A True IPM: Principles, Development and Adoption by the Australian Cotton Industry.

ROBERT MENSAH and ANGELA SINGLETON

NSW Agriculture, Australian Cotton Research Institute, Locked Bag 1000, Narrabri, NSW 2390, Australia, E-mail: Robert.Mensah@agric.nsw.gov.au

Introduction

Cotton production worldwide uses 11 per cent of global insecticides each year and the trend continues to increase (Pesticide News, 2001). Overuse of pesticides can cause human ill-health, increase pest resistance and disrupt the activities of beneficial insects. At least 520 species of insects and mites, 50 plant diseases and 113 weed species have become resistant to insecticides, fungicides and herbicides meant to control them (Pesticide News Vol. 47 and 48).

There are two extremes in pest management. The first is organic where no pesticides are used to produce crops (this is not economical in Australian cotton production); the second is chemical control where only synthetic insecticides are used in pest management (this strategy is not sustainable and environmentally not acceptable). In between the two or halfway between the two extremes lies an integrated pest management system (IPM) where all types of control options viz; biological, cultural, chemical etc are integrated to manage pests on crops. The IPM approach reduces dependence on synthetic pesticides to control pests.

The adoption of IPM for insect control by the Australian Cotton Industry may be regarded as a continuous journey of discovery. The industry has come a long way to reach where we are now. The industry has reached a point in their journey and are stagnating instead of moving forward to reach its goal (i.e. adoption of a true IPM). The point where the industry has reached and which is causing stagnation is the so called "soft option" IPM.

What is a soft option IPM:

A soft option IPM is not a true IPM. This type of IPM utilises a cocktail of synthetic insecticides regarded by many growers, researchers, consultants and chemical companies as "soft" on beneficial insects. But all these synthetic insecticides really soft? If they can kill *Helicoverpa* larvae on contact, how come they cannot kill adults and larvae of predatory insects. As we conduct more and more large scale trials, it has been found that some products originally classified as "soft" within small plot trials may have significant effects on the abundance of beneficial insects in commercial cotton fields. As a result, insecticides with short residual effect may be mistakenly classified as "soft". There is no doubt that growers have recognised that adopting a so called "soft option" approach to pest management has improved returns but it is not a true IPM. Soft option is a way forward but is not a true IPM. It is not sustainable and has problems with resistance associated to it. For example, insect resistance to Tracer® has been detected in the industry. We need to protect our valuable insecticides. To achieve this, it is crucial to use these "soft option" synthetic insecticides be on a "as needed basis" to correct high pest pressure situations in the context of a true IPM. Thus, the journey to adopt a true IPM should not stop at "soft option" IPM but continue to gain new knowledge that will enable the whole industry adopt a true IPM program.

What constitutes a true IPM

A true IPM is a system that integrates all means of managing pest populations with the aim of reducing insecticide use while maintaining profitability (yield, fibre quality, crop maturity) (see IPM guidelines, 1999). In a true IPM

- the presence of pests does not automatically require control measures, as damage may not be significant,
- the decision to control pests should be based on beneficial insects, pests and the physiology of the crop (vegetative damage, fruit retention, fruiting factors etc),
- when pest control measures are deemed necessary, a system of non-chemical pest methodologies should be considered before a decision is taken to use pesticides,
- pesticides should be used only as needed basis and only as a last resort.

Development of a true IPM

A true IPM program is developed in a step-wise fashion commencing with

- techniques to establish, concentrate and stabilise natural enemy populations (using food sprays and beneficial insects refuges) in the cotton crop system,
- followed by integration of beneficial insects with other control tools (such as Bt, NPV, myco-insecticides etc) which are least disruptive to natural enemy activity, and
- finally with the use of synthetic insecticides to achieve economic yield. In such an IPM system, synthetic insecticides are used as the last resort on a "as needed" basis (Mensah, 2002).

Development of IPM in commercial cotton farms (1992-98).

Since 1992, we have conducted a series of experiments in commercial cotton fields in NSW to integrate biological and synthetic insecticides with beneficial insects to form a true IPM program (see Mensah, 2002). In addition, a decision support system based on predator to pest ratio as a threshold to incorporate the activity of beneficial insects in pest management system has also been developed. (see Mensah, 2002; 2000; this proceedings). This paper is an extract from Dr Robert Mensah's IPM paper (two part series) published in 2002 in the International Journal of Pest Management volume 48, pages 85 -106.

Where were the studies conducted?

The studies were conducted in 4 commercial cotton fields. The study sites were at Norwood near Moree, Alcheringa in Boggabilla, Yarral in Narrabri and Bellevue near Warren. The plot sizes ranged from 50 ha (Yarral), 132 ha (Bellevue), 170 ha (Norwood) and 168 ha (Alcheringa). This paper addresses results at the Norwood study site.

