

The Importance of Heliothis and Sucking Pests, and Role of Beneficial Arthropods

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Summary

- A season-long field trial was conducted to determine the relative influence of different pest management programmes: an unsprayed control; chewing pests managed with the addition of selective insecticides; sucking pests managed with the addition of insecticides; and both chewing and sucking pests managed with the addition of insecticides.
- The density and impact of beneficial arthropods varied significantly between the treatments; the highest densities of beneficial and pest arthropods were achieved in the unsprayed control and chewing pests managed treatments. However fruit counts, crop yield and profitability were highest in the sucking pests alone and combined chewing and sucking pests managed treatments, despite additional insecticide costs and lowered beneficial arthropod activity.
- We conclude that sucking pests were relatively more important than chewing pests, and naturally occurring predators and parasitoids failed to afford satisfactory control of both sucking and chewing pests in unsprayed *B.t.* cotton. It is likely that the activity of the arthropods present and pattern of insecticide use contributed to reducing outbreaks of sucking pests such as aphids and mites in both sucking pests managed treatments. This information should be useful for researchers and pest managers making educated pest management decisions.

Introduction

There appears to have been a change in the importance of pests present in cotton over the last decade. This has involved former secondary pests, such as aphids, *A. gossypii*, mirids, *Creontiades* spp., green vegetable bugs, *Nezara viridula* (L.), and whitefly, *Bemisia tabaci* (Gennadius), having attained greater prominence (Wilson 2002); relative pest pressures for these species are higher in *B.t.* than non-*B.t.* cotton (Doyle *et al.* 2002). The change in pest spectrum is likely to be a consequence of widespread adoption of IPM programmes (Wilson 2002). These sucking pests are a problem in IPM programmes, as broad-spectrum insecticide treatment is very disruptive to the beneficial arthropod fauna (particularly early-season applications), few narrow-spectrum insecticides are available, densities may flare following treatment with broad-spectrum insecticides (Wilson *et al.* 1998, 1999; Slosser *et al.* 2000), and little is known about the impact of their natural enemies (Wilson *et al.* 1996; Wilson 2002).

As a consequence there is a requirement to determine the damage potential of a 'new' pest complex that contains several key pest species, not just a single species such as heliothis, and for refinement of IPM programmes to better manage these pests. We conducted a season-long field trial to better understand the impact of beneficial and pest arthropods, and to refine IPM

programmes to better manage these 'secondary' pests. Treatments were designed to selectively manipulate beneficial and pest arthropod densities to enable examination of predator-prey relationships, and measurement of the relative impact of different beneficial and pest arthropod groups. We recognised two broad prey categories based on the mouthparts of the economically damaging life-stage; 'chewing' and 'sucking' pests. The chewing pest group predominantly comprised heliothis, the traditional major pest of cotton, while the sucking group comprised species formerly considered secondary pests, such as aphids, green mirids, green vegetable bugs and whitefly. These pest groups were managed alone or in combination using narrow-spectrum insecticides to supplement 'natural' mortality factors, although the treatments are 'imperfect', as the insecticides also reduced the abundance of beneficial arthropods.

Methods

Our study was conducted at Wayne & Liz Thomson's property "RMB 1371" at Bye in the South Burnett region of Queensland. The trial area was located at the end of a 30 ha irrigated solid-plant Ingard[®] (cv NuPearl Roundup-Ready) cotton field. Cotton was grown using standard commercial agronomic practices, apart from modified use of insecticides. The trial area was effectively 128 m wide and 300 m long (3.84 ha) and contained 12 plots, each 32 m wide and 100 m long (0.32 ha). The treatments were: an untreated control; insecticide intervention used to manage chewing pests (mainly heliothis); insecticide intervention used to manage sucking pests (mainly mirids and green vegetable bugs); and insecticide intervention used to manage both chewing and sucking pests (i.e., standard practice). Each treatment was replicated three times in a randomised-complete block design.

We monitored the trial site during the growing season to record the number of beneficial and pest arthropods, mortality rates of sentinel prey, fruit counts, crop yield and fibre quality (see Methods section in Wade *et al.* 2004 for further details). Insecticides were applied in 100 L water per ha by ground rig to appropriate treatment plots when target pest densities exceeded dynamic action thresholds. Action thresholds and insecticide product and rate selection were modified from industry best management practices (Shaw & Watson 2001; Gibb *et al.* 2002); thresholds for mirids and green vegetable bugs were higher than industry thresholds, as industry thresholds were based on visual or vacuum sampling techniques which produce counts approximately half the value of beat sheet sampling (Deutscher *et al.* 2003). Dynamic action thresholds were predetermined thresholds rationally adjusted for present and future densities of beneficial and pest arthropods, mortality of sentinel prey, and fruit counts, in context of the current situation. The predetermined action thresholds were: 1 heliothis larva of any stage except very small (first-instar) per half-metre (2/m) on two consecutive occasions, or 0.5 medium-large or large larvae per half-metre (1/m) on any occasion; 2-3 green or brown mirid adult equivalents (AE) per metre before flowering, then reduced by 50 % at flowering and boll filling stages; and 0.5-1 green vegetable bug AE per metre. Each first- to third-instar mirid and green vegetable bug was considered half an adult equivalent, and each fourth- and fifth-instar was considered a full adult equivalent.

