Managing Beneficial Insects in Commercial Cotton Fields

Robert Kofi 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 crops in Australia are visited by a wide range of beneficial insects. These include generalist predators and specialist parasitoids which attack key pests. The potential value of these beneficial insects has not been widely exploited in cotton pest management due to lack of understanding of their impact on pests, lack of techniques to maximise their abundance and effectiveness and indiscriminate use of broad-spectrum insecticides on cotton crops against major pests.

The adoption of within field monocultures in the cotton production system in Australia also discriminate against and reduce the activity of beneficial insects because they lack ecological diversity (Hagen and Hale, 1974). In such agroecosystems, pest populations increase, minor pests become major pests and non-pests become pests. This is because the food, hosts, prey, and hibernating or overwintering sites of the natural enemies are reduced thus affecting biological control (DeLoach 1971; Mensah, 1997; 1999). Natural enemies of cotton pests usually have different food requirements in the larval and adult stages to develop and survive through the season. In contrast, adult pests particularly *Helicoverpa* spp. can normally lay their eggs without any feeding, relying only on food reserves transferred from their larval stage (Beirne, 1967). *Helicoverpa* spp. are highly migratory and can rapidly infest cotton crops and lay their eggs. Unless natural enemies are present and well established in high numbers before the pest arrive, they cannot respond rapidly enough to control these pests (Fitt, 1989; Mensah, 1997, 1999).

Many beneficial insects have been found and identified in cotton crops in Australia. The development of a strategy that may conserve and maximize the abundance and effectiveness of these beneficial insects in cotton fields will be crucial to enhance biological control. The questions to be asked therefore is "what are the key management strategies for beneficial insects in cotton fields to enable growers get the best value out of these insects or to enable the beneficial insects have an on-going economic role in modern cotton production?" These questions and many more have been answered in this article in the light of available research data. In addition, strategies currently used in Australia to manage beneficial insects in cotton fields have been discussed.

1.0 Key management strategies for beneficial insects in cotton fields

Natural enemies of pests (see Table 1) like other insects need to be managed in the crop system in order to maximise both their abundance and effectiveness. There are various ways of modifying the environment and manipulating beneficial insects to increase their effectiveness. Whatever strategy used, the approach is to modify the natural enemy or beneficial insect to pest ratio in favour of natural enemies in order to achieve biological control of a pest species. In any strategy chosen to manipulate natural enemy populations, it is important to act when the pest population is low rather than high because in a high pest population it may be too late for the natural enemies to respond effectively to the pest numbers. Some of the strategies that can be used to manage and modify the beneficial insects to pests ratio are provision of supplementary food, intercropping with non-crop plants, release of natural enemies, selective pesticides, resistant plant varieties and planting cotton in stubble.

Table 1. Major predators of cotton pests in cotton crops in Australia.

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

2.0 Provision of Supplementary food

The application of supplementary food products such as artificial honeydews to crops has been reported to attract and concentrate predatory insects and enhance biological control (Neuenschwander and Hagen, 1980; Hagen, 1986).

In Australia, many food spray products such as Envirofeast®, PredFeed® and Amino Feed are commercially available for use in pest management programs. However, with the exception of Envirofeast®, not all these food spray products has undergone strict peer review in international literature. Predfeed® was developed and tested by Abdulmajeed *et al.* (1972). They reported that PredFeed® combined with honey and molasses can only increase the numbers of green lacewings and nabids. There is no known literature on Amino feed in international journal making it difficult to comment on the product's efficacy. Envirofeast® product was developed and tested by Mensah (1995, 1996, 1997). The product when applied to cotton crops attract, arrest and conserve predatory insects in cotton (Figure 1).

