Australian Government

Cotton Research and Development Corporation

# Annual, Progress and Final Reports

## Part 1 - Summary Details

# REPORTS

*Please use your TAB key to complete Parts 1 & 2.*

| | | |
|---|---|---|
| **CRDC Project Number:** | | **DAQ110C** |
| **Annual Report:** | ☐ | Due 30-September |
| **Progress Report:** | ☐ | Due 31-January |
| **Final Report:** | ☒ | Due 30-September (or within 3 months of completion of project) |

**Project Title:** Pest status and management of shield bugs in cotton

**Project Commencement Date:** 1 July 2001 **Project Completion Date:** 30 June 2004

**Research Program:** Crop Protection

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## *Part 3.3 – Final Reports (due 3 months after completion of project)*

### 1. Outline the background to the project.

The 'shield bug' (= stinkbug) pests including green vegetable bug (GVB), *Nezara viridula* (Linnaeus), red banded shield bug (RBSB), *Piezodorus hybneri* (Gmelin), green stink bug (GSB), *Plautia affinis* (Dallas), brown stink bug (BSTB), *Dictyotus caenosus* (Westwood), harlequin bug (HRLQB), *Tectocoris diopthalmus* (Thunberg), and cotton stainer bug (CSB), *Dysdercus sidae* (Montrouzier), are emerging pests in cotton in Australia. In conventional cotton use of broad-spectrum insecticides to kill *Helicoverpa* spp. effectively controlled the stinkbugs, but with the introduction of transgenic cotton the use of broad-spectrum insecticides to control *Helicoverpa* spp. has been reduced (Fitt 2000). Further reduction of insecticides is expected with the increasing adoption of Bollgard II and IPM which will aggravate the stinkbug problem further. Moderate to severe GVB damage was reported in many Australian cotton crops over the last few seasons.

Little is known about the damage potential of stinkbugs in cotton. With the Australian cotton industry emphasising IPM, an understanding of the damage relationships is the prerequisite to developing IPM system for the pests. Effective and reliable sampling techniques to monitor stinkbugs and accurate thresholds are integral components of this approach.

The insecticides registered for stinkbugs are mostly non-selective and are extremely disruptive to a wide range of beneficial species. Use of these insecticides at stage II will minimise the impact of existing IPM programs. Therefore less disruptive control tactics including soft chemicals for stinkbugs are necessary.

As with soft chemicals, parasitoids may be useful tools in managing stinkbugs with less or no disruption. One parasitic fly of GVB, *Trichopoda giacomelli* (Blanchard), has been released in the South Burnett and Darling Downs recently. The impact of this parasitoid in cotton systems needs investigation.

Quite a few CRDC funded projects are involved with the use of other crops as nurseries or refuges for beneficials, and/or as trap crops for *Helicoverpa* and other pests. Also there is considerable interest among dryland cotton growers for the use of other crops grown in strips through cotton fields. The impact of these crops on stinkbugs in cotton needs to be investigated. Investigation also needs to identify suitable trap crops for stinkbugs.

### 2. List the project objectives and the extent to which these have been achieved.

1. To investigate the damage potential of stinkbugs in cotton and to develop management guidelines that are compatible with the implementation and adoption of IPM approaches.

2. To investigate pest damage relationships and develop economic thresholds.

3. To evaluate sampling methods to monitor stinkbugs in cotton.

4. To investigate management approaches of stinkbugs including (a) selective insecticides for stinkbug control (b) biological control with the parasitic fly, *T. giacomellii* and (c) use of trap crops for stinkbug management in order to develop IPM compatible tactics.

All of these objectives have been achieved. In addition research compared stinkbug damage with mirid damage at the boll stage. Trials also studied the effectiveness of salt mixture against mirids.

**3. Detail the methodology and justify the methodology used.**

### *Damage assessment of shield bug pests in cotton*

A series of replicated experiments were carried out both in field and in an outdoor insectary in Byee and at J. Bjelke Petersen Research Station (JBPRS), Kingaroy to understand the nature of damage and to compare damage between stinkbugs species. Stinkbugs were confined on 10 day-old bolls, age being determined by tagging bolls at bloom, using polystyrene foam cup cages, nylon hose and twist ties. The insects were allowed to feed for 3 – 7 days. Thereafter another 5 – 7 days were allowed to develop symptoms and half of the treated bolls brought back to the laboratory and checked thoroughly, both externally and internally (by dissecting) for the number of black spots and warts respectively. Remaining bolls were allowed to mature without any further infestation/damage and seed cotton weight at harvest was recorded.

Once it was established that GVB was the most damaging stinkbug, further trials were conducted with GVB to determine the most damaging insect stage, the most susceptible boll age and the damage density relationship to estimate an economic threshold level (ETL).

To determine the most damaging stage of GVB, 3$^{rd}$, 4$^{th}$ and 5$^{th}$ instar nymphs and adults were used in replicated trials in field cages. Since 1$^{st}$ instar do not feed and 2$^{nd}$ instar cause very negligible damage (personal observation), these were not included in the trials. Insects were confined on 10 day-old bolls for 3 days and damage was assessed as described above.

The most susceptible boll age was determined by allowing 7 day-old GVB adults to feed for 24 hours on bolls of different age. Boll age was determined by tagging at bloom. Insects were confined on the boll and damage assessment was as described above.

For damage density relationship, trials were conducted on Ingard® cotton using field cages and manipulated natural infestations. Replicated cage trials were conducted with different densities of GVB on 1 m-row cotton using 1 m x 0.8 m x 1.2 m field cages. Cotton was kept insect free until caging and insects were confined on cotton at boll development stage for 10 days. Thereafter cotton was sprayed until maturity to avoid further damage. At boll opening, damage such as black spots, warts and brown or tight lock was recorded. At harvest seed cotton weight was recorded and tight lock and brown lint portion were discarded from the record since machine harvest can not pick tight lock and brown lints have quality implications (Tom *et al.* 2002). For trials with natural populations, four treatments, < 1/m, 1/m, > 1/m and sprayed control were accommodated in a 5 hectare block of Ingard® cotton. Each replication measured 300 m x 18 rows. Crops were monitored weekly and GVB numbers for each treatment were maintained using different rates of fipronil. Other insects also kept under control. Damage assessment was as described above.

### *Determination of most efficient sampling method for stinkbugs*

Three different sampling methods viz, visual counting, suction sampling and beat sheet were tested to determine the most efficient method to monitor stinkbugs on cotton crops. All three sampling methods are currently used by growers and consultants in their day-to-day scouting of cotton plants. Replicated trials were conducted at JBPRS, Kingaroy and at Macalister, on the Darling Downs. The plot size of each replication was 100 m X 10 rows at JBPRS and 40 m X 10 rows in Macalister. Observations were taken in 5 X 1 m rows at JBPRS and 3 X 1 m rows in Macalister for beat sheet and visual counting and 3 X 10 m for suction sampling from each replication. While the JBPRS observations were taken during early squaring and late boll setting stages, the Macalister observations were only at the boll stage.

### *Population studies of stinkbugs on cotton*

The study was undertaken in dryland cotton at JBPRS, Kingaroy and in irrigated cotton at Byee, 60 km north of Kingaroy. Both sites were mixed cropping areas. At JBPRS the main crops were peanut, soybean, mungbean and corn while at Byee, in addition to cotton there were some soybean, mungbean and corn. At JBPRS sampling was done for 2001-02 season while in Byee sampling was done for 2001-02, 2002–03 and 2003–04 seasons. At Byee during 2003-03 and 2003-04 seasons, sampling was done at two locations, PE and WT. Study at JBPRS was not possible for 2002-03 and 2003-04 seasons because of drought. At each site population estimates were obtained from December to April by sampling once every week. A single 1-metre beat sheet sampling of cotton plants constituted a sample and 6 samples were taken randomly in each plot.