The insecticides used were likely to have minimal impact on beneficial arthropods (Wilson *et al.* 2002), and to be selective for the targeted pest group (Table 1); i.e., low rates of Folimat[®] and Endosulfan[®] have negligible impact on heliothis, while Gemstar[®], Steward[®] has negligible

impact on mirids and green vegetable bugs (Shaw & Watson 2001; J. Stanton, crop consultant, pers. comm. 2002) (note, Steward[®] has been registered for 'suppression' of mirids since the study was conducted). Hence any treatment differences were considered relative, as the densities of a particular target pest species were never eliminated in any one treatment, and heliothis were suppressed for most of the season in all treatments by *B.t.* toxin in the plant.

Table 1. Details of insecticides applied in a season long study to manipulate the abundance of chewing and sucking pests. A tick indicates spray was applied to this treatment.

Spray no.	Date (days after planting)	Details	Treatment			
			None	Chew only	Suck only	Both
1	27 Dec 2001 (71)	70 ml/ha Folimat*	.	.	✓	✓
2	13 Jan 2002 (88)	100 ml/ha Folimat*	.	.	✓	✓
3	31 Jan 2002 (106)	667 ml/ha Steward [†] , 200 ml/ha Gemstar [‡] , 1 l/ha Amino-Feed UV	.	✓	.	✓
4	31 Jan 2002 (106)	1.05 l/ha Endosulfan [✓]	.	.	✓	✓
5	12 Feb 2002 (118)	1.05 l/ha Endosulfan [✓]	.	.	✓	✓

*contains 800 g/l omethoate; [†]200 g/l indoxacarb; [‡] 2×10^9 POB's/ml HzNPV; [✓]350 g/l endosulfan

To examine the effect of manipulated predator-prey relationships from insecticide treatments, we compared beneficial and pest arthropod densities, yield measures, fibre quality measures. We predicted that compared to the untreated plots, treated with insecticides would have higher production costs, fewer beneficial and pest-other arthropods and lower mortality rates of sentinel prey, but an equivalent number of open bolls, yield and fibre quality, and therefore lowered profitability. In addition, we investigated the strength of relationship between the densities of various arthropod groups alone, and between the density of various arthropod groups and fate of sentinel heliothis eggs on cards for each category. We used a series of ANOVA and Spearman rank correlation tests to analyse the data.

Results

Density of Mobile Beneficial and Pest Arthropods

We found that four insecticide treatments for sucking pests significantly ($P < 0.05$) lowered the density of predatory bugs, predatory beetles, spiders and all beneficial arthropods, across all sampling dates. A single insecticide treatment for chewing pests did not significantly affect the density of each beneficial arthropod category. Multiple insecticide treatments for sucking pests significantly lowered the density of jassids, green mirids (adult equivalents), and all pests; analyses not valid for green vegetable bug (adult equivalents) and other true bugs. A single insecticide treatment for chewing pests did not significantly alter the density of each pest arthropod category (selected pest and beneficial groups shown in Figure 1).