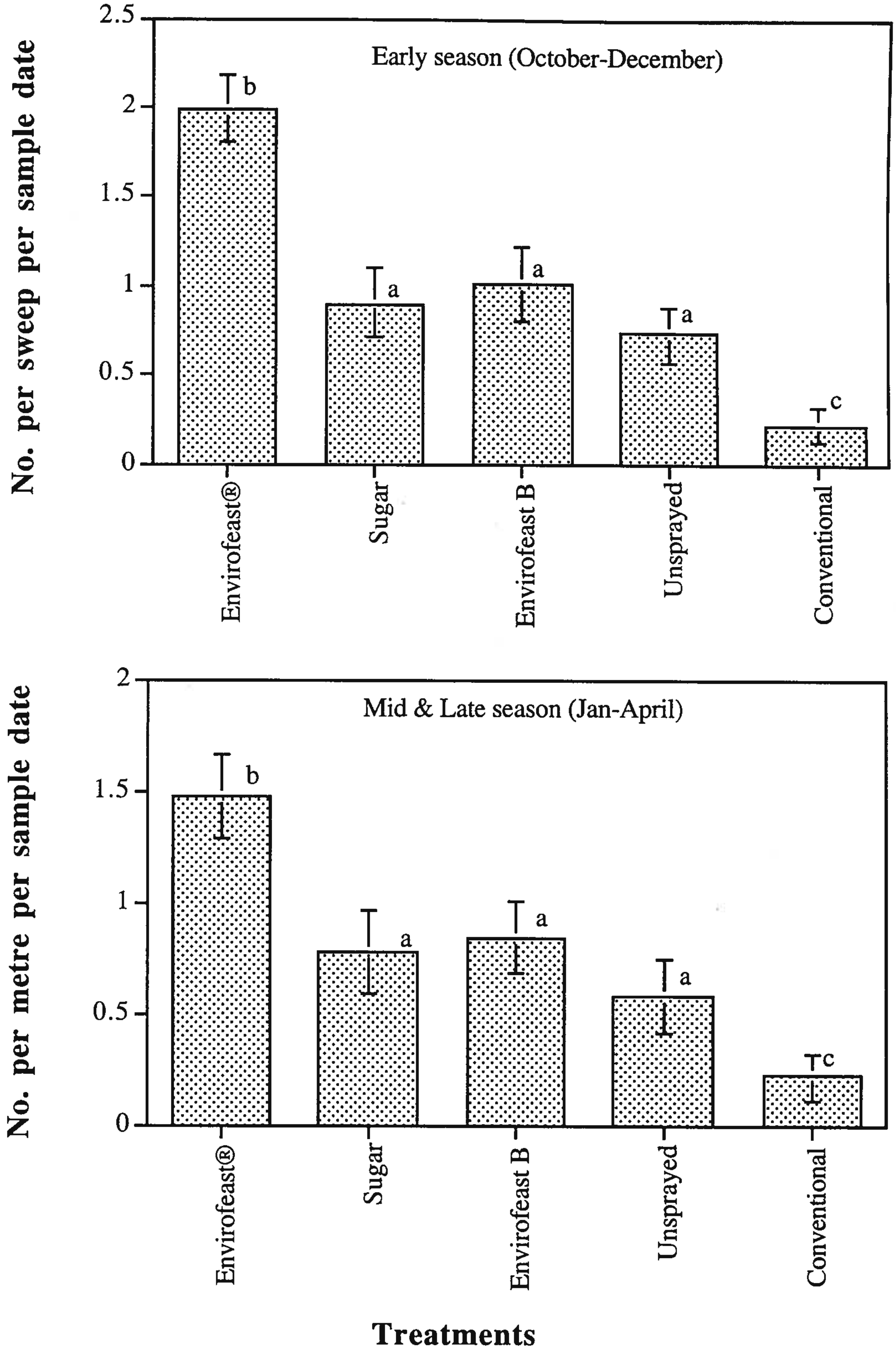

Figure1: Effect of food sprays on numbers of predatory insects on commercial cotton during early, middle and late cotton season in Auscott at Narrabri, NSW, 1992-93. (Means between treatments followed by same letter are not significantly different (P>0.05). Error bars represent standard errors.

In general, food sprays can either attract or arrest predators. The species of beneficial insects which can be attracted by a particular food product may depend in part on the type of food supplement or ingredients in the food product, the strength of the food odour, the timing and rate of application of the food product. A food supplement containing a specific protein component can attract and or arrest some beneficial insects whereas those with sugar base can only arrest not attract. In addition, the presence of a refugia source for beneficial insects within or close to the cotton farm where the insects can be attracted is crucial for the effective attraction of beneficial insects by the food sprays. A refugia for the beneficial insects can be set up in the form of alternative crops interplanted as or as borders or in a centrally-located field in the cotton farm.

The use of food sprays alone may not provide satisfactory pest control for farmers to achieve their expected high yields, but it can delay the need for synthetic insecticide sprays. In an experiment to determine the effect of application of Envirofeast® (food) supplement on the yields of cotton crop at Norwood, it was found that cotton crops managed with Envirofeast® alone yielded 1.05 bales per acre compared to 3.20 and 0.40 bales per acre in conventional insecticide managed crops and an unsprayed plot (Table 2). Integrating Envirofeast® sprays with a biological and synthetic insecticides significantly reduced synthetic insecticide sprays and increased cotton yields (Tables 3 and 4).

Table 2. Effect of food supplements on cotton yield (bales per acre) at Norwood near Moree in NSW, 1992-93.

Treatments	No. of sprays	Yield (bales per acre)
Envirofeast®	11	1.05 ± 0.13 a
Sugar	11	0.51± 0.24 b
Envirofeast B	11	0.75 ± 0.25 b
Oil + Gum	11	1.50 ± 0.29 c
Control (Unsprayed)	0	0.40 ± 0.16 b
Conventional	9	3.20 ± 0.28 d

Table 3. Yields (bales per acre) of cotton crops managed under Envirofeast®, biological and conventional insecticide regimes in commercial cotton farms at Norwood near Moree in NSW, 1995-96.

Treatments	No. of Envirofeast® sprays	No. of Envirofeast® + Biopesticides	No. of Synthetic insecticides	Yields (bales/acre)
Envirofeast®+ Bt +Synthetic insecticides	6	6	1	3.10 a
Envirofeast® + Gemstar virus + Synthetic insecticides	6	6	1	3.19 a
Conventional insecticide managed normal cotton	0	0	9	3.40 b

Table 4. Yields of cotton crops managed under Envirofeast®, biological and conventional insecticide regimes in commercial cotton farms at Norwood near Moree in NSW, 1996-97.

Treatments	No. of Envirofeast® sprays	No. of Envirofeast® +Virus sprays	No. of Selective insecticides	No. of Synthetic insecticides	Yields (bales/ac)
Envirofeast®+Gemstar +Synthetic insecticides	4	4	2	3	3.0 a
Envirofeast® + Tracer Synthetic insecticides	4	0	4	3	3.20 a
Conventional insecticide managed normal cotton	0	0	4	6	3.10 a

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

Food sprays particularly Envirofeast® can also increase the consumption rate of some predators, particularly ladybird beetles (Figure 2), increase their searching ability and suppress oviposition of *Helicoverpa* spp. females (Mensah, 1996).

In a study to determine the effect of food sprays on the consumption rate of the transverse ladybird beetle of *Helicoverpa* spp. eggs, cotton leaves containing the moth eggs were treated with either Envirofeast®, Envirofeast B, sugar solution or water (control). The results showed that the number of eggs consumed by the transverse ladybird beetle was significantly higher ($P<0.05$) on cotton leaves treated with Envirofeast® than leaves treated with either sugar solution or water (Figure 2).