### *Evaluation of GVB parasitoid,* Trichopoda giacomellii *activites*

*Trichopoda giacomellii* a parasitoid from South America (Argentina) was released in 1996 by CSIRO and QDPI in northwest NSW near Moree and in the Lockyer Valley and South Burnett (Kingaroy and Byee) in Queensland. The establishment of this parasitoid in north-western New South Wales and coastal south-eastern Queensland has been reported (Coombs and Sands 2000). We conducted a survey to determine the extent of parasitism by this fly in the South Burnett and cotton growing areas in NSW. Between August to May, regular weekly surveys in the South Burnett and occasional surveys in NSW searched different hosts of GVB. Percentage of parasitism was calculated from GVB collections. During winter months, June and July, parasitism could not be assessed due to lack of GVB. Studies were also made to determine if parasitim varied with gender or GVB hosts. Since GVB are long-lived, even after parasitised by *T. giacomellii*, a replicated trial was conducted to determine if there is any damage implication. Parasitised GVB of different days after parasitisation were confined on 10 day-old bolls and damage assessed as described above.

### *Evaluation of trap crops for managing stinkbugs in cotton*

Attractiveness of soybean, lablab and pigeon pea for GVB interplanting with cotton were evaluated in replicated trials in two locations, Byee and JBPRS. Once these comparisons established that soybean was the most attractive host of GVB, further trials were conducted to examine the attractiveness of mungbean relative to soybean. A replacement for soybean is necessary where whitefly is an issue since soybean is the preferred host of whitefly. Trials were also conducted to examine the effectiveness of soybean as a trap crop on a field scale.

### *Evaluation of salt mixture and new and existing chemistry against stinkbugs*

In Australia the insecticides registered for stinkbugs are mostly non-selective and are extremely disruptive to a wide range of beneficial species. To overcome this problem common salt (NaCl) mixed with low rates of chemicals were tested and their impact on beneficial insects was evaluated.

Two trials were conducted in Ingard® cotton in Boggabri, NSW and in Byee, QLD. Treatments were summarised in Table 1. In both trials treatments were replicated 3 times in randomised complete block (RCB) design. Each replication measured 10 m X 10 rows for the first trail and 15 m X 16 rows for the second trial. The chemicals were applied with a knapsack sprayer in the first trial and with a ground rig in the second trial.

For both trials pretreatment observations (0 DAT) were made the day before treatment. Post treatment observations were made at 3 and 7 days and 2 and 6 days after treatment for the 1st and 2nd trial respectively. Pest and beneficial insects were sampled by beat cloth, in 3 X 1 m and 5 X 1 m samples per replication in 1st and 2nd trial respectively.

### *Statistical analysis*

Unless otherwise stated all data were subjected to one-way analysis of variance and where necessary means were separated by using Fisher's least significance difference test at the 5% level (MINITAB statistical package, Ryan *et al.* 1992). Regression analysis was also performed on some data set combinations as appropriate.

Table 1. Treatment details of the salt mixture and new and existing chemical trials

**Trial 1**

| Chemical name | Trade name | Rate |
|---|---|---|
| Control (unsprayed) | | |
| endosulfan | Thiodan | 2.1 L/ha |
| dinotefuran | Dinotefuran | 500 g/ha |
| thiamethoxam | Actara | 400 g/ha |
| pyriproxyfen | Admiral | 1000 mL/ha |
| pymetrozine | Chess | 600 g/ha |
| emamectin | Affirm | 700 mL/ha |
| emamectin | Affirm | 350 mL/ha |
| emamectin+sodium chloride | Affirm + Table Salt | 350 mL/ha + 10 g/L of water |
| sodium chloride | Table Salt | 10 g/L of water |

**Trial 2**

| Chemical name | Trade name | Rate |
|---|---|---|
| fipronil | Regent | 125 mL/ha |
| fipronil | Regent | 40 mL/ha |
| fipronil + sodium chloride | Regent + Table Salt | 40 mL/ha + 10 g/L of water |
| diafenthiuron | Pegasus | 800 mL/ha |
| indoxicarb | Steward | 325 mL/ha |
| emamectin | Affirm | 700 mL/ha |
| endosulfan | Thiodan | 2.1 L/ha |
| Control (unsprayed) | | |

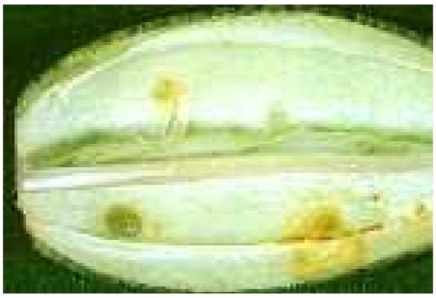
**4. Detail and discuss the results including the statistical analysis of results.**

### *Nature of damage*

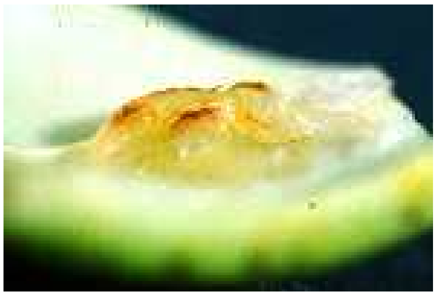
All stinkbugs cause similar damage, both externally and internally. External damage is characterised by dull to shiny black spots at feeding sites (Plate 1a), which contain white stylet sheaths. These sheaths can only be seen using a magnifying glass if not dropped off during handling. External damage symptoms are not always related to internal damage. Only those feeding spots that result from severe and prolonged feeding translate into internal damage. Internal damage is easily visible and is a much better guide to damage than external feeding marks. Internal damage is characterised by warty growths inside the carpels and by discoloured lint. Depending on the extent of feeding, warty growths could be small and light green (Plate 1b) or large and brown coloured (Plate 1c). In the later case, lint turns brown (Plate 1d) and it is hard to peel the carpel off the damaged lint. In undamaged bolls, the carpel is readily separated from the lint. At boll opening, damaged lint with brown discolouration is easily seen (Plat 1e). The damage caused by stinkbugs cannot be distinguished from the damage caused by mirids at the boll stage.

**1a**

**1b**



**1c**



**1d**

**1e**

**Plate 1**. Damage caused by stinkbugs. (1a) external black spots; (1b) small warty growth from light damage; (1c) large warty growth from severe damage; (1d) lint damage; (1e) damage levels at harvest

### *Comparing damage between stinkbugs*

The most damaging stinkbug is GVB followed by GSB, RBSB, CSB, HRLQB and BSB (Figure 1). GVB produced 2, 3 and 4 times more warts than GSB, RBSB/CSB and HRLQB respectively. Brown stinkbug produced least warts.

In a separate experiment it was found that GVB caused significantly more yield loss than other stinkbugs. GVB caused 52% yield loss compare to control. GSB, RBSB and BSB caused 35, 25 and 12 percent yield loss respectively (Figure 2). The yield loss due to BSB was insignificant compare to control.

### *Most damaging GVB stage*

Both nymphs and adults caused damage to bolls. While the first instar did not feed and second instar's feeding was negligible, third instars had sufficiently developed stylets to penetrate the boll wall and reach soft seed. The number of warts per boll increased during successive stages (Table 2). Fifth instar produced more warts than others. However, difference between 4$^{th}$, 5$^{th}$ and adult were not significant. The adults may have spent time mating and ovipositing, consequently producing fewer warts than 5$^{th}$ instar. Third instar produced significantly fewer warts than late instar nymphs and adults. The relationship between number of warts and seed cotton was significant ($r = 0.58$). Seed cotton weight for adults was lower than 5$^{th}$ instar. Compare to number of warts, adult feeding was perhaps more prolonged and severe.

Table 2. Damage caused by different stages of GVB to 10 day old boll

| *GVB stages* | No of warts per boll ± SE | Seed cotton (g/boll) ± SE |
|---|---|---|
| 3$^{rd}$ instar | 7.8 ± 1.4 b | 6.7 ± 0.4 b |
| 4$^{th}$ instar | 14.9 ± 2.0 a | 4.9 ± 0.5 c |
| 5$^{th}$ instar | 18.8 ± 2.9 a | 4.4 ± 0.4 c |
| Adult | 15.4 ± 2.3 a | 4.1 ± 0.3 c |
| Control (no bug) | 0 ± 0 c | 8.1 ± 0.2 a |

Means in a column followed by different letter are significantly different at $P < 0.05$

### *Most susceptible boll age*

Damage varied with boll age (Figure 3). Small bolls were more vulnerable to GVB damage than older bolls. GVB caused significantly more damage to bolls up to 21 days old than older bolls, the preferred age being 10 days or less. Bolls 26 day-old bolls suffered 20 times less damage than younger bolls (Figure 3). Four day-old bolls produced fewer warts than 10 or 14 day-old bolls because most (about 85%) of the 4 day-old bolls dropped off, and the remaining bolls incurred less damage. Bolls aged up to 7 days old could shed due to stinkbug damage.

