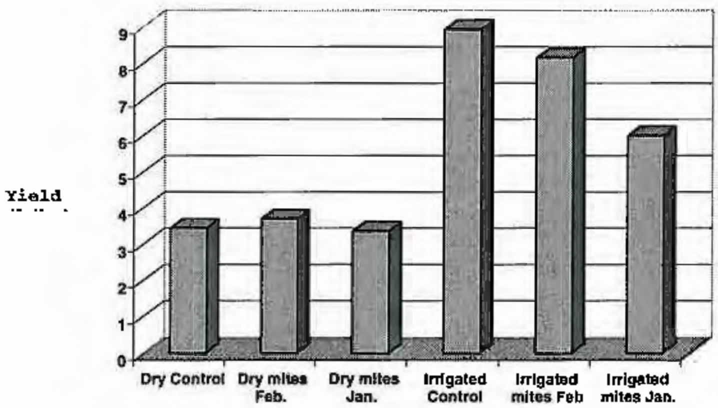

Figure 1. Effect of spider mites and water stress on yield (b/ha) of cotton.

The lower yield loss due to mites on the water stressed cotton indicates that chemical or morphological changes in response to water stress may have enhanced resistance to mites. Water stressed leaves were thicker and harder than non stressed leaves. Choice tests showed that mites preferred non-stressed to stressed leaf tissue. Similarly, rearing studies showed that mites developed more slowly, and laid fewer eggs on the leaves from dryland cotton than on irrigated cotton, both young and old leaves. We also did plant growth analysis studies as a component of these experiments and this information will be useful in validating the interaction between mites and cotton yield when this is incorporated into the OZCOT model. For cotton growers the implications are important, control of mites on severely water stressed cotton is unlikely to be very economic, however, if a dryland crop is growing well and has adequate soil moisture then it should be regarded as equivalent to irrigated cotton and mites managed accordingly.

Investigate the effects of aphids on yield of cotton.
Unfortunately this is the one aspect of our study where we can only report limited success. Each season we set up field experiments which were infested with aphids. The experiments were established successfully and were proceeding well, but in every case drift of insecticide from neighbouring farms resulted in death of our aphid infestations. Due to further insecticide drift events we were unable to re-establish aphid infestations despite repeated attempts to do so.

We did however establish small experiments in the glasshouse to investigate the effects of aphids on cotton growth and the possible link with the "Bunchy Top" syndrome that occurred in cotton in the 1998-99 season. We found that cotton is very tolerant of infestations of the cotton aphid (*Aphis gossypii*) and infestation typical of field infestations caused leaf curling but plants recovered quickly from this damage if the aphids were controlled. Very heavy infestations, sustained over a prolonged period (3 weeks) eventually caused stunting of plants. In contrast, the green peach aphid (*Myzus persicae*) caused far more severe damage symptoms at much lower densities than cotton aphid. Symptoms included severe shortening of internodes, dramatic reduction in leaf size, production of small squares and yellowing of leaves. These observations were confirmed independently by Bernie Franzmann and David Lea at QDPI, Toowoomba.

A combination of difficulty in controlling green peach aphid and its more severe effects on cotton growth lead us to recommend a different threshold for this pest. We are recommending a threshold of 25% of plants infested with green peach aphid compared with the conventional threshold of 90% of plants infested with cotton aphid.

- **Monitor resistance levels in mites to acaricides and investigate the effects of insecticides on mite reproduction and development.**

In each year of the project collections of mites were taken from commercial farms where there had been repeated use of acaricides or where there had been reported problems with the efficacy of acaricides. These collections were sent to Dr Grant Herron at NSW Agriculture (EMAI, Camden) to investigate possible acaricide resistance. Acaricides considered included propargite, dicofol, profenofos, monocrotophos, aldicarb, bifenthrin and more recently diafenthiuron and chlorfenapyr.

1996-97
Resistance was monitored in 3 strains from the Macquarie Valley and 2 strains from the Namoi Valley. No resistance was detected to either propargite or dicofol. All strains showed resistance to profenofos with the Cudgewa strain the worst (at 108 fold). Bifenthrin resistance was not evident in the LC50 ratios however 3 strains showed plateaus at about 98% mortality - possibly indicating low level incipient resistance. The worst of these strains has been kept and will be pressured by repeatedly spraying with bifenthrin to see if resistance levels change.