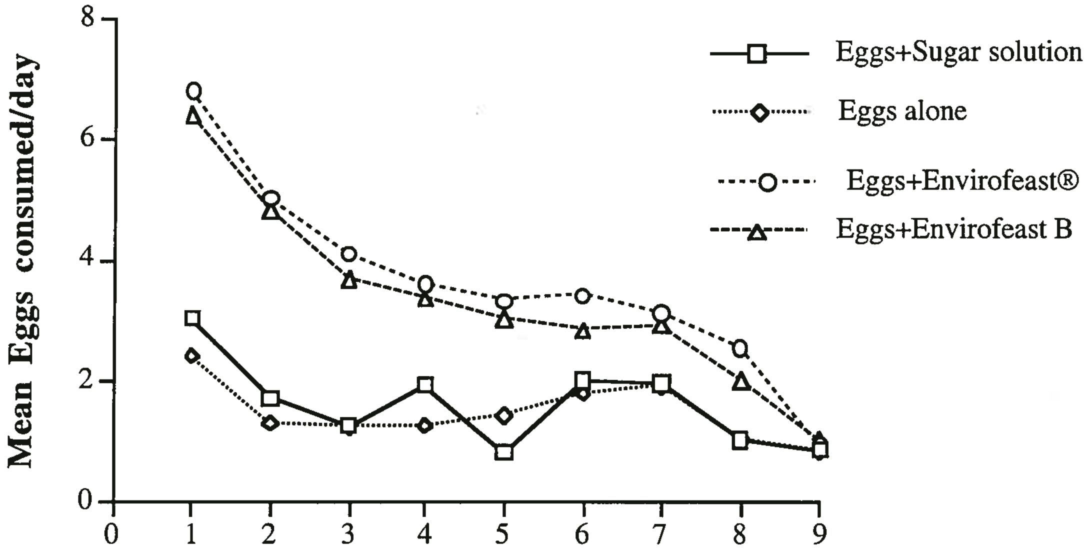

Figure 2. Effect of food sprays on the number of *Helicoverpa* spp. eggs consumed by *C. transversalis* in the laboratory at ACRI in Narrabri, 1997-98.

2.1 Guidelines for use of Food sprays in cotton systems

Beneficial insects form a major part of any sound pest management system. Therefore any pest management system, whether organic or IPM, which incorporates food sprays essentially focuses on the management of insect pests by manipulating predatory insect populations. For the success of this type of pest management strategy, it is important to select a field or whole farm farther away from insecticide drift or not to be surrounded by conventional insecticide managed farms. Growers should therefore form IPM support groups with their neighbours and work together. It is also very important for the grower or consultant or the pest manager to carry out visual checks (i.e bug checking or scouting) of pests particularly *Helicoverpa* spp. or bollworm eggs, very small (VS), small (S), medium (M) and large (L) larvae and all beneficial insects of whole cotton plants at least 2 times every week or as required by the grower for the particular farm. Both pests and beneficial insects should be recorded as numbers per metre. This is to allow a predator to prey or pest ratio to be determined and used as a protocol to make pest management decisions in a particular farm.

2.2 Recommended application of Food sprays

Food sprays can be applied as band or skip row early season or over the entire field in the mid and late season using a ground rig , knapsack or an aircraft. Application volume when using a knapsack or groundrig will vary according to the stage of growth of the cotton crop. Application to run off is recommended to ensure good coverage.

3.0 Use of Predator to pest ratio

Since beneficial insects particularly predators form a major component in pest management programmes, it is very important to incorporate their activity into pest management decisions. This can be achieved through the use of predator to pest (*Helicoverpa* spp.) ratio. The application of insect food attractants on commercial cotton crops can mediate changes in the predator to pest ratio by (1) attraction of the predatory insects to the area by volatile compounds emitted by the food attractant (2) arrestment of predatory insects in the area following contact and subsequent feeding on the food attractant; (3) increased searching activity induced by contact with and feeding upon the food attractant (4) increased consumption rate of predators and (5) decreased oviposition activity of *Helicoverpa* spp. due to the presence of the food attractant especially Envirofeast® (Mensah, 1996; 97; Mensah *et al.*, 2000; Mensah and Singleton, 1999). The decision to control *Helicoverpa* spp. should be based on the ratio of predators to pests in the cotton crop as indicated by scouting/bug checking counts. A predator to pest ratio of 0.5 or higher can reduce the survival of very small and small larvae to medium and large larvae (Figure 3). However, a ratio lower than 0.5 resulted in higher survival of *Helicoverpa* larvae (Figure 3).

3.1 Decision making protocol

The accepted predator to pest threshold is 0.5 or higher.

- When the predator to pest ratio fall below 0.5 but is higher than 0.4 and *Helicoverpa* population is mostly eggs, a food supplement such as Envirofeast® can be applied to attract more predators to feed on the eggs and improve the ratio.
- However, when the *Helicoverpa* population falls below 0.5 but is higher than 0.4 and Helicoverpa population in your bug check is predominantly neonates (rather than eggs) then a food spray and a biological pesticide should be applied to restore the ratio to 0.5 or higher (see IPM guidelines in Entopak, 1999 for details).
- If the predator to pest ratio is 0.4 or lower following application of biological insecticide and Helicoverpa population is more of larvae, use a selective insecticide to control the larvae before they develop to mediums. Three days after applying a selective insecticide, re-apply a beneficial insect food attractant to restore the system.

4.0 Provision of refugia for Beneficial insects in Cotton

Provision of refugia for beneficial insects in cotton within the growing season includes trap cropping, strip cropping or interplanting and other type of polyculture. The planting of shrubs or flowering plants around the cotton farm can also help in the management of beneficial insects. In Australian cotton systems, strip intercropping, trap cropping are used to diversify the cotton agro-ecosystem and manage pests and beneficial insects (Mensah, 1999). Interplanting alternative crops in cotton can serve as a refuge or source of beneficial insects to the cotton crop. However, an intercrop system in some cases may act as a sink for predators by being more attractive than the primary crop itself (Mensah, 1999) and unless predators are attracted or forced out of the intercrop system, the use of an intercrop strategy to maximise the abundance of beneficial insects in the primary crop may be counter productive to the enhancement of biological control.