Results and Discussion

Step 1: Establishment of beneficial insects in cotton system

Beneficial insects can be established in the cotton crops through the provision of food supplements (food sprays), release of beneficial insects, inter-cropping with non-cotton crops such as lucerne or a centrally located lucerne block or Ingard refuges (see supplementary sheets in IPM guidelines). There are two basic types of food sprays which are commercially available in the industry. They are yeast based food sprays (Envirofeast®, PredFeed®) and sugar based food sprays (AminoFeed® and Mobait®).

The initial development of the IPM program assessed at Norwood, used Envirofeast® as the food spray source and lucerne strips interplanted in cotton as predatory insect refugia. Predators identified in the treatment plots are given in table 2. The number of predators in the food spray plots were significantly higher than the unsprayed and insecticide treated plots (Table 3). However, their effect was not enough to maintain *Helicoverpa* spp. below the economic threshold and produce economic yields acceptable to the grower (Tables 1 and 3). Thus the addition of other complementary pest control tools was made to enhance the predator effect and improve pest management and cotton yields (see step 2).

Table 1. Effect of lucerne interplants integrated with Food spray at Alcheringa, 1994-95.

Treatments	Yields (bales/ha	No. of spray applications
Envirofeast®(Food) spray	2.72 ± 0.63 a	14 applications
Control (Unsprayed)	0.59± 0.123 b	No sprays
Conventional cotton	7.12±0.28 c	11 insecticide sprays

Means between treatments within column followed by the same letter are not significantly different (P>0.05), Tukey-Kramer Multiple Comparison Test.

Table 2. Predators of cotton pests identified from study plots from 1992 - 1998.

Order	Family	Species	Group

Coleoptera	Coccinellidae	*Coccinella transversalis* (Fabricius)	Predatory
		Adalia bipunctata (Linnaeus)	beetles
	Melyridae	*Dicranolauis bellulus* (Guerin-Meneville)	
Hemiptera	Nabidae	*Nabis capsiformis* (Germar)	Predatory
	Lygaeidae	*Geocoris lubra* (Kirkaldy)	bugs
	Pentatomidae	*Cermatulus nasalis* (Westwood)	
		Ochelia schellenbergii (Guerin-Meneville)	
	Reduviidae	*Coranus triabeatus* (Horvath)	
Neuroptera	Chrysopidae	*Chrysopa* spp.	Predatory
	Hemerobiidae	*Micromus tasmaniae* (Walker)	lacewings
Araneida	Lycosidae	*Lycosa* spp.	Spiders
	Oxyopidae	*Oxyopes* spp.	
	Salticidae	*Salticidae* spp.	
	Araneidae	*Araneus* spp.	

Table 3. Numbers of *Helicoverpa* spp. and predators on commercial cotton crops at Alcheringa near Boggabilla in NSW, 1994-95.

Treatments	No. per metre per sample date			
	Eggs± SE	*VS+S larvae±SE	*M+L larvae±SE	Predators±SE
Envirofeast®	2.96±0.33a	2.00±0.21a	1.47±0.19a	0.61±0.07a
Control (Unsprayed)	4.01±0.39b	2.68±0.28a	1.74±0.23a	0.28±0.05b
Conventional	4.38±0.49b	0.96±0.28b	0.78±0.16b	0.05±0.01c

Means between treatments within columns followed by the same letter are not significantly different (P>0.05), Tukey-Kramer Multiple Comparison Test.
* VS+S = Very small + small *Helicoverpa* spp. larvae * M+L = Medium + large *Helicoverpa* spp. larvae

Step 2: Integration of predatory insects, lucerne refugia system, Food supplement (Envirofeast®) with biological insecticides

In this study, equal number of *Helicoverpa* spp. eggs per metre per sample date were found on plots treated with conventional insecticides compared with food spray plus Bt and food spray plus NPV plots (see Table 4). However, the survival rates of larvae on the conventional insecticide plot was significantly lower ($P<0.05$) than the food spray plus Bt and food spray plus NPV plots (Table 4).

The cumulative total number of larvae per metre recorded throughout the study on the conventional insecticide treated plot was also significantly lower ($P<0.05$) than those recorded in the food spray plus Bt and NPV plots (Table 4).

Table 4. Effect of integration of lucerne interplants, food supplements and biopesticides (NPV, Bt) on *Helicoverpa* spp. and predators at Norwood, 1995-96.

Treatments	Eggs/m/sample date	Survival rate of larvae (%)	Cumulative total larvae/m	Predators/m/ sample date
Envirofeast (Food) spray+ NPV	1.46 a	43.5 a	24.36 a	0.75 a
Envirofeast (Food) spray + Bt	1.24 a	42.7 a	21.04 a	0.55 b
Conventional cotton	1.58 a	28.4 b	10.97 b	0.01 c

Means between treatments within column followed by the same letter are not significantly different ($P>0.05$), Tukey-Kramer Multiple Comparison Test.