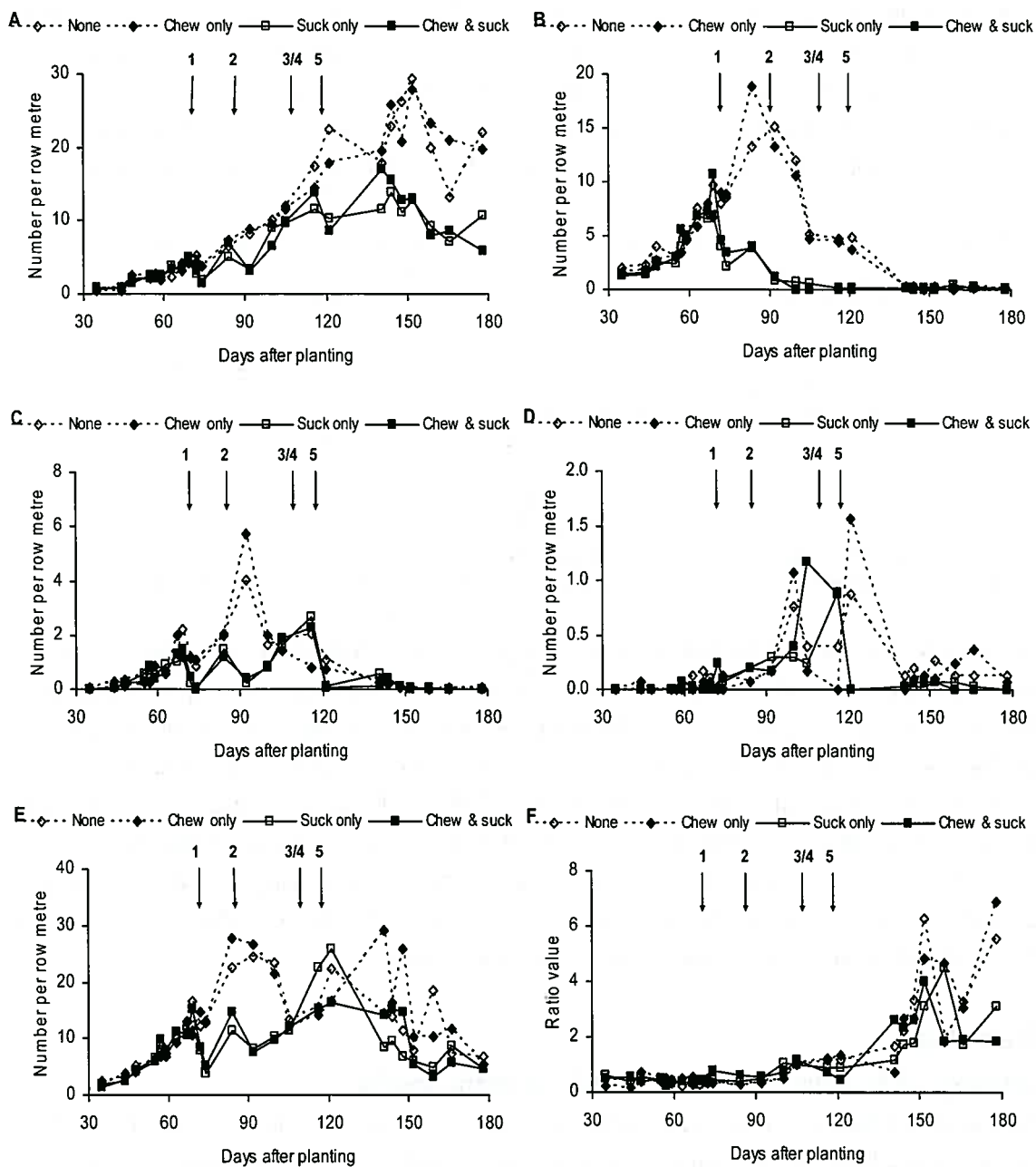


Figure 1. Variation in the mean density per metre of all beneficial (A), jassid (B), green mirid [adult equivalents] (C), green vegetable bug [adult equivalents] (D), all pests (E), and all beneficial to all pest arthropods as a ratio (F) over the growing season for various predator-prey treatments. Vertical downward arrows represent insecticide application dates (see Table 1 for details). Standard error bars were omitted for clarity.

Density of Aphid and Whitefly

Multiple insecticide treatments for sucking pests significantly lowered the density of aphids and whitefly. A single insecticide treatment for chewing pests did not significantly alter the density of aphids and whitefly. There was a significant interaction between chewing and sucking treatment effects for aphid densities (Figure 2).

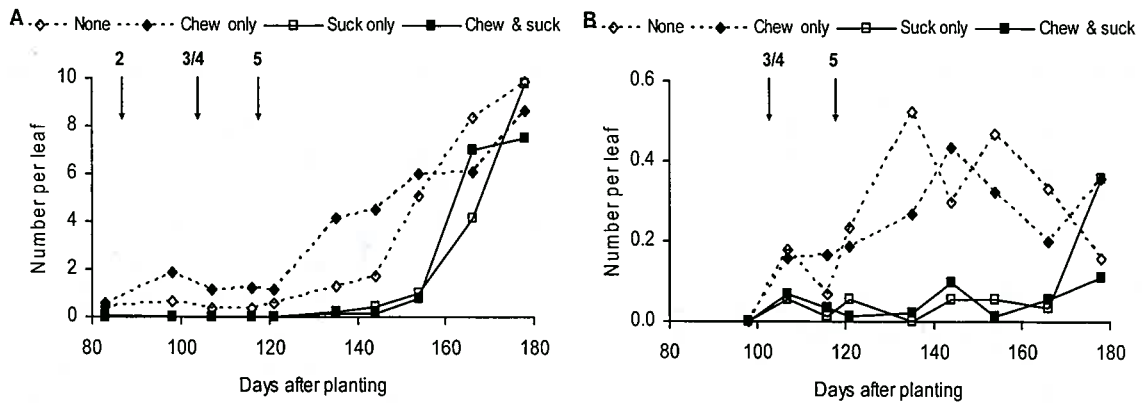


Figure 2. Variation in mean density per main-stem leaf of aphids (A; winged and non-winged forms combined) and whitefly (B; nymphs and adults combined) over the growing season for various predator-prey treatments. Vertical downward arrows represent insecticide application dates (see Table 1 for details). Standard error bars were omitted for clarity.