1997-98
Resistance was monitored in 4 strains from the Macquarie Valley and 2 strains from the Namoi Valley. Resistance to the organophosphates remains high, while no resistance

was detected to dicofol, diafenthiuron or avermectin. One strain (from the Macquarie Valley) showed resistance to propargite but this result needs to be confirmed in the 1998-99 season. Resistance to bifenthrin has been confirmed (see below). Results for percent mortality at the discriminating dose and resistance factor at LC_{50} and LC_{95} are as follows:

Table 4. Resistance levels to bifenthrin, 1997-98

Site	Valley	% mortality at discriminating dose	Resistance factor (LC50)	Resistance factor (LC90)
Weir Site	Macquarie	100%	1.6x	2.5x
Minoru	Namoi	100%	1.7x	2.3x
Mount Foster	Macquarie	90%	2.9x	9.0x
Togo	Namoi	99%	1.9x	3.9x
Killowen	Macquarie	95%	2.0x	3.8x
Auscott Warren	Macquarie	97%	2.0x	3.8x

Resistance levels to bifenthrin are still low but the number of populations with resistant individuals increased from 1 in 5 in 1996/97 to 4 in 6 in 1997/98.

1998-99

Resistance was monitored in 6 strains, 3 from the Macquarie, 1 from the Namoi and 2 from the Gwydir. No resistance was detected to dicofol, propargite, abamectin and or diafenthiuron. Bifenthrin resistance was detected in 5 out of the 6 strains tested with resistance level likely related to total number of field applications (Table 4). Resistance levels were extreme at the higher LC levels in many strains (RF 5,497x for Morecot Field 23 at the $LC_{99.9}$ level), which was due to a relatively low frequency of highly resistant individuals. Chlorfenapyr resistance was not detected, but some probit regressions did have unusually low slope values (Table 5) with strain Morecot Field 23 probit regression having a distinct plateau. Profenofos resistance was separated into two distinct groups (Figure 1) with resistance in the Morecot Field 23 and ACRI Field 17 group at a very high level.

Last season 100x profenofos resistance was detected in strain TO, which was approximately equal to the 108x resistance detected in strain CD (Cudgewa- Field 14) during season 1996/97. This season profenofos resistance has increased dramatically and is at 187x in strain Morecot Field 23 and 383x in strain ACRI Field 17. Such a dramatic rise in profenofos resistance is likely related to last season's high *Helicoverpa* pressure and consequent profenofos use.

In 1997/98, Dr Herron noted that changes in mortality at the discriminating dose against bifenthrin were still relatively subtle, which was reflected in low resistance levels. However, at the time he was concerned that the number of populations with resistant individuals increased from 1 in 5 in 1996/97 to 4 in 6 in 1997/98. Testing in 1998/99 shows bifenthrin resistance to be a reality and bifenthrin should now be considered as unreliable for two-spotted mite control in cotton.

Table 5. Testing results for the 1998/99 cotton season- twospotted mite against bifenthrin

Strain	Slope	LC50	RF	LC99.9	RF	Bifenthrin applications
Susc.	4.1	$8.9x10^{-4}$	-	$5.2x10^{-3}$	-	-
A.W. Field 17	1.47	$3.1x10^{-3}$	3.5x	0.42	80x	1
ACRI* Block 17	0.97	$7.2x10^{-3}$	8.1x	12.71	2,428x	2
Moolabah Field 24	1.14	$2.3x10^{-3}$	2.5x	1.28	245x	1
Elengerah Field 43	1.73	$3.9x10^{-3}$	4.4x	0.25	49x	1
Morecot Field 23	0.76	$2.2x10^{-3}$	2.4x	28.75	5,497x	1
Wearmatong+ Field 1	2.1	$1.0x10^{-3}$	1.2x	$2.8x10^{-2}$	5.4x	0

*NB This strain was not controlled with a 1.28% ai solution!
+Strain susceptible, 100% mortality at theoretical discriminating-dose.