Predators identified from the study plots are given in table 2. The highest number of predators per plot were recorded on the Food spray plus NPV followed by Food spray plus Bt treated plots. The conventional insecticide-treated plot had the lowest number of predators which were predominantly spiders (Figure 1, Table 4). In general predators were more abundant early in the season with numbers peaking on 24 November before declining thereafter (Figure 1). The rapid decline in the predator population in the conventional insecticide treated plot was the result of the insecticide used on these plots. However, the decline in the predator population in the Envirofeast®/Bt and Envirofeast®/NPV-treated plots was suspected by a combination of rainfall and drift of synthetic pyrethroid from neighbouring farms near the study site and also from the conventional insecticide plots despite the fact that insecticides were applied by groundrig until January (see Mensah, 2002).

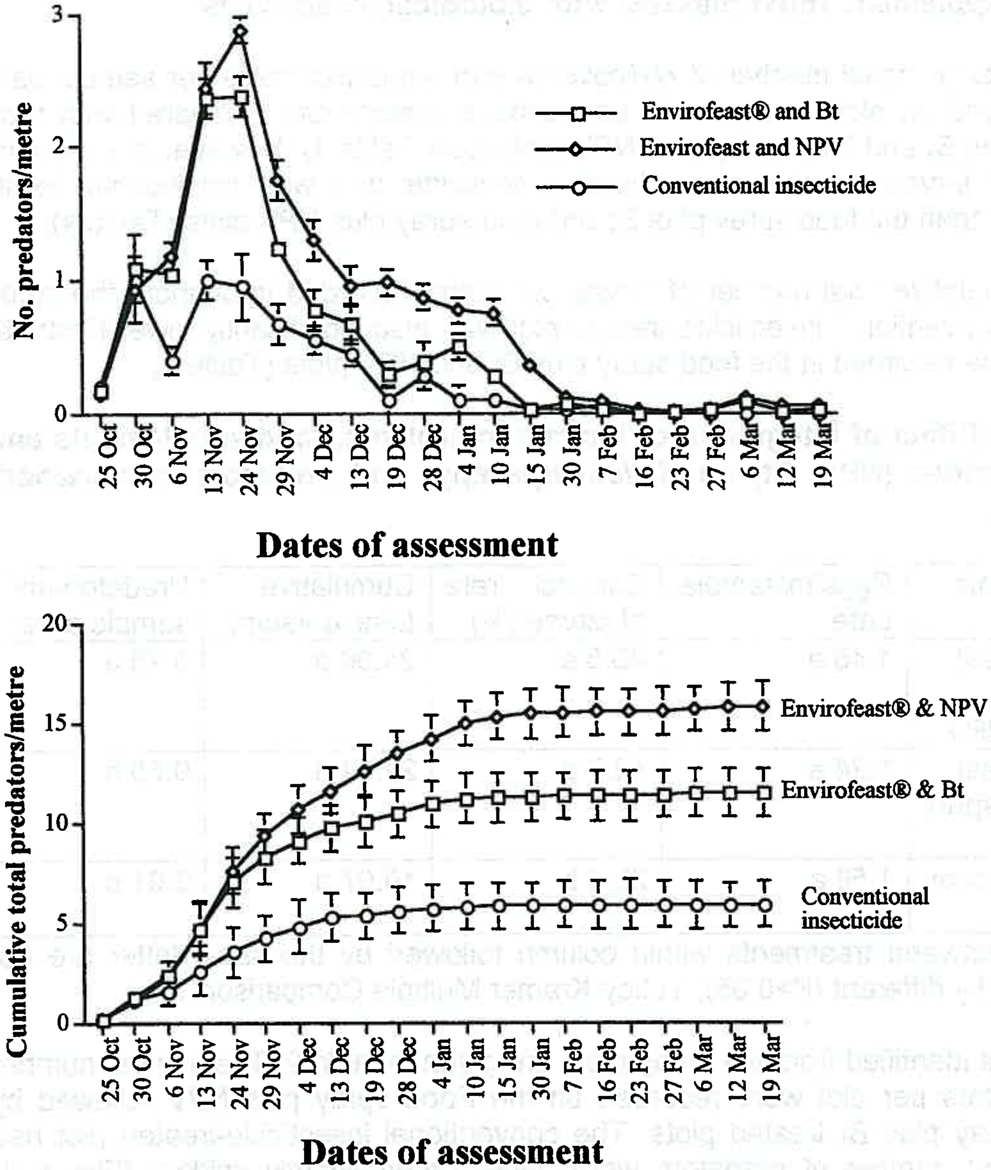

Figure 1. Numbers of predators of *Helicoverpa* spp. in cotton under Food spray, biological and conventional insecticide regimes in a commercial cotton farm at Norwood near Moree, 1995-96.
From: Mensah (2002) Int. Journal of Pest Management 48, 85-106.

The results showed that when the lucerne refugia system, food spray and predatory insects were integrated with the biopesticides, Bt and NPV (Gemstar®), cotton yields were 6.18 bales and 5.68 bales/ha respectively on Bt and NPV (Gemstar®) treated plots (Table 6). These yields were higher than those achieved when food (Envirofeast®) spray was used alone on cotton crops within lucerne/cotton interplants (see Table 1). However, the gross margin was significantly higher (P<0.05) on conventional insecticide treated plots than the food spray/biological insecticide treated plots (Table 6).