### *GVB density and damage relationship*

Results from cage trials showed that 1 GVB per metre caused significant yield loss compared to control (no GVB). While the control produced 8.98 bales/ha, 1 GVB/m produced 7.1 bales/ha and 6 GVB/metre only produced 5.6 bales/ha. Regression analysis indicated that the relationship between the mean lint yield and GVB/m was significant (Figure 4).

For trials with natural GVB populations, treatments never reached the existing threshold level and did not cause any yield loss compared to the control. Further analysis was not carried out.

### *Most efficient sampling method*

Figure 5 describes the efficiency of different sampling methods tested to monitor stinkbugs. At early squaring stage, both beat sheet and visual counting were equally effective methods to sample stinkbugs. However, at later crop development stage, beat sheet was x1.5 (Macalister) to x2 (JBPRS) more efficient than visual counting. This was perhaps due to the dense canopy of cotton at this stage compared to early squaring stage, the elusive nature of bugs (hiding inside bracts) and highly clumped distribution making it difficult to pick up bugs during visual sampling. Visual counting at the late stage was also very time consuming. At both stages suction sampling was found to be least effective. The equivalent of visual count to beat sheet was calculated to be 0.5, which is the average of 0.39 (JBPRS) and 0.68 (Macalister) at the late stage.

Cotton is attractive to stinkbugs from boll setting onwards and crops should be inspected using a beat cloth once a week during this period until bolls mature. In the field, distribution of stinkbugs is patchy; therefore thorough inspections throughout a crop are necessary. Stinkbugs are most visible during the early to mid morning when they move to the top of the crop to bask in the sun, making crop inspections easier at this time.

### *Economic threshold*

Figure 4 shows the damage and GVB density relationship in Ingard® cotton at Byee. The damage factor, 0.4579, in the graph is for 10 days feeding by an adult GVB i.e. for 1 days feeding it is 0.04579. Using this damage factor in a classical ETL model which considers two more factors, spray cost and value of the cotton, I calculated ETL for GVB as 1.3 ≅ 1 bug/m with beat sheet. Instars 4 and 5 and adults are regarded as equivalent and instar 3 is 0.5 of instars 4 and 5 and adults (see Table 2). A cluster of 1$^{st}$ or 2$^{nd}$ instars, clumped around the egg remnants, is equivalent to 1 later instar or adult.

Considering the fact that some consultants prefer to check visually and the efficiency of 1 visual count is equivalent to 0.5 beat sheet count, the ETL with visual counting is 0.5 bugs/m.

### *Seasonal changes of stinkbugs on cotton*

The results are summarised in Figure 6. The highest number of stinkbugs were recorded during 2001–02 season at JBPRS followed by 2003–04 season in PE, Byee. Least number of stinkbugs were recorded during 2002–03 season in both trials at Byee. This was perhaps due to the dry winter and spring contributing fewer plant hosts to build the initial population. Throughout the study periods the most abundant species was GVB followed by GSB. By and large in all trials stinkbugs moved to cotton during the first half of Januray. This coincided with the period when cotton crops coommenced boll setting. However, during 2003–04 season they moved to cotton very late, around the second week of February. This was again due to the dry spring and early summer contributing a low initial population. Figure 6 shows that once stinkbugs moved into cotton, they stayed there and continued to build up and reached peak levels around the third week of February, with the exception during 2003–04 season at both location at Byee where the population peaked in the second week of March.

### *Evaluation of Trichopoda activiies*

The fly attacks mainly GVB adults, attaching small white eggs predominantly on the thorax and pronotum. The eggs hatch out to larvae within 2 or 3 days and develop inside the bug. Within 2 weeks, the final instar larva emerges from the host and pupates in nearby soil. The adult flies emerge from pupae after 14 adys and live for a maximum of 10 days.

The study showed that the parasitoid is well established and continuing to spread in the release sites of South Burnett and Moree and adjoining areas. In the South Burnett, parasitised GVB and the parasitoid were detected from Goodger, Kumbia and Jimbour and in NSW they were detected from Bellata, Narrabri, Boggabri and Pilliga.

Monthly parasitim from August to May for 2001–02, 2002–03 and 2003–04 saesons are presented in Table 3. Monthly parasitism rate was consistently higher during 2002–03 than

2001–02 and 2003–04. The result showed that with rising temperature in August – September, both GVB and the fly started to breed. Breeding of the parasitoid continued through October and November before declining in December. From January they started to build up again with the exception during 2003–04 where parasitism rate declined steadily from February. This may be due to extensive and consistent rainfall which was recorded in January, leading to growers using chemicals, mainly through aerial spraying, which impacted on fly numbers. The parasitism rate was higher on adults, about 90%, than late instar nymphs. Parasitism of GVB varied on different host plants (Figure 7). The relationship between parasitism and number of GVB on host plants was significant. The level of parasitism was greater where bugs were clumped on wild hosts, rather than spread throughout a crop. The study also showed that parasitised GVB, up to 10 days after parasitization, caused similar levels of damage to cotton bolls as unparasitised GVB. Thereafter damage was not significant (Figure 8).

Table 3. Percent parasitism of GVB by *Trichopoda* in South Burnett

| Month | Percent parasitism (no. collected) | | |
|---|---|---|---|
| | 2001 – 02 | 2002 – 03 | 2003 - 04 |
| August | - | 14.3 (14) | 44.1 (68) |
| September | - | 50 (6) | 34.2 (164) |
| October | 26.1 (23) | 36.2 (58) | 40.1 (162) |
| November | 17.8 (45) | 20.9 (86) | 36.4 (22) |
| December | 1.4 (73) | 13.3 (75) | 10 (10) |
| January | 0 (12) | 44.2 (52) | 33.3 (3) |
| February | 31.4 (102) | 31 (145) | 13.3 (45) |
| March | 38.8 (121) | 43.4 (279) | 15.3 (183) |
| April | 33.3 (12) | 26.1 (142) | 16.5 (91) |
| May | 37.5 (40) | 34.7 (173) | 14.2 (120) |

To further aid establishment, more flies have been released into the Burnett region, Darling Downs, St George and Moree cotton growing areas.

## *Evaluation of trap crops for managing stinkbugs in cotton*

***Attractiveness of soybean, lablab and pigeon pea***

There were differences among plant species in attractiveness to GVB (Figure 9). At both locations significantly more bugs were found in soybean followed by lablab, but the differences between them were not significant. At JBPRS, however, soybean attracted significantly more bugs than lablab. Pigeon pea attracted the least number of GVB and was not significantly different from cotton.

***Attractiveness of mungbean relative to soybean***

Both soybean and mungbean were found equally effective in attracting GVB (Figure 10). The bugs moved to both soybean and mungbean in the second week of December, but in higher numbers in mungbean where they stayed until mungbeans started to dry off. Trap crop phenology might play an important role in attraction. Mungbean started podding during 2$^{nd}$ week of December while soybean started podding in 1$^{st}$ week of January.

***Effectiveness of soybean as a trap crop***

Two trails were conducted to examine the effectiveness of soybean as a trap crop on a field scale. In both trials soybean was found to be quite effective in trapping GVB and attracted 90% of the GVB caught during the trial period (Table 4). Cotton away from soybean attracted 2 times more GVB than cotton adjacent to soybean.

When data were analysed across time, it was found that in Trial 1 GVB reached threshold level (1 bug/m) twice at the end of the season in both cotton crops (Figure 11). This was perhaps due to the fact that soybean and cotton fields surrounding the trial plots were sprayed, resulting in GVB movement into the trial field. GVB numbers in cotton away from soybean (Cotton2) were higher than in cotton adjacent to soybean (Cotton1) on both occasions. In Trial 2 GVB never reached threshold level in cotton, indicating the effectiveness of the trap crops.

In Trial 1 cotton away from soybean suffered significantly more damage than cotton adjacent to soybean. However, in Trial 2 while the difference was not significant, cotton away from soybean incurred more boll damage (Figure 12).

### *Eavaluation of salt mixture and new and existing chemistry against stinkbugs*

In both trials GVB was the only available stinkbug and since treatments had similar impact on GVB adults and nymphs data were analysed together.