Continue research to into plant resistance to mites focussing on new genotypes from the Australian Cotton Breeding Program.

Plant resistance to mites was investigated in the field in two experiments, one in 1996-97 and in 1997-98.

1996/97
Fifteen genotypes were artificially infested with mites in early January and mite population development monitored. Morphological traits had the greatest effect on mite population increase, with the noticeable exception of Pima. Genotypes with deep narrow lobed leaf shapes generally showed the greatest resistance to mites, especially a glabrous super-okra genotype. Several okra genotypes had broader lobes and had higher mite numbers than the narrow okra leaf types, for instance Siokra V15 vs Siokra 14. A sub-okra genotype had high mite numbers. All of the normal leaf shape genotypes had relatively high mite numbers in comparison with Siokra 1-4. Comparisons of isogenic or near isogenic normal genotypes with smooth or moderately hairy leaf surfaces showed higher mite numbers on the hairy lines. The Pima has a lobed, hairy leaf and harboured significant numbers of adult mites, however the mites did little damage and Pima plants remained green and healthy - confirming that Pima has a strong antibiosis type resistance to mites.

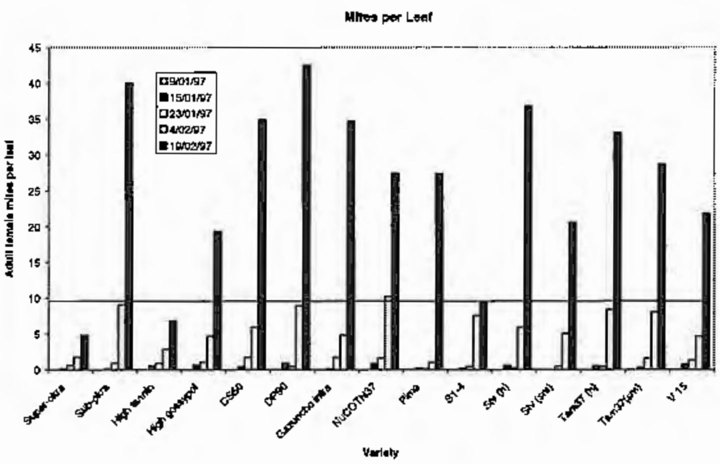

Figure 2. Number of adult female spider mites on different cotton genotypes, 1996-97.

1997-98

To extend the results from 1996-97 a larger scale experiment was set up, again with a range of genotypes. The aim of this experiment was to compare the relative tolerance of different genotypes to mite damage. This was done by comparing the relative yield of the genotypes under mite pressure (yield of mite infested cotton / yield of uninfested cotton. A wide range of other measurements was also made on each genotype including leaf hair density, leaf thickness, specific leaf weight and leaf hardness, but these data are not presented here.

Mite populations developed to very high levels in all genotypes, partly as a result of the use of broad spectrum insecticides to control other pests. Notably, high humidity levels occurred through much of the early part of the experiment and this is reflected in a reduction in the difference between normal leaf and okra leaf cottons in mite abundance. The resistance to mites in okra-leaf cotton is due to the shallower, more disrupted boundary layer of okra leaves which results in fewer high humidity sites suitable for oviposition and egg survival on okra shaped leaves than on normal leaves. However, high ambient humidity means the exposure of mite eggs to desiccating conditions will be far less and the magnitude of resistance afforded by the okra leaf shape could be expected to diminish.