Table 6. Effect of integration of lucerne interplants, food supplements and biopesticides (NPV, Bt) on *Helicoverpa* spp. and predators at Norwood, 1995-96.

Treatments	Yields (bales/ha)	Spray costs ($/ha)	Gross margin ($/ha)
Envirofeast (Food) spray+ NPV	5.68 a	$565.00	$2,304.00 a
Envirofeast (Food) spray + Bt	6.18 a	$611.00	$2,040.00 b
Conventional cotton	8.40 a	$592.00	$2,579.00 c

Means between treatments within column followed by the same letter are not significantly different (P>0.05), Tukey-Kramer Multiple Comparison Test.

The Australian cotton grower expects cotton yields of over 7.41 bales/ha as a result of the use of high yielding cotton varieties and the availability of synthetic insecticides (CRDC, 1997). The reduction in yield on the biopesticides treated plots compared with the conventional insecticide managed plots may be due to the narrow host range, retarded response and/or poor residual activity of biopesticides after application (Moscardi, 2000; Mcguire, 2000). The number of larvae per metre per sample date was 1.8 and 2 times higher on the Bt and NPV (Gemstar) treated plots compared with the conventional insecticide treated cotton crops (see Table 4).

The lower gross margin achieved on the biopesticide treated plots compared to the standard conventional insecticide treated cotton crops could make growers lose interest in the product. Hence, most cotton growers perceive biopesticides as more risky at high pest pressure than synthetic insecticides. Despite this perception, biopesticides in general have minimal effect on predatory insects than conventional insecticides and therefore offer an exciting new tool in combination with other non-chemical techniques that can be employed in IPM (Mcguire, 2000). Biopesticides are preferable in IPM programs over conventional insecticides (Scholz *et al.*, 1998). There is the need for grower education and understanding in the use of biopesticides and also the development of techniques to improve the efficacy of biopesticides against *Helicoverpa* spp. in cotton. Petroleum spray oils incorporated with Ultra -violet protected compounds have shown to significantly improve the efficacy of NPV and Bt against *Helicoverpa* spp. in cotton (Mensah and Liang 2002, this proceedings).

Step 3: Integration of food supplements, lucerne interplants with Tracer and compared with conventional Ingard and Normal cotton.

Tracer® (Spinosad) insecticide regarded in the cotton industry as "soft" and used in "soft" option IPM was integrated with lucerne/cotton interplant, food supplements and beneficial insects. The results showed that equal number of eggs were found on all treated plots (Table 7). Cumulative total number of larvae per metre varied significantly (P<0.01) among the treatments. Envirofeast® plus NPV had the highest, followed by Envirofeast plus Tracer® and Conventional Ingard and normal cotton (Table 7).

The highest number of predators were recorded on the Envirofeast® plus NPV plots, followed by Conventional Ingard, then Envirofeast® plus Tracer® and Conventional normal cotton (Figure 2).

The conventional insecticide recorded the highest yields and gross margin (Table 7). As a result, there is the need to integrate other synthetic insecticides to the food sprays, lucerne/cotton interplants, biological pesticides and Tracer® to improve *Helicoverpa* spp. control, cotton yield and gross margin to equal conventional insecticide managed cotton.

Table 7. Effect of integration of lucerne interplants, food supplements, biopesticides and Tracer on *Helicoverpa* spp. and predators at Bellevue, 1996-97.

Treatments	Eggs/m/sample date	Cumulative total larvae/m	Yield (bales/ha)	Gross margin (
Envirofeast (Food) spray+ NPV	3.15 a	62.5 a	5.93 a	$1,530.00 a
Envirofeast (Food) spray + Tracer	3.13 a	49.55 b	6.92 b	$1,995.00 b
Conventional Ingard cotton	3.58 a	44.25 b	6.67 b	$1,815.00 b
Conventional Normal cotton	4.51 a	48.90 b	7.41 c	$2,180.00 c

Means between treatments within column followed by the same letter are not significantly different (P>0.05), Tukey-Kramer Multiple Comparison Test.