Studies have been conducted in Australia to determine the utility of alternate crops such as refugia for predatory insects of *Helicoverpa* spp. when they were interplanted as strips in cotton fields in Australia (Mensah, 1999) (see Figure 4 and 5). The study showed that interplanting lucerne as strips in cotton fields can conserve and increase the densities of predatory insects of *Helicoverpa* spp. in cotton (Figure 4 and 5). The interplanted lucerne crop acted as a refugia and a source of the predators to the cotton crop (Figure 5). The refugia or source function of the lucerne strips may be attributed to the abundance of floral nectar and alternate prey, shelter, mating and oviposition sites etc provided by the lucerne crop (Bugg *et al.*, 1987), compared with the monocultural cotton. Thus given the abundance of food resources within the lucerne strips, higher numbers of predators may not have been inclined to move from the strips to forage the adjacent cotton crop.

The movement of the predators can be improved by either applying food spray to attract predators especially the predatory beetles, bugs and lacewings onto the cotton crop (Mensah, 1997) or by using smaller lucerne strips less than 12 m wide or slashing all the lucerne strips or allowing the lucerne crop to hay off (Mensah and Harris, 1995). The last three options may also force *Creontiades dilutus* (green mirids) another pest of cotton which prefers lucerne to cotton, to move from lucerne to cause damage in cotton (Mensah and Khan, 1997; Mensah, 1999).

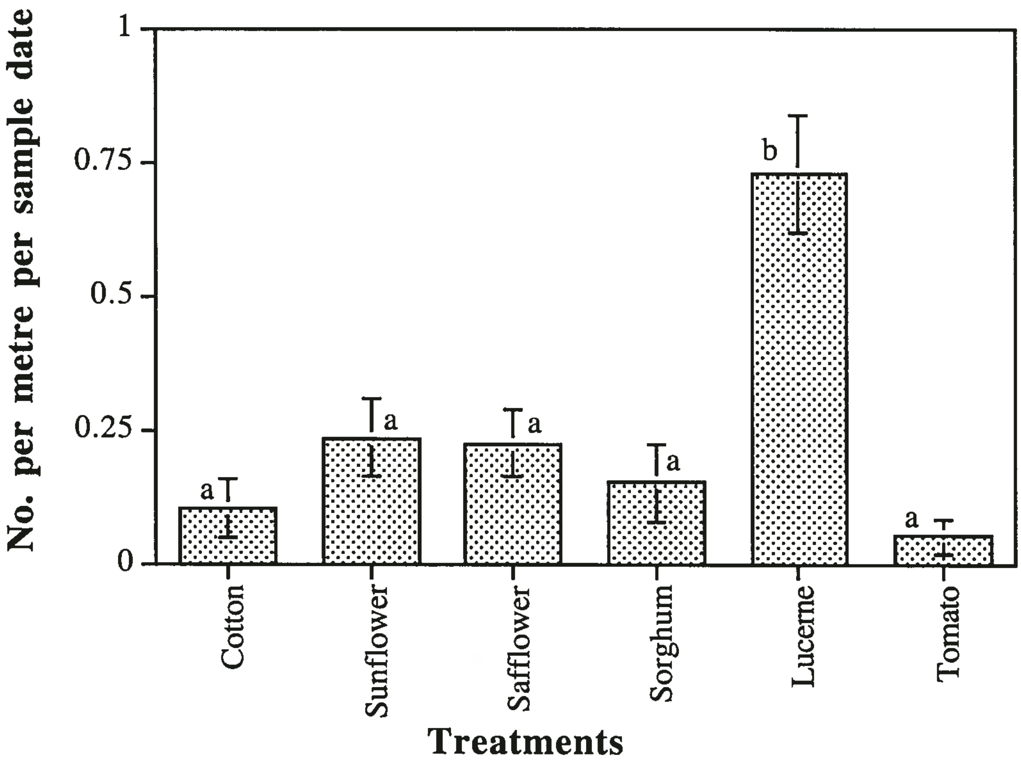

Figure 4: Responses of predatory insects to alternative crops interplanted in commercial cotton in the Australian Cotton Research Institute farm at Narrabri, NSW, 1993-94 (Means of treatments followed by the same letter are not significantly different (P>0.05)(Tukey-Kramer Multiple Comparisons Test). Error bars represent standard errors.