**Trial 1**

The results are presented in Figures 13 and 14. Figure 13 shows that Affirm half rate plus table salt killed 30% more insects than full rate Affirm. The figure also shows that the standard chemical endosulfan and two unregistered chemicals, dinotefuran and Actara were equally effective against GVB.

In this trial major beneficial arthropods were spiders, brown smudge bug (BSB) and red and blue beetle (RBB). Except for lower dose of Affirm and endosulfan at 7 days after treatment (DAT), almost all chemicals had a negative impact on brown smudge bug. The two unregistered products that killed significant number of GVB (Figure 13) also killed significant number of BSB and RBB (Figure 14). All most all chemicals were found to be less disruptive to spiders, except full rates of Affirm at 7 DAT (Figure 14).

**Trial 2**

The result shows that the mixture of Regent 40 mL/ha and table salt killed significant numbers of GVB and was as effective as full rates of Regent, endosulfan and Pegasus (Figure 15). Regent plus salt killed 94% of the treated insects at 6 DAT.

The impact of fipronil plus salt to beneficial insects is summarised in Figure 16. The major beneficial insects were BSB, damsel bug (DB) and spiders. The result shows that Regent 40 mL/ha and salt mixture was significantly less disruptive to BSB and spiders. Almost all chemicals tested, including salt mixture, were found to be disruptive to DB (Figure 16).

A trial was also conducted to investigate how salt mixture works. The results indicated that salt mixture encouraged insects to probe 30 – 35% more compared to chemical treatment alone. Therefore GVB produced significantly more black spots on the bolls treated with salt mixture than those treated with chemical alone but produced significantly fewer warts (real damage) compared to control (Figure 17).

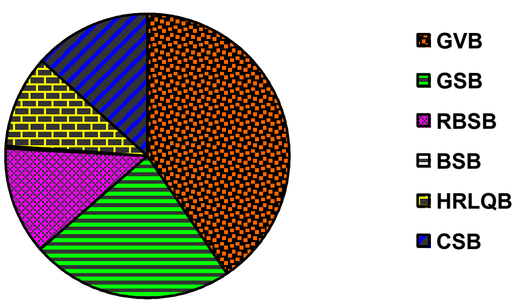


Figure 1. Relative internal damage to 10 day-old bolls by the stinkbug complex

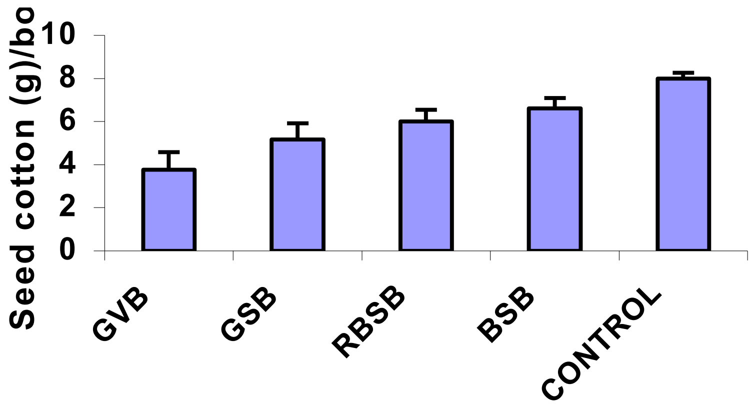



Figure 2. Yield loss due to stinkbugs feeding on 10 day-old bolls. Error bars indicate standard error of means.

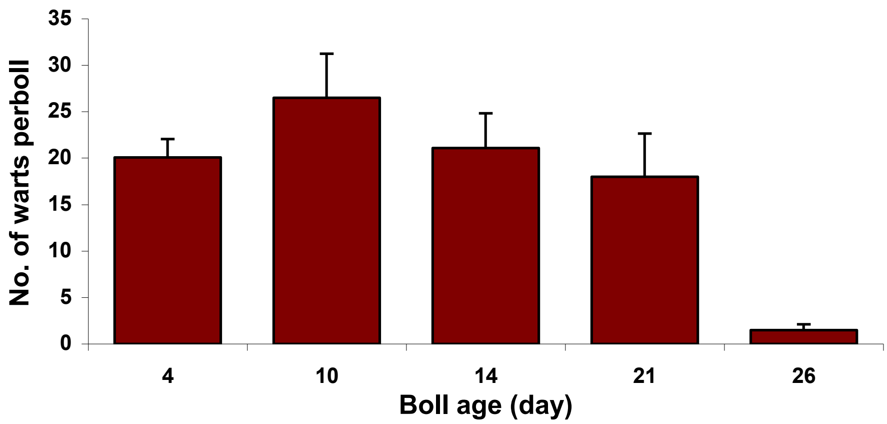



Figure 3. GVB damage to different aged bolls. Error bars indicate standard error of means.

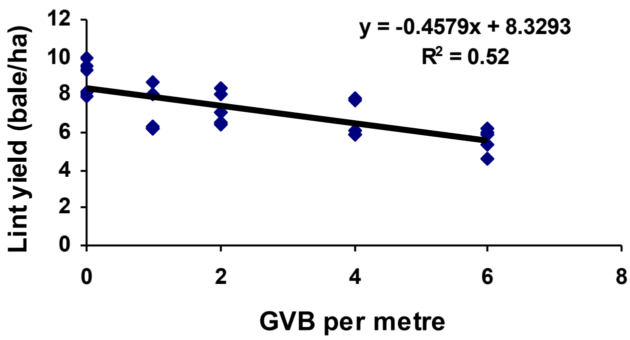



Figure 4. Relationship between lint yield and GVB damage in Ingard® cotton

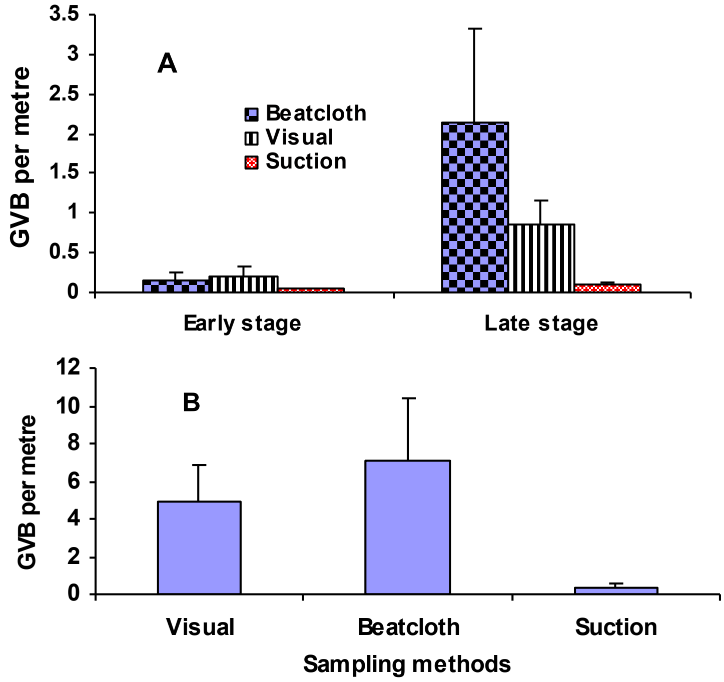



Figure 5. Comparison of sampling methods to monitor GVB, (A) JBPRS and (B) Macalister.