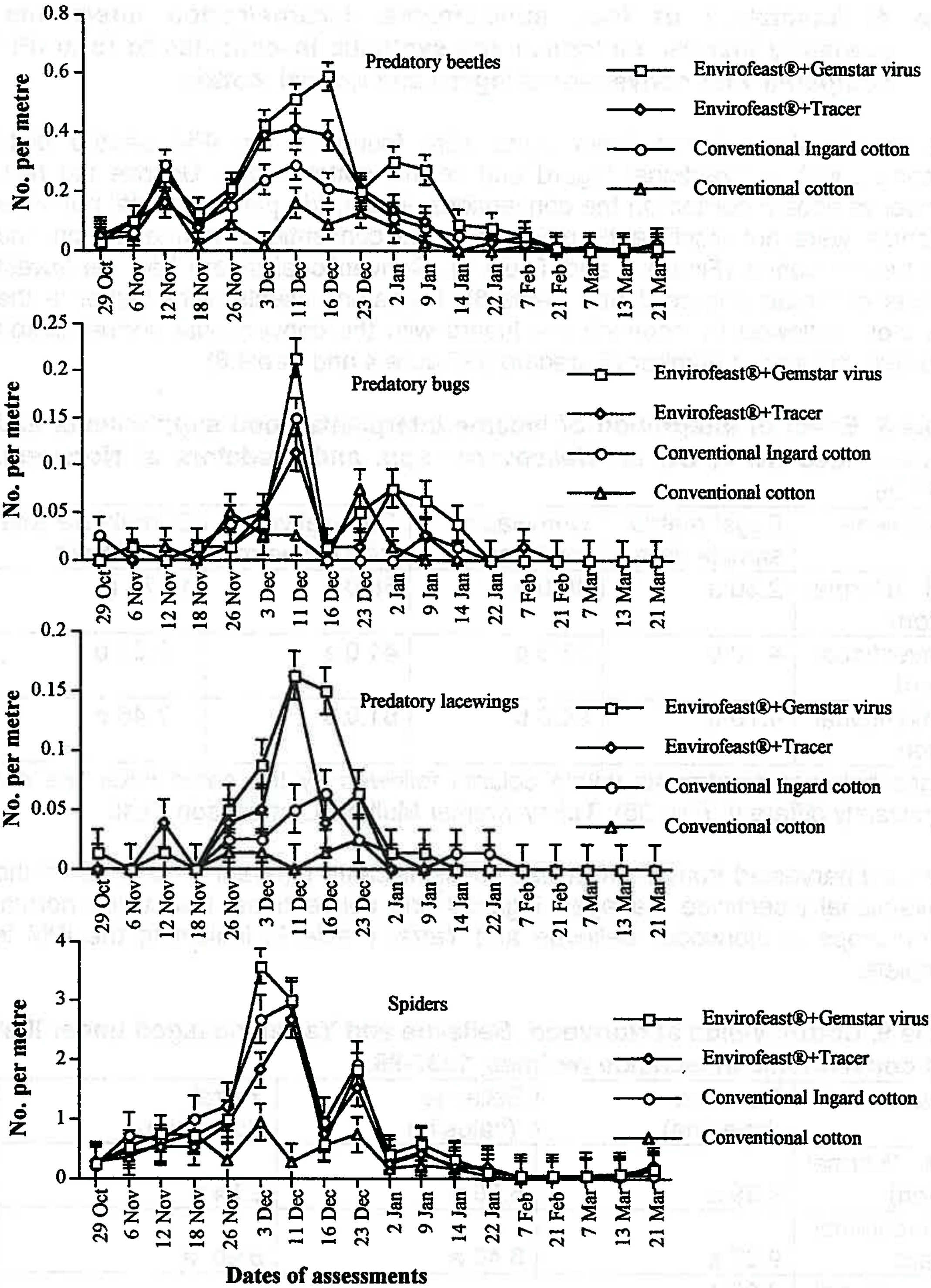

Figure 2. Numbers of predators per metre in commercial transgenic (Ingard) and normal cotton farms managed with food sprays, biological and conventional insecticides at Bellevue, 1996-97.

Source: Mensah (2002). International Journal of Pest Management 48, 85-106.

Step 4: Integration of food supplements, lucerne/cotton interplants, predatory insects, biological and synthetic insecticides to form IPM compared with conventional Ingard and normal cotton.

The results showed that fewer eggs were found on the IPM treated plots compared with conventional Ingard and normal cotton crops. Despite the high number of eggs recorded on the conventional insecticide plots, the total numvber of larvae were not significantly different in the conventional normal cotton and IPM treated cotton (Figure 3 and Table 8). Conventional Ingard had the lowest number of larvae (Figure 3 and Table 8). Predatory insects were higher in the IPM plot , followed by conventional Ingard with the conventional normal cotton recording the lowest number of predators (Figure 4 and Table 8).

Table 8. Effect of integration of lucerne interplants, food supplements and biopesticides (NPV, Bt) on *Helicoverpa* spp. and predators at Norwood, 1995-96.

Treatments	Eggs/ metre/ sample date	Cumulative total Eggs/m	Cumulative total larvae/m	Cumulative total predators/m
IPM (Normal cotton)	2.30 a	46.0 a	58.0 b	13.73 a
Conventional Ingard	4.18 b	83.5 b	41.0 a	9.28 b
Conventional cotton	4.70 b	94.0 b	61.0 b	7.45 c

Means between treatments within column followed by the same letter are not significantly different (P>0.05), Tukey-Kramer Multiple Comparison Test.

The yield harvested from the IPM was not significantly different (P>0.05) from the conventional insecticide managed Ingard® and conventional insecticide normal cotton crops at Norwood, Bellevue and Yarral (Table 9) indicating the IPM is complete.