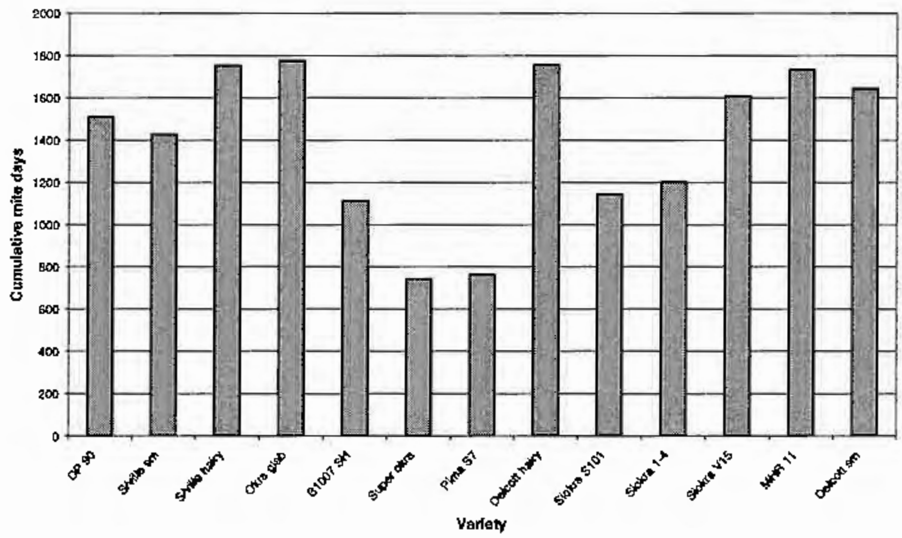

Figure 3 Cumulative mite days for a range of cotton genotypes, 1997-98.

Counts of mites indicate if a variety is suitable for the development of mite populations but do not indicate if there is any innate resistance or tolerance in the genotype to mite damage. Previous research has shown that although mite populations increase more slowly on okra leaf genotypes than normal leaf genotypes, there is no difference in the tolerance to mites, ie. the same mite population will cause the same amount of yield loss. Regression of relative yield against cumulative mite-days was done for the data in this experiment to identify genotypes which indicate higher resistance to mite damage. Unfortunately, most of the varieties tested all showed a similar response to mite damage – the higher the number of mite-days the lower the relative yield (= yield loss). Only the Pima S7 variety stands out as being particularly tolerant. Most other varieties showed a similar yield response to mite infestation. Of interest is the extremely hairy variety

B1007 which had relatively low mite densities but appears less tolerant of their damage. The super-okra variety also stands out, possibly because it has less leaf area, so even though it has less mites it also has less remaining undamaged leaf area.

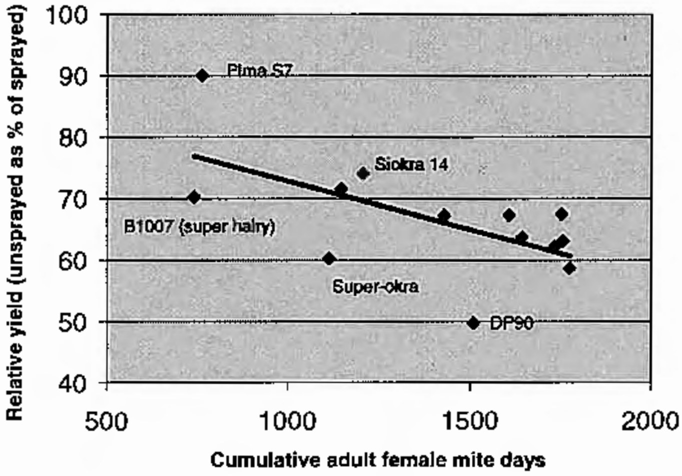

Figure 5. Relationship between relative yield and cumulative mite days for a range of cotton genotypes, 1997-98.

Investigate over-wintering of mites on winter rotation crops. Winter legumes such as faba beans and field peas are hosts for spider mites and their cultivation as rotation crops may lead to increased overwinter survival of mites. We monitored mite abundance through autumn, winter and early spring on two faba bean crops and field pea crop and on weeds associated with these crops, especially sowthistle and wireweed. These crops were planted following cotton (the cotton had just been harvested and slashed). Mites were found on weeds from the outset of the experiment. Some of the mites showed the orange colouration typical of diapause but the majority were of the green, non-diapause form. Colonies consisted of large numbers of eggs and larvae, indicating breeding. We also recorded mites from the seedling legume crops. These mite populations gradually increased in abundance until 100% of plants were infested by mites by September. Our results clearly show that the cultivation of winter legumes could increase carryover of mites by providing a good overwinter host. These crops are planted as soon as possible after harvest of the cotton and this increases the chance that mites will still be present in the field, on cotton regrowth or weeds, and will colonise the seedling legumes.