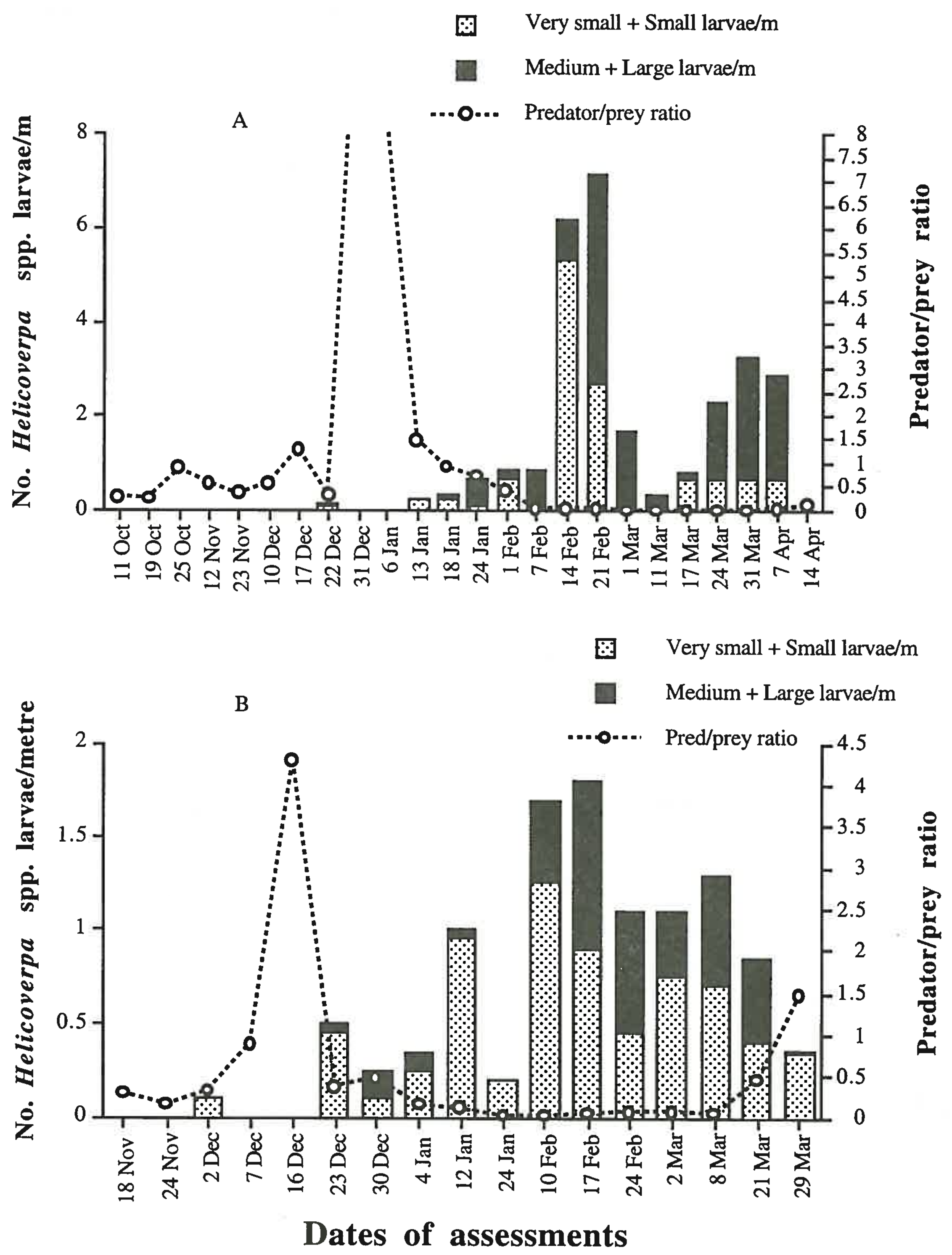

Figure 3: Comparisons of predator to prey ratio on numbers of *Helicoverpa* spp. larvae in cotton farms at (A) Norwood, 1993-94 and (B) Bellevue, 1994-95 seasons.

4.1 Guidelines for establishment and management of lucerne strips in commercial cotton

Apart from interplanted lucerne crop serving as a refuge for beneficial insects and spiders in cotton farms, lucerne crop is also preferred over cotton by the green mirid (*Creontiades dilutus*) and therefore can be used as a trap crop to manage this insect.

4.2 Size and placement of lucerne strips

Lucerne strips can be used:

- within the cotton field with a maximum width of 8 or 12 rows per 300 rows of cotton.
- as a field border; a lucerne crop can be placed on both sides of the field. In this case, a minimum area of 5% of the whole field should be planted to lucerne (eg 24 rows each side of a 1000 row wide field).
- as a block; a lucerne crop can also be planted in a centrally-located block in the farm. The last two options may be slightly less effective than strips grown within the field particularly for green mirid control. In all cases, the lucerne should be green and not allowed to hay off.

4.3 Establishment of lucerne

It is most important to have the lucerne strips established before cotton planting.
Seeding rates of around 5 kg/ha should be used in dryland situations and 10 to 15 kg/ha for irrigated crops. Good seed bed preparation is required to achieve good establishment.

4.4 Irrigation Management

A 20-day cycle from September to December and a 10 from December onwards are the recommendations for maximum production of lucerne in Northern NSW of Australia. Since cotton growers are not striving for maximum production, a first lucerne watering should be done when the cotton starts to square, all other lucerne irrigations can be applied as the cotton requires.

4.5 Management of lucerne within the strips

The lucerne strips should be kept attractive through the cotton growing season especially during the early squaring and flowering period of the cotton crop. Once lucerne begins to flower, vegetative growth is limited and it is less attractive to insects which may serve as food for the beneficial insects, hence as a refuge or trap crop. The attractiveness of the lucerne strips can be maintained or achieved by slashing or mowing half of each lucerne strip every four weeks to maintain new regrowth. The presence of new regrowth will enhance continuous infestation of insects such as aphids and thrips, jassids which serve as food for the beneficial insects.