Table 9. Cotton yields at Norwood, Bellevue and Yarral managed under IPM and conventional insecticide regimes, 1997-98.

Treatments	Norwood (bales/ha)	Bellevue (bales/ha	Yarral (bales/ha)
IPM (Normal cotton)	9.39 a	8.65 a	9.64 a
Conventional Ingard	9.37 a	8.40 a	8.90 a
Conventional normal cotton	9.32 a	8.90 a	9.14 a

Means between treatments within column followed by the same letter are not significantly different (P>0.05), Tukey-Kramer Multiple Comparison Test.

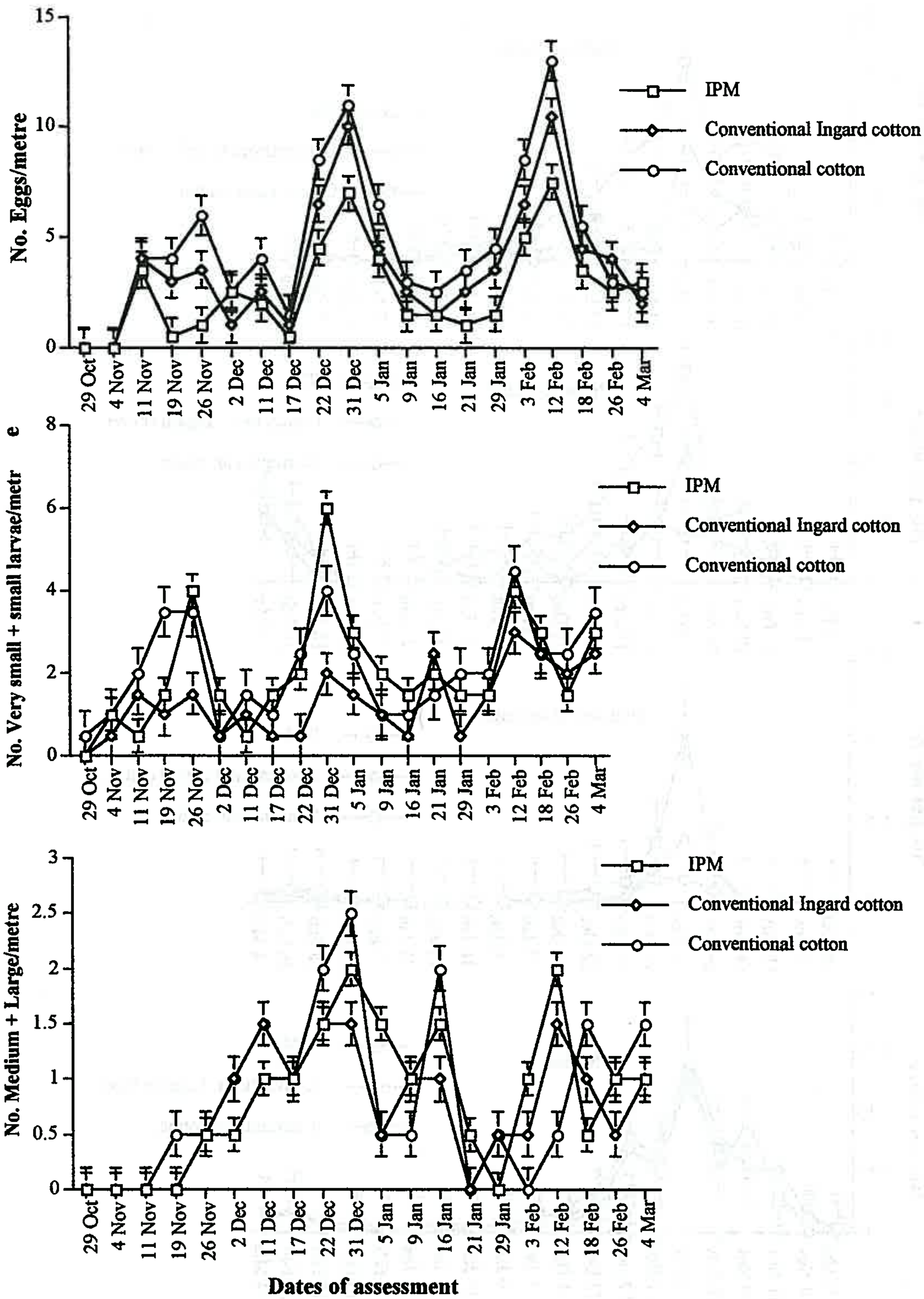

Figure 3. Number of *Helicoverpa* spp. per metre on cotton crops managed under IPM and conventional insecticide regimes at Norwood, 1997-98.
Source: Mensah (2002). International Journal of Pest Management 48, 85-106.