Density of *Heliothis* Eggs and Larvae

Multiple insecticide treatments for sucking pests and a single insecticide treatment for chewing pests did not significantly affect *heliothis* egg density. Multiple insecticide treatments for sucking pests appeared to increase the density of *heliothis* larvae, although this could not be verified statistically as the analysis was not valid. Increased *heliothis* larval density necessitated insecticide application in the chewing pests managed treatments (Figure 3).

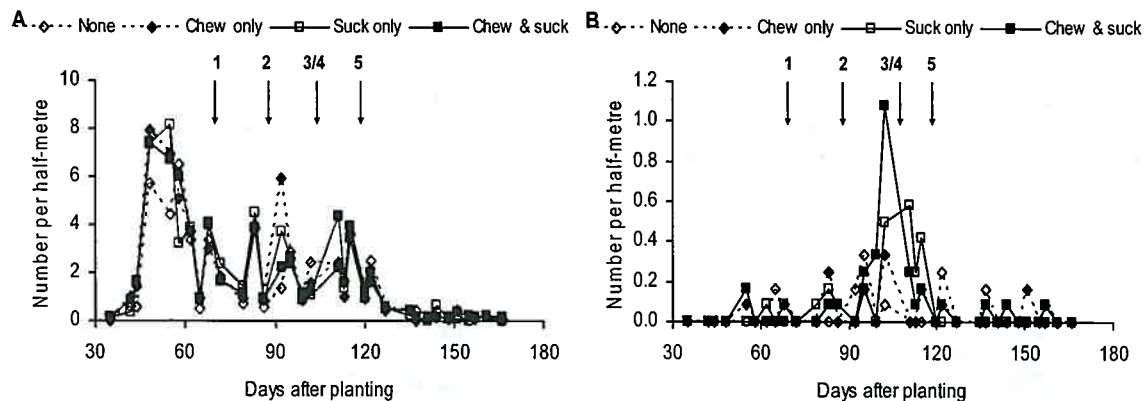


Figure 3. Variation in mean density per half-metre of *heliothis* eggs (A; white and brown stages) and larvae (B; small to large size classes) over the growing season for various predator-prey treatments. Vertical downward arrows represent insecticide application dates (see Table 1 for details). Standard error bars were omitted for clarity.

Mortality Rates of Sentinel *Heliothis* Eggs

The proportions of collapsed sentinel *heliothis* eggs on cards was significantly higher, and eggs attacked by all beneficial arthropods was significantly lower in plots that received multiple insecticide treatments for sucking pests. The fate of *heliothis* eggs was not significantly affected by a single insecticide treatment for chewing pests (Figure 4). The density of all beneficial arthropods and the ratio of all beneficial to all pest arthropods were weakly, negatively correlated with the proportion of eggs attacked by all beneficial arthropods (Figure 5).