Other achievements

- With Dr Neil Forrester and Dr Jonathan Holloway, assisted Dr Paul De Barro with initial surveys of cotton to look for B-Type *Bemesia tabaci.*
- Dr Wilson presented information on resistance in mites and on IPM research to grower/consultant groups at 10 locations (Narrabri, Moree, Goondiwindi, St George, Dalby, Emerald, Warren, Mungindi, Theodore and Gunnedah) on the "Insecticide Resistance Management Tour" organised by Dr Neil Forrester and Mr Bruce Pyke (1996-97).

- Hosted a Cotton CRC sponsored visit by Professor L. T. Wilson (Texas A&M University) to discuss research on early pest damage, predation and crop modelling
- Participated as a member of the TIMS committee and of the TIMS insecticide troubleshooting committee
- Addressed numerous grower field days and meeting and grower visitor to the ACRI
- Provided 2 lectures each year to students in the UNE Cotton CRC course.

Recommendations for Future Research

- Further define the effect of early season pest damage to cotton in terms of growth, development, yield, crop maturity and fibre quality, considering effects of pests alone and in combination, and interactions with crop agronomy. This will also involve experiments comparing simulated and real pest damage to test how well simulated damage indicates the responses of plants to pest damage. This type of research also need to be undertaken in new cotton regions, such as the MIA and Northern Australia. Dr T. Lei has already initiated research of this nature in the ORIA with Dr J. Singh. Such information can be used to test the capacity of the OZCOT cotton crop simulation model to simulate crop responses to early damage and to improve the model if required.
- Investigate effects of damage by early season pests on Bt production in transgenic cotton. This would initially involve experiments with simulated damage but could be extended to experiments with real pests if results suggest this is warranted.
- Extend research on early pest damage into a range of cotton regions through collaboration with the CRC Cotton Extension Team. This provides the IDO's with first hand experience and will give them more confidence in dealing with growers
- Finalise analysis and writing up of mite and thrips research data. This data set has been finalised and urgently needs to be analysed and written up for industry and scientific journals
- Investigate the effect of aphids on the yield, maturity and fibre quality of cotton. The heavy aphid infestations of the 1998-99 season highlighted the paucity of information on the effects of aphids on cotton growth and development. This would include a more detailed comparison of the effects of cotton aphid compared with green peach aphid. The possible link between severe early aphid infestations and the "Bunchy Top" syndrome also needs to be clarified.
- Investigate the ecology of aphids in cotton regions and the role of beneficial insects in influencing aphid population dynamics
- Investigate the efficacy of new insecticides/acaricides, particularly against aphids and mites, and their effect on non-target insects (predators/parasitoids).
- Continue studies of resistance in mites and aphids – this is the basis for a CRDC project in collaboration with Dr G. Herron and Dr V. Edge.

Application of Results to Industry

The results of the research reported build strongly on the basic information provided by the previous projects (CSP1C and CSP46C). Extension of this research to industry has contributed to changes in practices. Key impacts have been;

1. Highlighting the importance of early season pest management in 'setting the stage' for IPM in cotton.
2. Identifying the fit of a range of new insecticides into IPM and for the first time providing a table of insecticides and their impact on beneficials.
3. Providing a comprehensive risk analysis study for thrips and explaining to industry how plants 'recover' from damage
4. Identifying and promoting to industry the capacity of cotton to recover from pre-squaring damage of different types and combinations
5. The latter two achievements have contributed significantly to changing attitudes toward thrips and early damage and seen a dramatic reduction in the early season use of organophosphate sprays to control thrips.
6. Providing independent information on the efficacy of new acaricides.
7. Developing an acaricide resistance management strategy in cotton and monitored resistance levels to all current acaricides (in collaboration with Dr Herron, Dr Forrester and Dr Holloway).
8. Providing a deeper understanding of plants resistance to spider mites that may assist in breeding.
9. Showing that winter rotation crops can be a potentially important source of carryover of spider mites between years
10. Showing that dryland cotton is more tolerant of mite damage than irrigated cotton.