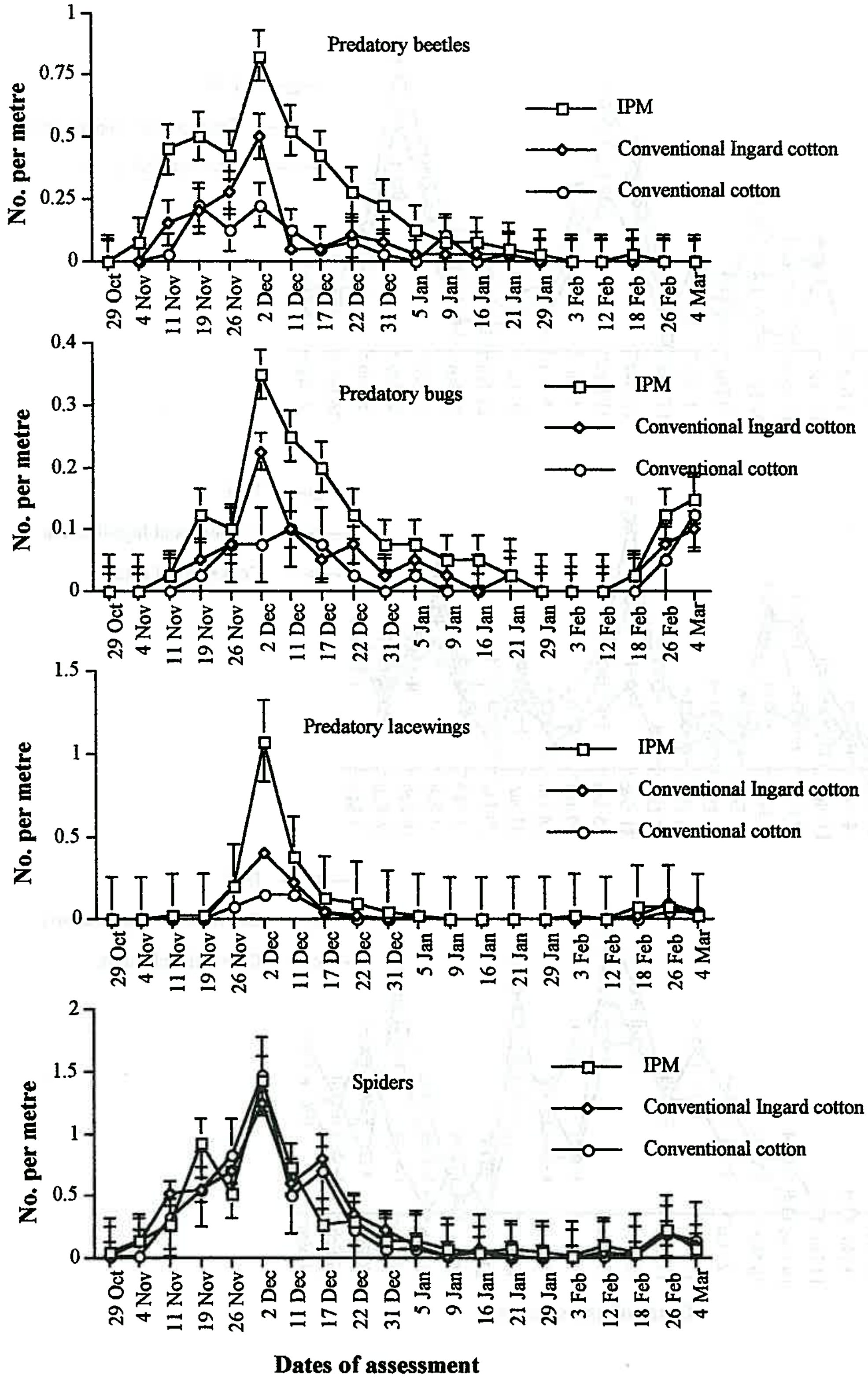

Figure 4. Number of predators per metre on commercial cotton crops managed under IPM and conventional insecticide regimes at Norwood, 1997-98.
Source: Mensah (2002). International Journal of Pest Management 48, 85-106.

The average gross margin for the IPM treated plot was A$3,255 compared with A$3,020 and A$3,218 respectively for the conventional insecticide managed Ingard® and normal cotton crops. The yield economics indicated no significant difference between IPM and the conventional insecticide regimes. Thus, it may be necessary to manage Ingard® cotton crops under IPM program in order to reduce chemical insecticide use on these crops and achieve ecological benefits.

Table 10. Average spray costs and gross margins of commercial cotton crops managed under IPM and conventional insecticide regimes at Norwood, Bellevue and Yarral, 1997-98.

Treatments	Norwood (bales/ha)	Bellevue (bales/ha	Yarral (bales/ha)
IPM	9.39 a	8.65 a	9.64 a
Conventional Ingard	9.37 a	8.40 a	8.90 a
Conventional normal cotton	9.32 a	8.90 a	9.14 a

Means between treatments within column followed by the same letter are not significantly different (P>0.05), Tukey-Kramer Multiple Comparison Test.