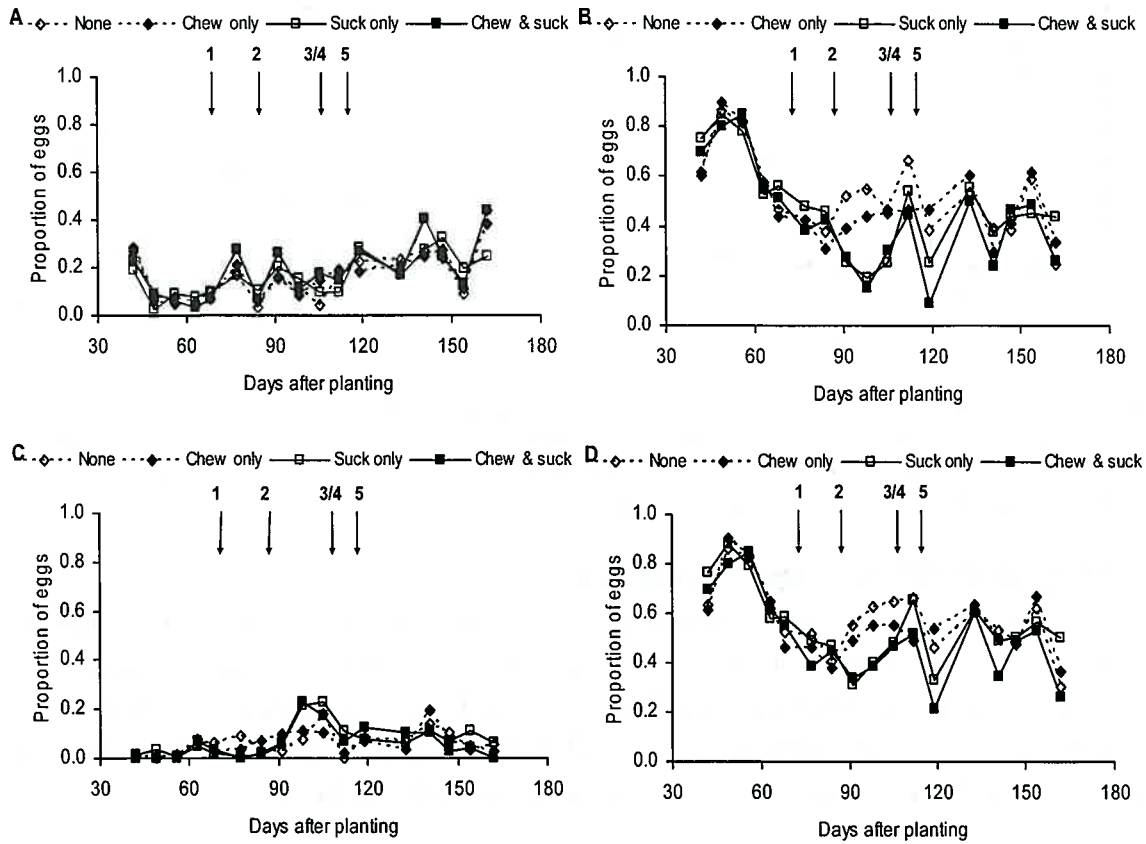


Figure 4. Variation in the mean proportion of sentinel heliothis eggs on cards that were hatched (A), predated (B), parasitised (C), or attacked by all beneficial arthropods (predated + parasitised; D) after 48 hours exposure in the field at different times of growing season for various predator-prey treatments. Data not shown for collapsed eggs. Egg card samples each contained a mean of 26.4 eggs (range 8 to 88). Vertical downward arrows represent insecticide application dates (see Table 1 for details).

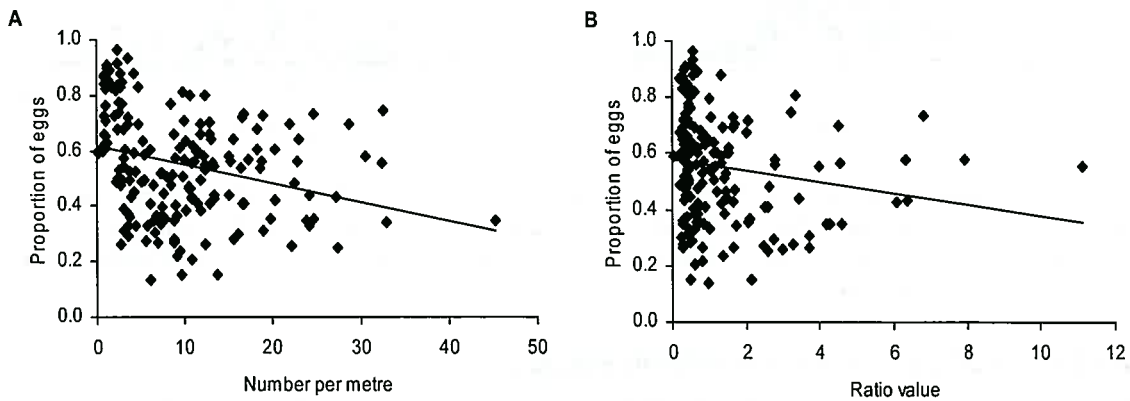


Figure 5. Scatter plot between the mean density per metre of all beneficial arthropods and mean proportion of sentinel heliothis eggs on cards that were attacked by all beneficial arthropods (A), and mean densities of all beneficial to all pest arthropods as a ratio and the mean proportion of heliothis eggs on sentinel cards that were attacked by all beneficial arthropods (B) after 48 hours exposure in the field for various predator-prey treatments and times of the growing season.

Fruit Counts

The number of squares plus flowers and potential fruit was significantly lower and open bolls significantly higher, while the number of closed bolls and all fruit was not significantly affected in plots that received multiple insecticide treatments for sucking pests. All fruit as a proportion of potential fruit was significantly higher in plots that received a single insecticide treatment for chewing pests (Figure 6).

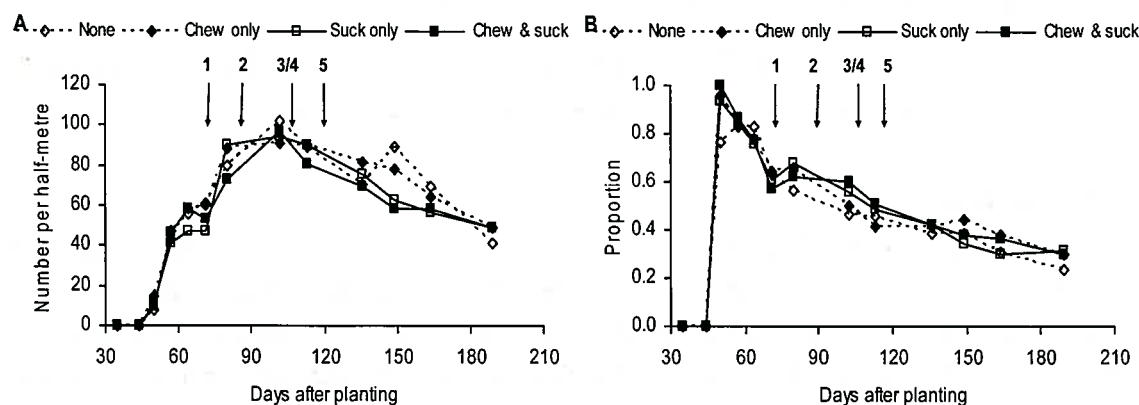


Figure 6. Variation in the mean number per half-metre of all fruit (A), and all fruit as a proportion of potential fruit (B) over the growing season for various predator-prey treatments. Data not shown for squares and flowers, closed bolls, open bolls, and potential fruit. Note different vertical scales used on figures. Vertical downward arrows represent insecticide application dates (see Table 1 for details). Standard error bars were omitted for clarity.