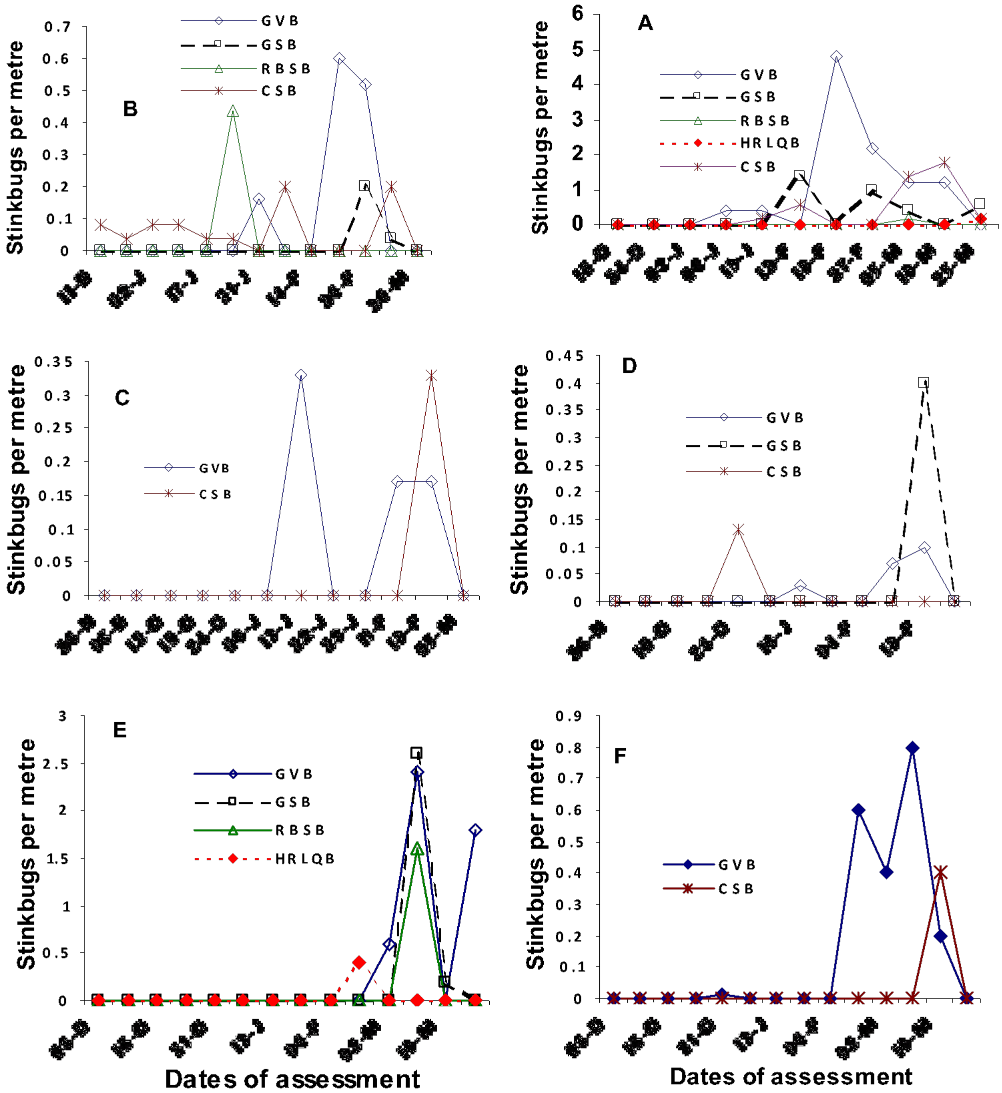



Figure 6. Seasonal abundance of stinkbugs on Ingard® cotton at JBPRS (A) and Byee (B) during 2001–02, in Byee PE (C) and Byee WT (D) during 2002–03 and in Byee PE (E) and Byee (F) during 2003–03.

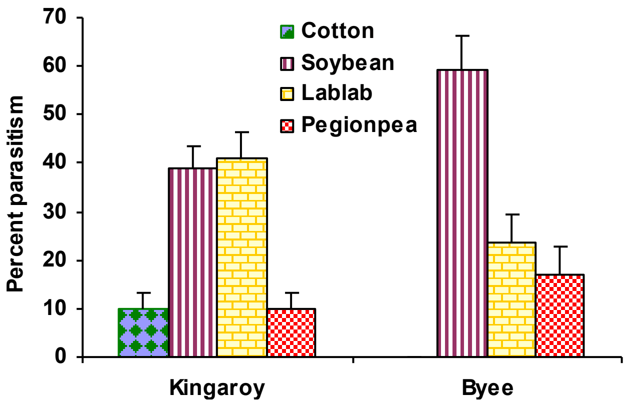


Figure 7. Parasitism of GVB by *Trichopoda* on different host plants. Error bars indicate standard error of means.

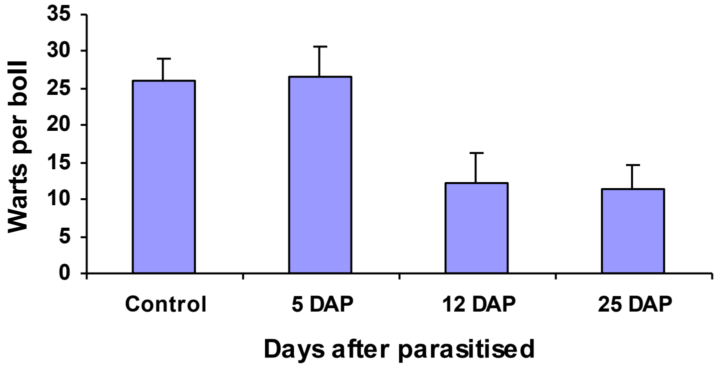



Figure 8. Damage caused by parasitised GVB. Error bars indicate standard error of means.

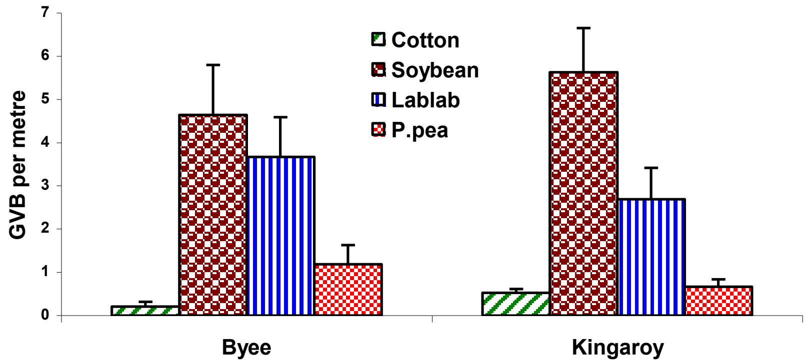



Figure 9. Number of GVB (average of 14 observations) in different hosts at Byee and Kingaroy. Error bars indicate standard error of means.

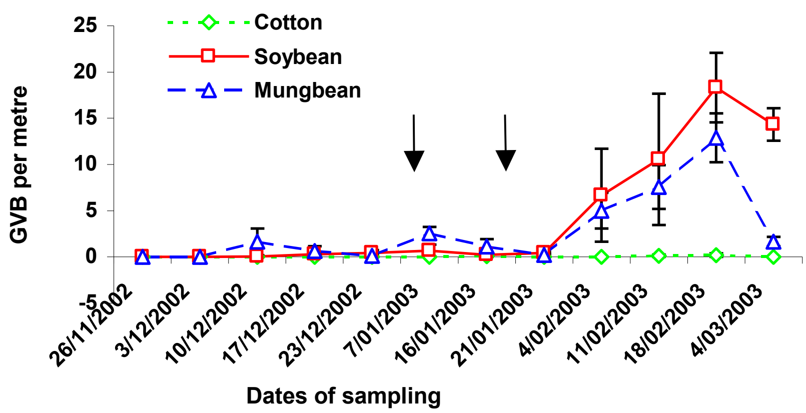



Figure 10. Number of GVB in mungbean and soybean. Arrows indicate spray time. Error bars indicate standard error of means.

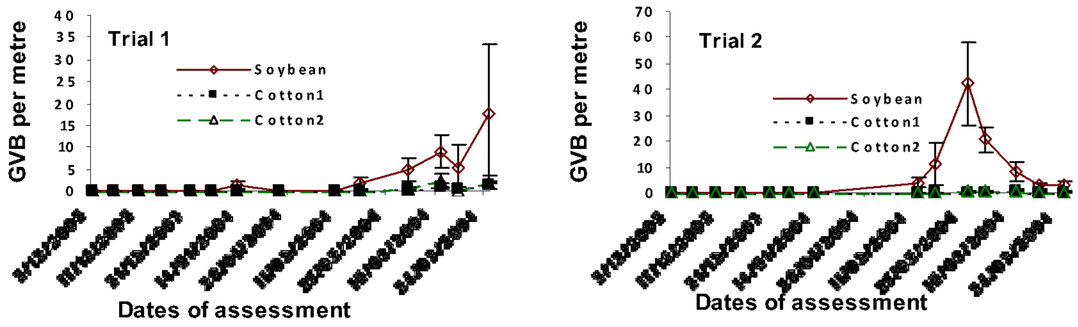



Figure 11. GVB numbers on different sampling occasions in soybean and cotton adjacent to (Cotton1) or away from soybean (Cotton2). Error bars indicate standard error of means.