Publications arising from this project

Refereed scientific publications

1. Herron, G.A., Edge, V. E., Rophail, J & Wilson, L. J. (1999) Development and use of a method to measure aldicarb resistance in *Tetranychus urticae* Koch (Acari: Tetranychidae) from cotton in Australia In, Proceedings of the 10th International Congress of Acarology. In press.
2. Sadras, V. O., Wilson, L. J. and Lally, D. A. (1998) Water deficit enhanced cotton resistance to spider mite herbivory. Annals of Botany *81*: 273-286
3. Sadras, V. O. and Wilson, L. J. (1998) Recovery of cotton crops after early season damage by thrips (Thysanoptera). *Crop Science* 38: 399-409.
4. Wilson, L.J., Bauer, L. R. and Lally, D. A. (1998) Effect of early season insecticide use on predators and outbreaks of spider mites (Acari: Tetranychidae) in cotton. Bulletin of Entomological Research *88*: 477-488.
5. Wilson, L.J., Bauer, L. R. and Lally, D. A. (1998) Acaricidal and stimulatory effects of insecticides on *Tetranychus urticae* Koch (Acari: Tetranychidae) in cotton. Australian Journal of Entomology (in press)
6. Wilson, L. J., Fitt, G. P. and Mensah, R. K. (1998) Ingard cotton – its role in cotton IPM. *Proc. 6th Australian Applied Entomological Research Conference*, September 29 - October 2, Brisbane, 1998. University of Queensland Press, Australia. pp. 267-276.
7. Wilson, L. J. and Sadras, V.O. (1999) Host plant resistance in cotton to spider mites. In, Proceedings of the 10th International Congress of Acarology. In press.

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1. De Barro, P. and Wilson, L.J. (1996) B-type *Bemisia tabaci* - an update. *Proceedings Eighth Australian Cotton Conference*, Broadbeach, August , 1996. pp 97-101.

2. Forrester, N.W., Buerger, P., Gunning, R., Gibb, D., Pyke, B. and Wilson, L. (1996) Insecticide resistance management strategy: cotton 1996/97. *Cotton Pesticides Guide 1996-97.* NSW Agriculture Agdex 151/680.
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5. Wilson, L.J. (1996) Will current secondary pests become problems in the transgenic era? *Proceedings Eighth Australian Cotton Conference*, Broadbeach, August , 1996. pp 85-96.
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7. Wilson, L.J. and Lally, D. (1996) Mites, resistance and early season use of insecticides. Australian Cotton Outlook. June, 1996.
8. Wilson, L.J., Sadras, V.O. and Lally, D. (1996) Early season pests need careful managing. In: Cotton Insight - Official public. of the South Qld Cotton Growers Assoc., November, 1996.
9. Wilson, L. J. and Sadras, V. O. (1997) Cotton recovery after thrips damage. *CSD Variety Trial Results Booklet* 1997.
10. Wilson, L. J., Larsen, D. and Sadras, V.O. (1997) Mite ecology in cotton. CRC Research Review Volume 3 No. 4. (ISSN 1327-0303)
11. Wilson, L. J. (1997) Managing mites on cotton. CRC Research Review.
12. Wilson, L.J. and Sadras V.O. (1998) How important is early season damage? Proceedings of the Ninth Australian Cotton Conference, Broadbeach, Queensland, August 12-14, 1998. Pp. 409-416
13. Wilson, L.J., Bauer, L. R. and Lally, D. A. (1998) Early season insecticide applications can induce aphid outbreaks. Proceedings of the Ninth Australian Cotton Conference, Broadbeach, Queensland, August 12-14, 1998. Pp. 417-421
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16. Wilson, L. J. and Sadras, V.O. (1998) How important is early season damage? Australian Cottongrower 19(6): 56-60
17. Wilson, L. J. and Hickman, M. (1998) Managing mites on young cotton. Australian Cottongrower 19(6): 46
18. Dillon, M., Wilson, L., Forrester, N. and Holloway, J. (1998) A few tips on managing tipworm. Australian Cottongrower 19(6): 40-44.
19. Wilson L. J. and Sadras V. O. (1998) How important is pre-squaring leaf damage or tip damage? *CSD Variety Trial Results Booklet* 1998.

Detailed Project Report

Most of the findings of this project have been written up either as formal scientific manuscripts or as extension articles for industry and a selection of these articles are included as the detailed project report.

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