Yield and Fibre Quality Measures

Multiple insecticide treatments for sucking pests significantly decreased the number of closed bolls and increased the number of open bolls. Seed cotton and lint mass, proportion lint turnout, and yield were significantly higher in plots that received multiple insecticide treatments for sucking pests. A single insecticide treatment for chewing pests significantly improved seed cotton and lint mass and therefore yield (Table 2).

Table 2. Variation in mean (\pm SE) value per half-metre of various yield measures at conclusion of the growing season for various predator-prey treatments.

Measure	None	Chew only	Suck only	Chew & suck
Squares + flowers	0.0 (0.0)	0.0 (0.0)	0.4 (0.1)	0.0 (0.0)
Closed bolls	4.2 (1.1)	5.7 (2.6)	1.4 (0.3)	1.0 (0.3)
Open bolls	49.4 (1.7)	53.3 (0.7)	57.9 (2.2)	61.2 (2.0)
All fruit	53.6 (2.2)	59.0 (3.2)	59.8 (1.8)	62.2 (1.8)
Potential fruit	238.1 (16.1)	210.2 (22.6)	195.8 (7.5)	213.5 (17.3)
Proportion actual fruit	0.23 (0.01)	0.29 (0.03)	0.31 (0.01)	0.30 (0.03)
Seed cotton mass (g)	210.7 (14.0)	233.0 (9.8)	265.6 (12.3)	284.8 (2.0)
Lint mass (g)	91.0 (5.5)	101.5 (4.8)	117.2 (5.2)	130.3 (0.9)
Proportion lint mass	0.43 (0.00)	0.43 (0.01)	0.44 (0.00)	0.46 (0.00)
Yield (bales per ha)	8.0 (0.5)	8.9 (0.4)	10.3 (0.5)	11.5 (0.1)

Multiple insecticide treatments for sucking pests significantly increased the fibre elongation index and decreased the yellowness colour index. A single insecticide treatment for chewing pests significantly increased fibre fineness. There was a significant interaction between chewing and sucking treatment effects for yellowness colour index (Table 3).

Table 3. Variation in mean (\pm SE) value of various fibre quality measures at conclusion of the growing season for various predator-prey treatments.

Measure	None	Chew only	Suck only	Chew & suck
Length (hundredths of inch)	1.16 (0.01)	1.17 (0.01)	1.16 (0.01)	1.16 (0.01)
Length uniformity index [*]	83.5 (0.4)	84.0 (0.2)	83.7 (0.2)	83.5 (0.2)
Short fibre index [†]	7.1 (0.7)	6.5 (0.1)	6.7 (0.4)	6.9 (0.1)
Strength (g/tex)	32.3 (1.0)	30.5 (0.4)	30.7 (0.3)	30.5 (0.5)
Elongation index [‡]	3.9 (0.1)	4.1 (0.1)	4.3 (0.1)	4.2 (0.0)
Fineness [√]	4.6 (0.0)	4.9 (0.1)	4.6 (0.0)	4.8 (0.0)
Reflectance colour value (Rd)	80.8 (0.8)	80.6 (0.9)	81.3 (0.4)	82.0 (0.7)
Yellowness colour value (+b)	6.9 (0.1)	6.8 (0.1)	6.6 (0.1)	6.8 (0.1)

^{*}ratio of mean length to upper half mean length; [†]percentage of fibres less than 0.5 inches long;

[‡]as a percentage of overall length; [√]fibre mass per unit length (μg per inch)

Discussion

Sucking pests, predominantly mirids and green vegetable bugs, were relatively more important than chewing pests (mainly heliothis) in this study. Insecticide intervention was required for mirids on four occasions on two occasions for green vegetable bugs (which corresponded with the mirids) in the sucking pests managed treatments (i.e., sucking only, and chewing plus sucking) (Figure 1). Chewing pests required insecticide intervention on one occasion in the chewing treatments (i.e., chewing only, and chewing plus sucking) (Figure 3B). The insecticide use results were expected. An average of 2.9 insecticide sprays are applied to *B.t.* cotton crops each growing season to manage sucking pests (includes 1.2 sprays for mirids and 0.1 for green vegetable bugs), and another 1.6 sprays for chewing pests (i.e., heliothis) (Doyle *et al.* 2002). Secondly, *B.t.* toxin in transgenic cotton is known to effectively control heliothis larvae for the first 112 days after planting, and thereafter an average of 1.6 insecticide sprays are applied for this pest (Doyle *et al.* 2002). It is unclear whether most insecticide applications for sucking pests and/or heliothis are actually necessary, as fixed action and dynamic action thresholds for these pest species are currently under development and/or revision (Wilson & Sadras 1999; Gibb *et al.* 2002; Khan & Bauer 2002; Lei 2002; Lei *et al.* 2002).