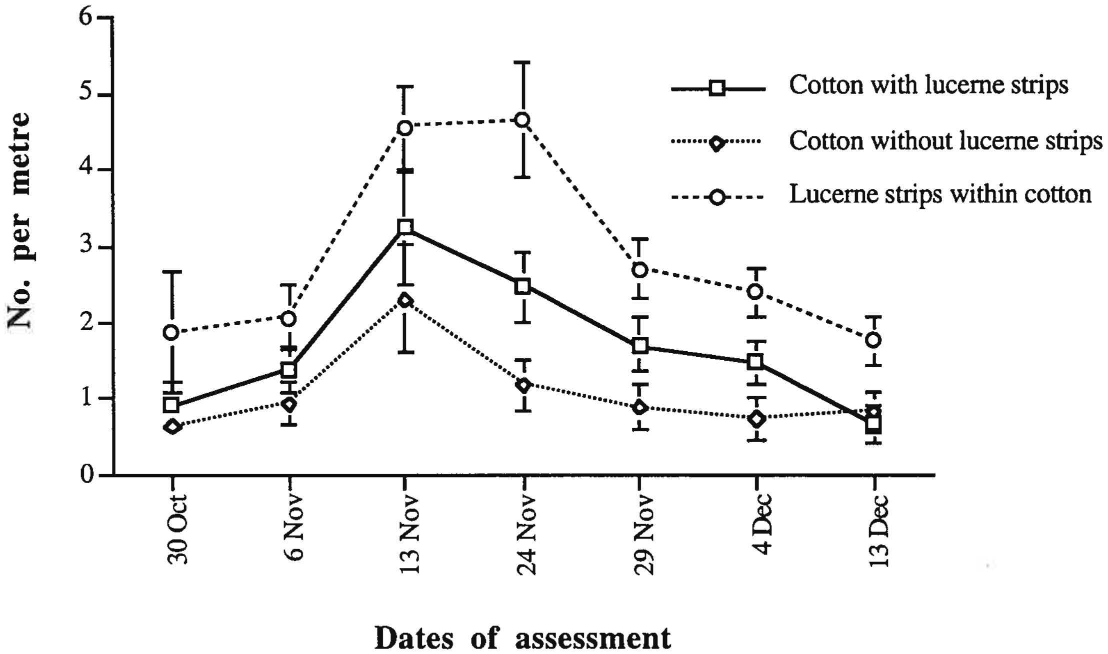

Figure 5: Comparisons of predatory insects in lucerne strips, cotton with and without lucerne strips at Norwood near Moree, NSW, 1995. Error bars represent standard errors.

5.0 Planting cotton into wheat stubble

Wheat is one of the rotation crops used in Australia. Wheat stubble is known to provide a high surface soil cover which can reduce soil erosion by 70 per cent (Walter *et al.*, 1999). Planting cotton in wheat stubble can conserve some beneficial insects in cotton by providing shelter for these insects. Studies conducted at Auscott in Narrabri during the 1999-2000 cotton season showed that densities of predators such as red and blue beetles and also soil predators such as earwigs, carabid beetles, ants etc. increased in cotton planted in wheat stubble (Figure 6). Populations of sucking bugs such as apple dimpling bugs and green mirids were reduced on cotton planted in the wheat stubble. However, densities of transverse ladybird beetle, two spotted ladybird beetle, big-eyed bug, lacewings and spiders were unaffected by the wheat stubble.The effect of planting cotton in wheat stubble on soil structure, cotton seedling diseases, growth and yield of cotton etc is reported elsewhere in this proceedings.

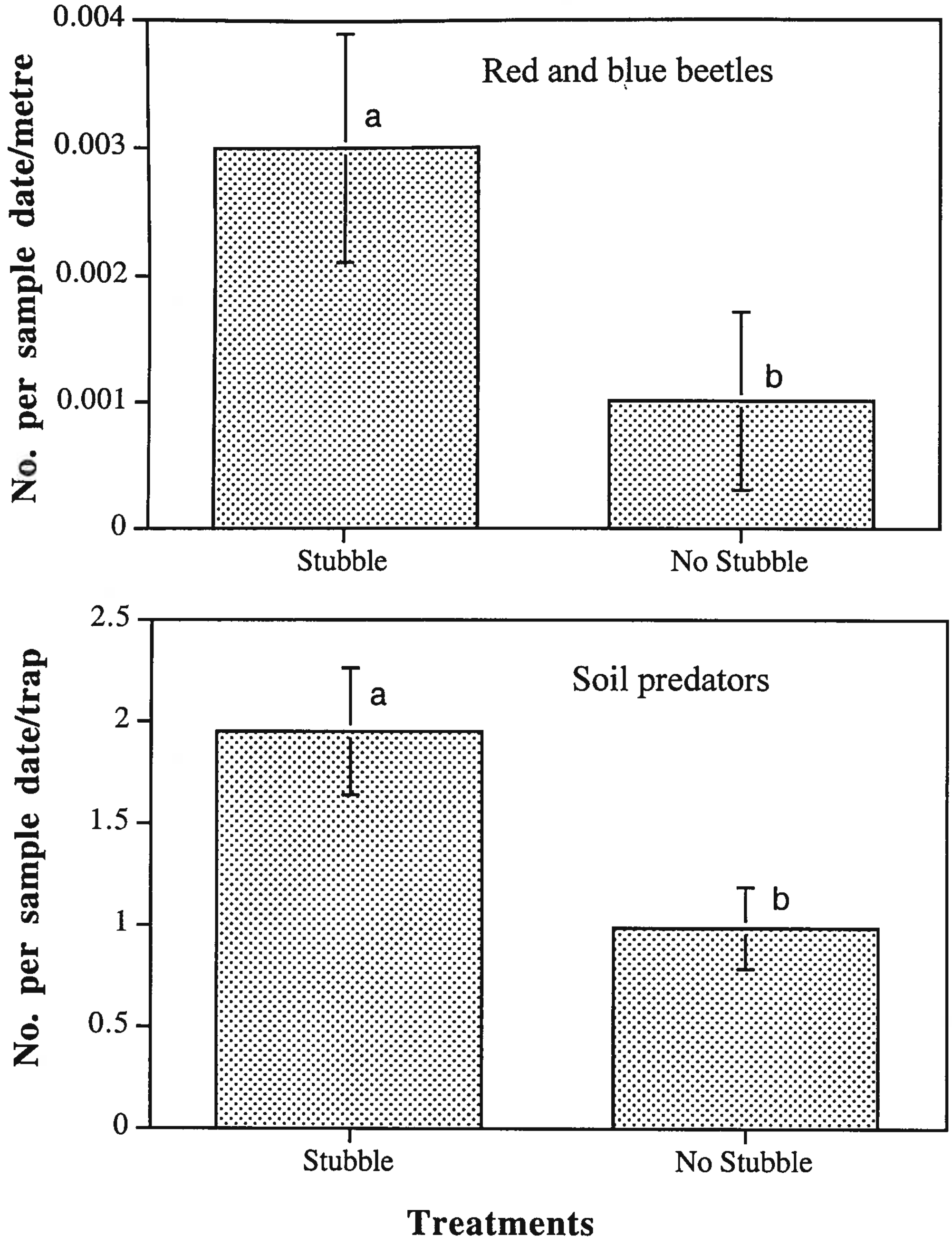

Figure 6. Effect of wheat stubble on densities of red and blue beetles and soil predators. Error bars represent standard error of the mean.