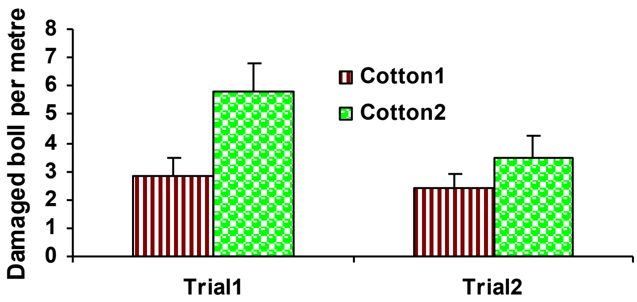



Figure 12. Boll damage in cotton adjacent to (Cotton1) or away from soybean (Cotton2). Error bars indicate standard error of means.

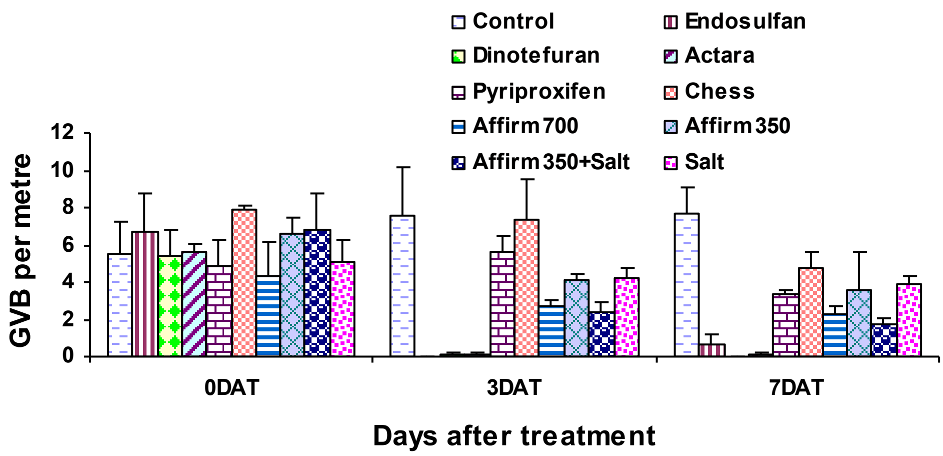



Figure 13. Effect of table salt along with other chemicals on GVB in cotton. Error bars indicate standard error of means.

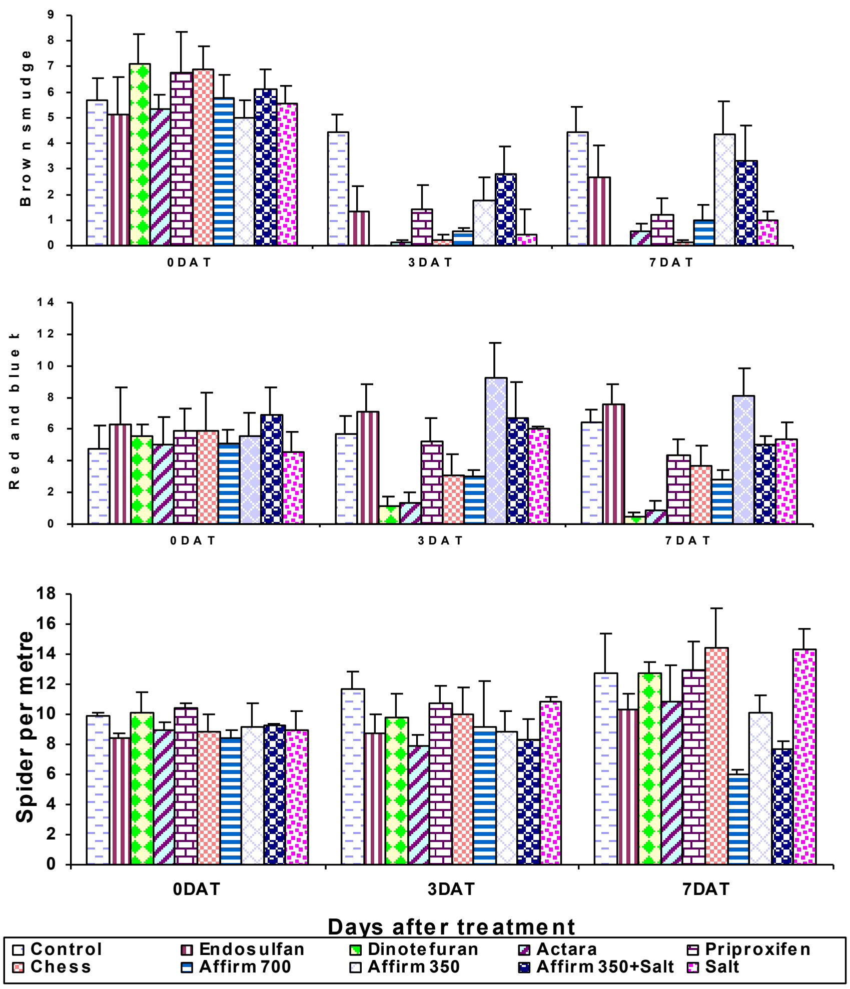



Figure 14. Effect of table salt along with other chemicals on beneficial insects in cotton. Error bars indicate standard error of means.

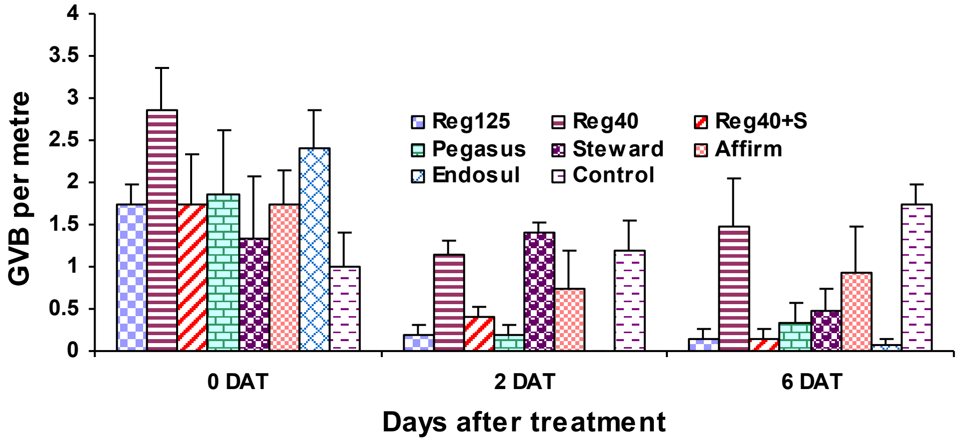



Figure 15. Effect of table salt and chemical mixture on GVB in cotton. Error bars indicate standard error of means.