Numerous field trials have evaluated IPM programmes for *B.t.* and non-*B.t.* cotton crops in Australia (e.g., Bishop & Blood 1980; Waite 1983; Murray *et al.* 1996; Mensah & Khan 1997; Stanley 1997; Mensah 2002a, b; Scholz *et al.* 2002a, b). Apart from Mensah & Khan (1997), the focus of trials has been on heliothis, while cursory treatment has been given to sucking pests. However these 'secondary' sucking pests have gained greater prominence as a consequence of widespread adoption of IPM programmes (discussed previously). This will likely continue as IPM tactics improve, particularly as narrow-spectrum insecticides are further developed, more effective two-gene *B.t.* cotton replaces single-gene *B.t.* cotton in 2004-05, and as restrictions on the maximum cultivation area of *B.t.* cotton lift from 30 to 90 % (Wilson 2002). It is necessary to separate the importance of chewing and sucking pests so they can be better managed, but this has rarely been investigated in IPM trials.

Management tactics for one pest group are known to directly and/or indirectly affect the other group, and this is undesirable in an IPM programme. Repeated applications of broad-spectrum insecticides for heliothis management (i.e., the chewing pests) can cause outbreaks of 'secondary' pests, such as aphids (Wilson *et al.* 1999; Slosser *et al.* 2000) and mites (Wilson *et al.* 1996, 1998), which has been attributed to reduction in abundance and activity of beneficial

arthropods. Conversely, application of broad-spectrum insecticides for sucking pest management may cause subsequent heliothis outbreaks (this study). The experimental design of the present trial enabled a relative distinction between chewing and sucking pest groups.

Four applications of insecticides for sucking pests significantly reduced the densities of jassids, mirids, all pests, aphids and whitefly; i.e., the intended target species (Figures 1-2). It is possible that aphid and mite populations (latter not sampled) would have flared if endosulfan was not substituted for omethoate in the two final sprays, as the former is thought to be less disruptive to beneficial arthropods (Wilson *et al.* 2002) and provides better control of these pest groups (*sensu* Wilson *et al.* 1998). The non-target effect was a significant reduction in densities of predatory bugs, beetles, spiders, all beneficial arthropods (Figure 1), and a corresponding decline in the proportion of sentinel eggs that were attacked by all arthropods (Figures 4-5). The net effect was a significant reduction in the number of squares-flowers and potential fruit, while the number of open bolls increased, and all fruit remained unchanged, as measured by fruit counts over the season (Figure 6). This pattern indicates that damage caused by higher densities of sucking pests essentially delays fruit development. Final season fruit counts and yield assessment confirmed a delay in maturity; the number of closed bolls was significantly lower, and open bolls was significantly higher, but total fruit were unchanged in the sucking pests managed treatment. This resulted in significantly increased seed cotton and lint mass, but also lint turnout, which translated into higher yield estimates (Table 2). This may have been avoided by delaying defoliation for approximately 14 to 21 days, although early crop maturity ('earliness') is a key consideration (Milroy *et al.* 2002).

Lowered seed cotton mass and lint turnout has been reported as a result of boll damage by sucking pests. Plants exposed to mirids had lowered seed cotton mass because more damaged bolls were present and each was smaller, although the reduced number of undamaged bolls present were each slightly higher in mass (Lei *et al.* 2002). Percentage lint turnout was lowered because cotton fibres damaged by sucking pests were partly excluded during ginning (Lei *et al.* 2002). Management of sucking pests significantly improved the fibre elongation and yellowness colour indices (Table 3). It seems not all discoloured, damaged fibres caused by sucking pests were removed during ginning. Lei *et al.* (2002) found that mirid damage significantly increased short fibre index, but not the fibre elongation index (the yellowness colour index was not reported). The yield and fibre quality increases indicate that four insecticide applications for sucking pests were economically justified, and natural enemies of green mirids and green vegetable bugs were unable to maintain these pests below currently acceptable densities. However it is likely that the activity of the arthropods present contributed to preventing an outbreak of all sucking pests, particularly aphids and mites, in both sucking pests managed treatments.