6.0 Use of Selective insecticides

In most crop production systems such as cotton, a wide range of pests and beneficial insects occur and synthetic insecticides used against them may affect the efficacy and activity of these beneficial insects. However, by suitable choice of a selective insecticide rather than broad spectrum ones, selective use of insecticides such as timing treatments, modifying dosages, techniques of formulation and application, beneficial insects can be conserved and their efficacy improved. The impact of insecticides and miticides on predators in cotton have been studied in Australian cotton systems (see IPM guidelines Support Document 1). The use of selective insecticides such as foliar Bt and NPV against cotton pests particularly *Helicoverpa* spp. enable beneficial insects to survive to shift the beneficial insects to pest ratios in favour of natural enemies. Both Bt and NPV are specific to *Helicoverpa* spp. larvae and therefore permit enough non-target pests to survive and provide enough food for beneficial insects to feed, survive and reproduce to shift the beneficial insects to pest ratios in favour of natural enemies. Preserving aphids or mite colonies this way may serve as a food source for beneficial insects.

In addition to Bt, and NPV, research has been proposed, depending on the availability of CRDC funding, to develop mycoinsecticides (biopesticides based on fungus), ultra-violet protected petroleum spray oils and behaviour modifying compounds to support IPM programs against cotton pests. Transgenic cotton can be classified as selective insecticide since it is specific against *Helicoverpa* spp. larvae.

7.0 Bt Cotton and beneficial insect strategies

Transgenic (Bt) cotton contains the gene producing CryIAc protein which is toxic to *Helicoverpa* larvae. The susceptibility of *Helicoverpa* larvae to the Bt toxin means that the transgenic crop offers the possibility of substantially reducing the number of synthetic insecticide sprays needed to manage *Helicoverpa* spp. on these crops. Unfortunately, the poor efficacy of transgenic cotton crops has not matched their promise prior to their release (Wilson, *et al*, 1998), with their efficacy declining through the flowering and boll maturation period of the cotton crop to the point in some instances where survival of the larvae is little different to that in conventional cotton (Wilson, *et al*, 1998).

In addition, the efficacy of the transgenic cotton crop during the early cotton season is variable and interacts with variety. The variability in the efficacy of the transgenic plants has resulted in the use of alternative control strategies to enhance pest management on these crops. Where growers have used synthetic insecticides to manage pests on the transgenic crops, particularly early in the cotton season, has resulted in the disruption of beneficial insect activity, thereby reducing the potential gains in conservation of beneficial insect populations.

Transgenic crops are also known to have minimal or no effect on beneficial insects. However, when the transgenic crop is expressing the toxin effectively, it may kill most of the *Helicoverpa* spp. neonates which serve as food for most predatory insects, thus reduce the food source and the predatory insect population. The value of transgenic cotton crops in commercial fields will be increased if it is combined with and supported by other IPM components such as food sprays and lucerne trap refuge crop system (Mensah, 1997). In a nutshell, the transgenic crops should be managed in the context of true IPM.

Studies conducted at the Australian Cotton Research Institute (ACRI) in Narrabri, Norwood near Moree, Yarral in Narrabri, and Bellevue near Warren during 1996/97 and 1997/98 seasons showed that transgenic cotton fit in very well with beneficial insect management strategies. In the study an IPM program consisting of beneficial insects, food sprays, lucerne strip refugia and biological pesticides reduced synthetic insecticide sprays and enhanced the efficacy and durability of the transgenic crops. In some instances, the IPM program increased the yield of transgenic cotton crops over the same crops managed under conventional insecticide regime (Tables 5 and 6).

Table 5. Yields of Ingard cotton crops interplanted with lucerne and normal cotton crops as strips in Norwood, near Moree, 1996-97.

Treatments	No. of synthetic insecticide sprays	Yield (bales/acre)
Ingard cotton interplanted with lucerne crop as strips	4	3.10 a
Ingard cotton interplanted with normal cotton crop as strips	4	2.94 a
Ingard cotton with no interplants	4	2.90 b

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

Table 6. Summary of Yields (bales/acre) and sprays used in trials conducted at Bellevue near Warren, Yarral near Narrabri, Norwood near Moree and ACRI in Narrabri, 1997-98.(Average for 4 sites).

Treatments	No. of Envirofeast sprays	No of Envirofeast +virus sprays	No. of selective insecticides	Synthetic insecticide sprays	Yields (b/acre)
1. Sicala V2 + Lucerne strips + Envirofeast® + Envirofeast/ Gemstar virus+ insecticides	3	3	1	3	4.10
2. Sicala V2 (Ingard)+Lucerne + Envirofeast®+Envirofeast/ virus + synthetic insecticides	4	1	1	2	3.75
3.Sicala V2+Lucerne strips + Gemstar Virus+insecticides (No Envirofeast)(Control)	0	2	2	2	2.97
4. Sicala V2 (Ingard)+Lucerne strips + Virus + insecticides (No Envirofeast)(Control)	0	1	2	2	3.30
5. Sicala V2+insecticides (Conventional cotton)	0	0	3	4	3.60
6. Sicala V2 (Ingard) + insecticides (Conventional Ingard)	0	0	2	5	3.70

Conclusions

The use of beneficial insect food attractants in pest management is not new. Food sprays especially Envirofeast® has been used in cotton pest management systems in Australia for the past 6-8 years. The product has been used to intergrate with other tools in IPM programs to manage cotton pests effectively. The performance of beneficial insects food attractants is enhanced by the presence of a refugia system such as lucerne strips where insects can be attracted. An IPM program based on food sprays, lucerne strips, predator to pest ratio and integrated with biological and synthetic pesticides has been used to manage cotton pests, and reduce synthetic insecticide sprays by 40-60 per cent without any significant yield loss.