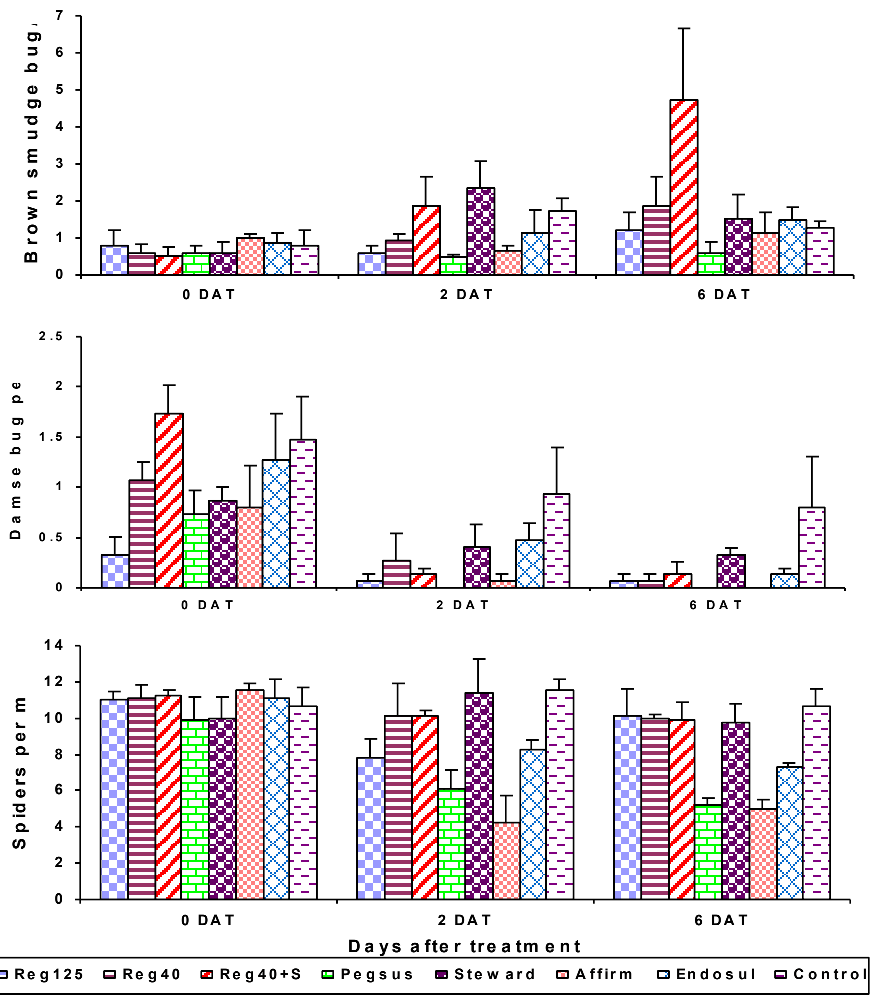



Figure 16. Effect of table salt and chemical mixture on beneficial insects in cotton. Error bars indicate standard error of means.

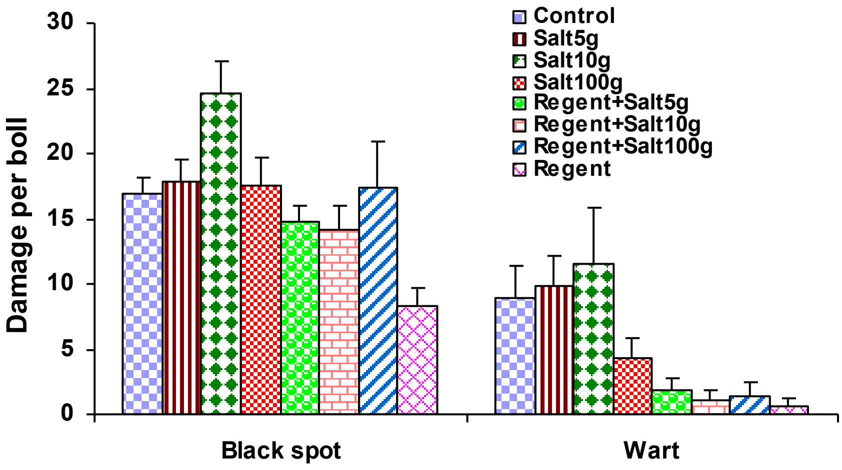



Figure 17. Effect of salt mixture on GVB feeding. Error bars indicate standard error of means.

**5. Provide a conclusion as to research outcomes compared with objectives. What are the "take home messages"?**

Conclusions and "take home messages' are outlined below.

- Stinkbugs move to cotton from wild winter or spring crop (early mungbean) hosts after Christmas at the boll setting stage and pass at least one generation.
- All stinkbugs cause similar damage. Damage is characterised by black spot, warty growth inside the boll wall, brown coloured lint and tight lock. The damage cause by stinkbugs cannot be distinguished from the damage cause by mirids at boll stage.
- The most damaging stinkbug is GVB, causing damage 2, 3 and 4 times more than GSB, RBSB/CSB and HRLQB respectively. BSTB caused negligible damage.
- Fourth and fifth instar nymphs and adults of GVB cause the same amount of damage. Third instars cause half the damage of $4^{th}$ and $5^{th}$ instar nymphs and adults. First instars do not feed and $2^{nd}$ instar nymphs cause negligible damage.
- Bolls up to 20 day-old suffer significant damage from GVB compared to older bolls, the preferred age being 10 days or less. Bolls up to 7 days can shed due to GVB feeding. Bolls older than 25 days suffer very negligible damage.
- The most efficient method to monitor stinkbugs is a beat sheet. It is 2 times more efficient than a visual count. Early to mid morning is the best time to sample stinkbugs as they move to the top of the crop to bask in the sun.
- The threshold for GVB is 1 bug (adult, $4^{th}$ and $5^{th}$ instar nymphs)/m with beat sheet or 0.5 bugs/m with visual counting. When calculating the threshold, $3^{rd}$ instar are equivalent to 0.5, and $1^{st}$ or $2^{nd}$ instar, clumped around the egg remnants, are equivalent to 1 $4^{th}$ or $5^{th}$ instar nymph or adult. The thresholds for GSB, RBSB/CSB and HRLQB are 2, 3 and 4 with beat sheet and 1, 1.5 and 2 with visual counting respectively.
- Besides insect threshold damage, a threshold can be used for management decisions and US guidelines (Greene *et al*. 2001) suggest a damage threshold of 20% damage to small bolls (14 days old). At least 100 bolls from a management unit should be selected randomly to assess damage and the presence of warts or stained lint deems a boll to be damaged.
- The GVB parasitoid, *Trichopoda,* established well in the released sites and continues to spread. Since the parasitoid is very slow acting and GVB are long-lived and continue to breed, even after parasitisation, any impact on overall GVB population will only be noticed after a number of years.
- Soybean strip or bulk areas can be used as trap crop to manage stinkbugs. Since soybean is a preferred host of whitefly, it can be replaced with mungbean where whitefly is an issue. Since stinkbugs preferred podding stage of soybean/mungbean, trap crops should be planted in such a way that they start podding in early January when stinkbugs move to cotton from wild hosts.
- Salt mixture is an effective and profitable IPM option to manage stinkbug. Salt @ 10 g/L water mixed with reduced rate (1/2 to ¼ of full rate) chemical increase chemical efficacy by 40 % compared to low rate of chemical alone. Salt mixture increases palatability of the chemical.

## 6. Detail how your research has addressed the Corporation's three Outputs - Economic, Environmental and Social?

This project has addressed an emerging pest group, stinkbugs in cotton. Until this project little was known about the pest. Therefore any decision to manage them was taken either from overseas information or without understanding the pests. This may have led to incorrect decisions, thus jeopardising the existing IPM within the cotton industry. Management approaches for this pest should complement the adoption of IPM, be based on accurate, locally developed thresholds and should be less reliant on insecticides. My study to understand the pest and their damage, including economic thresholds, will clearly improve growers and consultants decision processes. They are now more equipped with the information such as when to or not to apply chemical and how many insects can be tolerated without suffering economic loss. No doubt these will increase the cotton industry's economic profile. Moreover the IPM tool, salt mixture, I have developed allows a reduction of chemical rate by ½ to 1/3. This will reduce the cost of some insecticide sprays substantially. Salt mixture also will increase the industry's environmental and social profile, as salt mixture is less disruptive to beneficial insects. In addition non-chemical management tools including trap crops and parasitoids will benefit people and communities by reducing use of traditional pesticides and reduce contamination of the environment and food chain.

**7. Provide a summary of the project ensuring the following areas are addressed:**

**a) technical advances achieved (eg commercially significant developments, patents applied for or granted licenses, etc.)**

**b) other information developed from research (eg discoveries in methodology, equipment design, etc.)**

**c) are changes to the Intellectual Property register required?**

Through this project an IPM tool, salt mixture, has been developed. Methodology developed to study damage assessment is being used by other researcher within the cotton industry. For example Mark Hickman of DFI&F is using this methodology for his Masters research.

No IP or patents are involved.

**8. Detail a plan for the activities or other steps that may be taken:**

**(a) to further develop or to exploit the project technology.**

**(b) for the future presentation and dissemination of the project outcomes.**

**(c) for future research.**

Use of salt mixture in cotton may have legal implications and this needs to be clarified with Australian Pesticide and Veterinary Medicine Authority.

The information generated from this project can be published into a brochure and placed on the Cotton CRC website. The principal researcher is writing refereed journal papers on research outcomes. The project outcomes will also be disseminate through grower meeting, field days, CCA meetings, farm walks and conferences.

More research is needed to find other compatible chemistry for salt mixtures. Further research also needs to verify thresholds. Monitoring of stinkbugs is always a big challenge due to their highly clumped distribution in the field. Stinkbugs are well known for their aggregate pheromone and research needs to address this aspect to develop pheromone based monitoring systems. Research on the egg parasitoid, *Trissolcus,* in particular how to boost its effectiveness, needs to be addressed.