One application of a mixture of narrow-spectrum insecticides for the management of chewing pests had less pronounced effects than results for the sucking pests managed treatments. The densities of beneficial and pest arthropods and mortality rates of sentinel prey were unchanged in the chewing pests managed treatments. Statistical analysis was not valid for heliothis larvae, the target pest life-stage (Figure 3B). While the insecticide application satisfactorily reduced densities of heliothis larvae, the reason for the spray should be considered. Densities of heliothis larvae required control in the chewing and sucking pests managed treatment, but not in the

chewing pests only treatment. Nevertheless, insecticides were applied to both chewing pests managed treatments, as mandated by the experimental design. At the same time heliothis larval density was above threshold in the sucking pests only managed treatment, but no action was taken. Increased larval density may be attributed to reduction in levels of larval predation and parasitism by beneficial arthropods from treatment with Folimat[®] on two previous occasions. An explanation for significantly increased actual fruit as a proportion of potential fruit, and seed cotton and lint mass, and therefore yield, in the chewing pests managed treatment was unclear given that densities of beneficial and pest arthropods were unchanged. Increased sample size and replication may help distinguish treatment differences in future trials where arthropod densities were low and/or variable. The yield and fibre quality increases indicate a single application of a mixture of insecticides for chewing pests was economically justified.

Profitability of the four treatments tested was examined using a partial budget. Compared to the unsprayed treatment that had a gross profit of \$3208 per ha, profitability was increased by \$292 per ha in the chewing pests only managed treatment, \$824 per ha in the sucking pests only managed treatment, and \$1212 per ha in the chewing plus sucking pests managed treatment. These calculations were based on yield values from Table 2, a return of \$400 per bale (Doyle *et al.* 2002), and product plus application costs of \$76, \$96 and \$172 per ha for each treatment, respectively (J. Stanton, cotton crop consultant, pers. comm. 2002), and no financial discounts for these particular fibre quality measures (M. O'Rielley, Queensland Cotton classer, pers. comm. 2002). The chewing and sucking pests managed treatment was the most profitable, even compared to the sucking only pests managed treatment. This was not predicted given the low occurrence of significant interaction terms between the chewing and sucking pests managed treatment factors for variables such as yield and arthropod densities. The only significant treatment interactions present were for aphid densities and the yellowness fibre index. Aphid densities in the sucking pests managed treatments were generally lower than the chewing pests managed treatment, but towards the end of the growing season this trend was partially reversed, but this was hardly biologically significant (Figure 2A). The reduction in the yellowness fibre index was more pronounced in the sucking pests only managed treatment compared to the chewing plus sucking pests managed treatment (Table 3).

The relationships between beneficial arthropod density and mortality rates of sentinel prey were commonly significant and weak to moderate, although the direction of the relationship was contrary to expectations. The proportion of eggs attacked by all natural enemies was significantly, negatively associated with the density of all beneficial arthropods ($r = -0.373$), and the proportion of eggs attacked by all natural enemies significantly, negatively associated with the ratio of all beneficial to all pest arthropods ($r = -0.255$) (Figure 5). The non-significant and/or unpredictable direction of these relationships made the results difficult to interpret. It is logical to associate a reduction in prey numbers to the abundance of common beneficial arthropods that were readily sampled. However poor correlation between densities of beneficial arthropods and mortality rates of sentinel prey could be caused by other poorly sampled or incorrectly classified arthropod species, such as minute parasitoid wasps or nocturnal ground-dwelling predators. For example, night stalking spiders, *Cheiracanthium* sp., ants, *Iridomyrmex* sp. and apple dimpling bugs, *Campylomma liebknechti* (Girault), were considered key predators of heliothis eggs in cotton after conducting diurnal and nocturnal observational studies (Scholz *et al.* 2000). Alternatively, the fate of sentinel prey may poorly reflect that of naturally occurring

prey, but see Scholz (2000) and Pearce (2003). It was assumed here that all beneficial species will attack heliothis eggs, however this is unlikely based on laboratory and field trials (Mansfield *et al.* 2003). Despite this, the predator-to-pest ratio used here included all beneficial arthropods as 'predators' (or parasitoids), and all pest arthropods as 'prey' (or hosts), to account for a potentially wider range of feeding relationships, but this may be too general. Previous predator-to-pest ratios have only considered heliothis as prey (Scholz 2000; Mensah 2002a). Finally, time-delays or lag periods between densities of beneficial and pest arthropods could account for poor correlations if these groups were not tightly 'synchronised'; time adjustments to the datasets may overcome some difficulties (Stanley 1997; Scholz 2000; Pearce 2003). An analysis at a species rather than ordinal level for only confirmed predator and prey species combinations may be more informative, although this may be restricted by current knowledge of predator-prey relationships.

In summary, the results failed to demonstrate that naturally occurring predators and parasitoids afforded satisfactory economic control of sucking and chewing pests in the unsprayed treatment. Sucking pests were relatively more important than chewing pests in *B.t.* cotton. The chewing plus sucking pests managed treatment was the highest yielding and most profitable, despite increased insecticide costs and lowered densities of beneficial arthropods. There was an indication that heliothis larval densities were higher in plots that had been sprayed for sucking pests on two prior occasions.

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