The total number of synthetic insecticide applications to the IPM treated plots was reduced relative to the insecticide managed cotton crops without sacrificing yield and profitability at all study sites (see Table 11). The study showed that 50 per cent of synthetic insecticides applications in the normal cotton crops at all the study sites were replaced by biological sprays in the IPM plots thus conserving the natural enemies and increasing the environmental advantage on the IPM plots. The Ingard cotton crop accounted for a 25 per cent saving of synthetic insecticide use over conventional cotton.

General Discussion

The development of IPM programs in a stage-wise progression as undertaken in this study, allowed the role of each IPM tool in the system (particularly its impact on natural enemies, pests and cotton yield) to be determined and quantified. For example the integration of Tracer® insecticide with Envirofeast® (food) spray and lucerne/cotton interplant system, increased cotton yields and gross margin over Envirofeast® and NPV (Gemstar®) treated plots.

Table 11. Spray records of cotton managed under IPM and conventional insecticide regimes at Norwood near Moree in NSW from November 1997 to March 1998.

Treatments	Product/chemical	Date applied
IPM	2.5kg/ha Envirofeast®	13/11/97
	2.5kg/ha Envirofeast®	29/11/97
	2.5kg/0.75L/ha Envirofeast®/NPV	6/12/97
	2.5kg/ha Envirofeast®	22/12/98
	750ml/ha NPV	7/1/98
	2.5kg/0.75L/ha Envirofeast®/NPV	28/1/98
	1.5 L/ha Profenofos	22/1/98
	0.8 L/ha Beta-cyfluthrin	7/2/98
	1.75/2.0 L/ha Chlorpyrifos/Amitraz	12/2/98
	0.7/2.0 L/ha Deltamethrin/Amitraz	21/2/98
Conventional insecticide managed Ingard (Bt) cotton	2.5kg/ha Envirofeast®	22/10/97
	2.1 L/ha Endosulfan	12/12/97
	0.8/2.0 L/ha Beta-cyfluthrin/Amitraz	21/1/98
	0.7/2.5 L/ha Deltamethrin/Propargite	30/1/98
	0.8 L/ha Beta-cyfluthrin	12/2/98
	1.75 L/ha Chlorpyrifos	9/3/98
Conventional insecticide managed normal cotton	2.1 L/ha Endosulfan	2/12/97
	2.1 L/ha Endosulfan	12/12/97
	2.1/2.0 L/ha Endosulfan/Dipel (Bt)	27/12/97
	2.1/2.0 L/ha Endosulfan/Amitraz	15/1/98
	0.8/1.4 L/ha Beta-cyfluthrin/Parathion-methyl	21/1/98
	0.7/2.5 L/ha Deltamethrin/Propargite	30/1/98
	2.0 L/ha Thiodicarb	12/2/98
	1.75 L/ha Chlorpyrifos	9/3/98

Tracer® significantly reduced predator populations in treated plots compared to NPV (Gemstar®). Despite, its effect on predator populations compared to NPV, the effect of Tracer® on predators was significantly lower than conventional broadspectrum synthetic insecticides. This does not mean that Tracer® does not kill predators. It does and can significantly reduce predator populations and therefore should be used as when needed basis to correct high pest pressure situations when biological pesticides and predators fail.

This study has shown that to grow cotton economically in Australia, pest management must ensure protection of natural enemies of *Helicoverpa* spp. at least early in the cotton season from October to the end of December or first week of January and to avoid anything that could affect stability through disruption of the natural enemy activity.

There is also the need in any IPM system to have a decision support system which incorporates the activity of beneficial insects in the pest management system and which guides the grower or IPM practitioner to take pest management decisions non-deterimental to beneficial insect activity. In this study, the decision to use either biological or chemical insecticide to manage *Helicoverpa* spp. in cotton was based on the ratio of predators to *Helicoverpa* spp. (pest) (Mensah, 2000, 2002, see this proceedings). The guidelines for use of the predator to pest ratio has been reported elsewhere (Mensah, 2002; 2000; Mensah and Wilson, 1999; in this proceedings). The predator to pest ratio allows biological control sufficient time to work in the IPM system in order to reduce chemical insecticide use without sacrificing yield (Mensah and Singleton, 1998; Mensah, 2002, 2000). The IPM program developed in this study, has achieved economic cotton yields comparable to commercially insecticide managed cotton. However, I must stress that, this IPM program may not be the most desirable strategy for every crop or pest situation. Each pest problem and each crop has its own unique biological and ecological characteristics and this must be understood and analyzed before any IPM is developed or used.

Conclusion

- The IPM system developed in this study achieved 50% reduction in synthetic insecticide use over conventional cotton without any yield loss.
- The IPM has environmental advantage over conventional insecticide.
- Ingard® cotton managed under IPM rather than conventional insecticides will drastically reduce insecticide use.
- Cotton growers in Australia have come a long way to understand and adopt a true IPM program.
- The journey to adopt a true IPM is on-going and should not be broken by stagnating on "soft" options IPM because the cocktail of insecticides used is similar to conventional managed cotton. As a result, the "soft" option IPM still have resistance and environmental problems associated it.
- The adoption of a true IPM is the only way that the future sustainability of the cotton industry will be guaranteed.

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