**9. List the publications arising from the research project and/or a publication plan. (NB: Where possible, please provide a copy of any publication/s)**

1. Khan, M. and Murray, D. (2004). Salt mixture- an IPM option for managing sucking pest in cotton. Twenty Second International Congress in Entomology, Brisbane.

2. Khan, M. and Murray, D. (2004). Use of *Glycine max* (L.) as a trap crop to manage green vegetable bug *Nezara viridula* (L.) in cotton. *Proceedings of the 12th Australian Cotton Conference*, Gold Coast.
3. Khan. M. (2004). Salt mixture – an IPM tool to manage mirids and green vegetable bug. Cotton Consultants Australia Cotton Production Seminar, Narrabri.
4. Khan, M. (2004). Evaluation of Intruder against mirids and beneficial arthropods in cotton. Final Report for Du Pont. 11 pp.
5. Khan, M. (2003). Salt mixtures- an IPM option to manage mirids in cotton. *The Australian Cottongrower* 24(3): 10-13
6. Khan, M. (2003). Stinkbugs in cotton- damage, sampling methods and thresholds. Cotton Consultants Australia Cotton Production Seminar, Goondiwindi. 4 pp.
7. Khan, M. (2002). Evaluation of two registered products (Affirm and Pegasus) and two unregistered products (Actara and Chess) against stinkbugs and beneficial arthropods in cotton. Final report for Syngenta. 9 pp.
8. Khan, M. (2002). Evaluation of two unregistered products, Dinotefuran and Pyriproxifen against stinkbugs and beneficial arthropods in cotton. Final report for Sumitomo. 6 pp.
9. Khan, M. and Murray, D. (2002). Evaluation of field parasitism of green vegetable bug, *Nezara viridula* (L.) (Hemiptera: Pentatomidae) by *Trichopoda giacomellii* (Blanch.) (Diptera: Tachinidae) in the South Burnett District of Queensland. *Proceedings of the 33rd Australian Entomological Society Conference*, Perth.
10. Khan, M. and Bauer, R. (2002). Damage assessment, monitoring and action thresholds of stinkbug pests in cotton. *Proceedings of the 11th Australian Cotton Conference*, Brisbane. 395-400.
11. Khan, M., Bauer, R. and Murray, D. (2002). Enhancing the efficacy of insecticides by mixing with table salt – a soft approach to manage stinkbugs in cotton. *Proceedings of the 11th Australian Cotton Conference*, Brisbane. 401-406.
12. Lei, T., Khan, M. and Wilson, L. (2002). Boll damage by sucking pests: An emerging threat but what do we know about it? *Proceedings of the 11th Australian Cotton Conference*, Brisbane. 385-393.
13. Khan, M. and Murray, D. (2002). Vegie bug biocontrol poised to strike. *The Australian Cottongrower* 23(1): 58-60
14. Khan, M., Kay, A., Eveleigh, R., Kauter, G. and Marshall, J. (2002). The Green Vegetable Bug. Introduction and Life Cycle. *Grower Information Brochure*, February 2002, CSD.

**10. Have you developed any online resources and what is the website address?**

Article has been put into Cotton CRC website.

**11. Provide an assessment of the likely impact of the results and conclusions of the research project for the cotton industry. Where possible include a statement of the costs and potential benefits to the Australian cotton industry or the Australian community.**

The project outcomes will impact positively on the cotton industry. Understanding damage and thresholds will help the cotton industry to take the correct management decisions and will boost IPM. Salt mixture, trap crops and parasitoids are all environmentally friendly management options which will enhance the industry image to the community. Salt mixture is a very profitable control option by which growers can save at least $10/ha per spray.

## *Part 4 – Final Report Executive Summary*

Provide a one page Summary of your research that is not commercial in confidence, and that can be published on the World Wide Web. Explain the main outcomes of the research and provide contact details for more information. It is important that the Executive Summary highlights concisely the key outputs from the project and, when they are adopted, what this will mean to the cotton industry.

Stinkbugs are emerging pests in cotton. In conventional cotton the use of broad-spectrum insecticides to kill *Helicoverpa* spp. effectively controlled the stinkbugs, but with the introduction of transgenic Bt cotton the use of broad-spectrum insecticides to control *Helicoverpa* spp. has been reduced. Further reduction of insecticides is expected with the increasing adoption of Bollgard II and IPM will aggravate the stinkbug problem. Little was known about their damage, thresholds, IPM tools, etc. This project addressed these issues.

In Australia there are six different types of stinkbugs- green vegetable bug (GVB), *Nezara viridula* (Linnaeus), red banded shield bug (RBSB), *Piezodorus hybneri* (Gmelin), green stink bug (GSB), *Plautia affinis* (Dallas), brown stink bug (BSTB), *Dictyotus caenosus* (Westwood), harlequin bug (HRLQB), *Tectocoris diopthalmus* (Thunberg), cotton stainer bug (CSB), *Dysdercus sidae* (Montrouzier).

Stinkbugs move to cotton from wild winter or spring crop (early mungbean) hosts when these hosts dry off or are harvested after Christmas at boll setting stage and pass at least one generation causing considerable damage to cotton. All stinkbugs cause similar damage. Damage is characterised by black spots, warty growths inside boll walls, brown coloured lint and tight lock. The damage caused by stinkbugs cannot be distinguished from the damage cause by mirids at the boll stage. The most damaging stinkbug is GVB, causing damage 2, 3 and 4 times more than GSB, RBSB/CSB and HRLQB respectively. BSTB caused negligible damage. Fourth and fifth instar nymphs and adult GVB cause equivalent damage. Third instars cause half the damage caused by 4$^{th}$ and 5$^{th}$ instar nymphs and adults. First instars do not feed and 2$^{nd}$ instar nymphs cause negligible damage. Bolls up to 20 days old suffer significant damage from GVB but compared to older bolls, the preferred age is 10 days or less. Bolls up to 7 days can shed due to GVB feeding. Bolls older than 25 days suffer very negligible damage and therefore do not need protection at that stage.

The most efficient method to monitor stinkbug is beat sheet sampling. In the field, distribution of stinkbugs is patchy; therefore thorough inspections at least once in a week throughout a crop are necessary. Stinkbugs are most visible during the early to mid morning when they move to the top of the crop to bask in the sun, making crop inspections easier at this time.

Once stinkbugs number reach the threshold level, control option should be selected in the light of the IPM strategy. The threshold for GVB is 1 bug (adult, 4$^{th}$ and 5$^{th}$ instar nymphs)/m with beat sheet or 0.5 bugs/m with visual counting. When calculating threshold, 3$^{rd}$ instar are equivalent to 0.5, and 1$^{st}$ or 2$^{nd}$ instars, clumped around the egg remnants, are equivalent to 1 4$^{th}$ or 5$^{th}$ instar nymph or adult. The thresholds for GSB, RBSB/CSB and HRLQB are 2, 3 and 4/m with beat sheet and 1, 1.5 and 2/m with visual counting respectively. As well as the insect threshold, a damage threshold can be used for management decision. US guidelines suggest a damage threshold of 20% damage to small bolls (14 days old). At least 100 bolls from a management unit should be selected randomly to assess damage and the presence of warts or stained lint deems a boll to be damaged.

For managing stinkbugs, soybean strip or bulk can be used as a trap crop. Since soybean is a preferred host of whitefly, it can be replaced with mungbean where whitefly is an issue. Since stinkbugs preferred podding stage of soybean/mungbean, the trap crop should be planted in such a way that they start podding in early January when stinkbugs move to cotton from wild hosts.

Salt mixture is an effective and profitable IPM option to manage stinkbugs. Salt at 10 g/L water mixed with reduced rate (1/2 to ¼ of full rate) chemical increase chemical efficacy by 40 % compared to low rate of chemical alone. Salt mixture increased palatability of the chemical. Mixing salt with chemicals should be approached cautiously. Chemicals that are registered for *Helicoverpa,* mites, whitefly and aphids should not be mixed at the low rate with salt if one of these pests is present in the field. The stinkbug spray at lower rate may have resistance implications for those pests. In terms of the IRMS, a low-rate application is counted the same as a full-rate application. If there is a maximum of three applications allowed then three low-rate applications is equivalent to three full-rate applications.