From the trials, experiments and our commercial experiences with beneficial insect management, we can conclude that beneficial insects have an on-going economic role in modern cotton production in Australia. As Australian cotton growers use IPM strategies more, and synthetic insecticides, particularly broad spectrum ones, less, the role of beneficial insects in Australian cotton production system will be enhanced and their economic value fully realised. For IPM program to achieve its maximum potential in the cotton industry, there is the need for more growers to adopt the program. Also, there is the need for a search for new non-chemical control tools to support the program. The successful development of new non-chemical control tools will require continuous grower support and research funding. Lack of grower support and funding in this wise will result to lack of new tools to support IPM. If this problem does occur, then, the future sustainability of the Australian cotton industry will surely be in doubt because the problem of insecticide resistance and environmental concerns by the community will never go away. The future sustainability of the cotton industry, require a reduction in the use of synthetic pesticides and beneficial insects and their management strategies are options to assist in this process.

Acknowledgements

We thank Wendy Harris, Ray Morphew, Armie Forster, Dianna Owens and Kristie Vaughan for their technical assistance. Special thanks to Peter Glennie, Kylie May, John and Ross O'Brien, Chris Lehmann, Vic Melbourne, Auscott Narrabri and Auscott Macquarie for co-operating with most of the trials reported in this article. The Australian Cotton Research and Development Corporation (CRDC) in collaboration provided funding for these projects (DAN 68C, 89C, 98C and 119C).

References

1. Alderweireldt, M. 1994. Habitat manipulations increasing spider densities: possibilities for biological control? *Journal of Applied Entomology*, 118, 10-16Mensah, R. K. and Harris, W. E. 1995. Using Envirofeast® spray and refugia technology for cotton pest control. *Australian Cotton Grower*, 16, 30-33.

2. Beirne, B. P. 1967. Pest Management (Cleveland, Ohio: CRC Press), 123pp.

3. DeLoach, C. J. 1971. The effect of habitat diversity on predators: *Proc. Tall Timbers Conference on Ecology and Animal Control*, 2, 223-241.

4. Bugg, R. L., Ehler, L. E. and Wilson, L. T. 1987. Effect of common knotweed (Polygonum aviculare) on abundance and efficiency of insect predators of crop pests. *Hilgardia*, 55, 1-51.

5. EntoPak, 1999. A Compendium of information on insects in cotton: Integrated pest management guidelines for Australian Cotton Growers (Prepared by R.K. Mensah and L. Wilson), Australian Cotton Co-operative Research Centre, Technology Resource Centre Press, Australian Cotton CRC, Narrabri, Australia.

6. Fitt, G. P. 1989. The ecology of Heliothis in relation to agroecosystems. *Annual Review of Entomology*, 34, 17-52.

7. Hagen, K. S. 1986. Ecosystem analysis: Plant cultivars, entomophagous species and food supplements, In D. J. boethel and R. D. Eikenbary (eds) *Interactions of plant resistance and parasitoids and predators of insects* (New York; Wiley New York Press), pp 151-197.

8. Hagen, K. S. and Hale, R. 1974. Increasing natural enemies through use of supplementary feeding and non-target prey. *Proceedings Summer Institute for Biological Control of Plant insects and diseases*, Mississippi University Press, Jackson, 647 pp.

9. Mensah, R. K. and Harris, W.E. 1995. Using Envirofeast® spray and refugia technology for cotton pest control. Australian Cotton Grower, 16, 30-33.

10. Mensah, R. K. 1996. Suppression of *Helicoverpa* spp. oviposition by use of the natural enemy food supplement Envirofeast®. Australian journal of Entomology, 35, 323-329.

11. Mensah, R. K. and Khan, M. 1997. Use of *Medicago sativa* interplantings/trap crops in the management of the green mirid, *Creontiades dilutus* in commercial cotton in Australia. *International Journal of Pest Management*, 43, 197-202.

12. Mensah, R. K. and Khan, M. 1997. Use of *Medicago sativa* interplantings/trap crops in the management of the green mirid, *Creontiades dilutus* in commercial cotton in Australia. *International Journal of Pest Management*, 43, 197-202.

13. Mensah, R. K. 1997. Local density responses of predatory insects of *Helicoverpa* spp. to a newly developed food supplement "Envirofeast®" in commercial cotton in Australia. *International Journal of Pest Management*, 43, 221-225.

14. Mensah, R. K. and Singleton, A. 1998. Integrated pest management in cotton based on Envirofeast® and lucerne technologies: where are we? Proc. of Australian Cotton Conference, 9, 363-377.

15. Mensah, R. K. 1999. Habitat diversity: implications for the conservation and use of predatory insects of *Helicoverpa* spp. in cotton systems in Australia. *International Journal of Pest Management*, 45, 91-100.

16. Mensah, R. K., Verneau, S. and Frerot, B. 2000. Deterrence of oviposition of adult *Ostrinia nubilalis* Hubner (Lepidoptera: Pyralidae) by a natural enemy food supplement Envirofeast® on maize in France. *International Journal of Pest Management*, 46, 49-53.

17. Neuenschwander, P. and Hagen, K. S. 1980. Role of the predator Hemerobius pacificus in a non insecticide treated artichokes field. *Environmental Entomology*, 9, 492-495.

18. Walters, D., Drysdale, R. and Kimber, S. 1999. Benefits of planting into wheat stubble. *The Australian Cotton Grower*, 20, 8-15.

19. Wilson, L. J., Fitt, G. P. and Mensah, R. K. (1998). Transgenic (Ingard®) cotton: its role in cotton IPM in Australia. In: Pest Management, Future challenges" editors MP Zalucki, RAI Drew and GG White, Pages 267-276.