BUREAU OF SUGAR EXPERIMENT STATIONS

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FINAL REPORT – SRDC PROJECT BSS166
EFFECT OF FARMING PRACTICES ON CANEGRUB INCIDENCE

by

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SD02027

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CONTENTS

SUMMARY

The impact of farming practices on numbers of Childers canegrubs was determined in southern Queensland by a survey of 441 field-year combinations that related practices to the numbers of second- and third-instar larvae in those fields, and by a field experiment that tested combinations of insecticide application, cultivation practices and crop-residue retention on numbers of larvae and associated entomopathogens. There were significant differences in levels of infestation among years, soil types, crop ages, cultivars grown, insecticide-use strategies, crop-replacement strategies, intensity and frequency of tillage during crop replacement, and irrigation strategies. In the field trial, numbers of third-instar larvae declined as the larvae aged, probably through infection by the fungus *Metarhizium anisopliae* and the protozoan *Adelina* sp. Application at planting of the controlled-release insecticide suSCon® Blue had an immediate effect on the number of larvae carried over from the previous crop cycle and this effect continued into the second-ratoon crop. The insecticide application increased cane and sugar yields, particularly in the first-ratoon crop. More intensive preplanting tillage initially reduced numbers of larvae, but the effect did not continue into the ratoon crops. Management of crop residues had no consistent impact on numbers of larvae, but cane yields were higher and sugar content lower in the second-ratoon crop when residues were retained, and led to higher sugar yields where suSCon® Blue had been applied. In general, long breaks between successive sugarcane crops, coupled with intensive tillage in that break and application of controlled-release insecticide, will reduce subsequent populations of larvae. The alternative strategy of herbicide destruction of the previous crop, long fallow with minimum tillage, replanting without controlled-release insecticide and prudent use of transient insecticides in heavily infested ratoon crops will also minimise numbers and may allow better survival of entomopathogens. These strategies are integrated into management practices attractive to growers and have been extended within the *Southern GrubPlan* format.

Our study with greyback canegrubs showed that in north Queensland numbers follow trend of increasing to the first ratoon and then decreasing in most treatments. This is consistent with a slow build-up of entomopathogens. The exception was the most invasive treatment, Intensive cultivation + Burning + suSCon use, where numbers continued relatively high in the third ratoon. This is consistent with better survival of *Metarhizium* and *Adelina* under minimum tillage, no insecticide and/or trash retention. Our work reinforced previous work that the 'softer' treatments do not lead to high grub populations, can be done by growers and do not incur yield penalties. In fact, the 'softer' treatments give the highest economic returns.

Trials in the Burdekin with different tillage and trash-management regimes generally had too few larvae to draw useful conclusions about the effect of these treatments on grub numbers. However, the trials showed that minimum tillage and trash retention were both feasible farming practices in this area and adoption was possible. Both were also considerably cheaper options than either conventional tillage and/or burning trash.

Diseased greyback canegrubs from the area from Mulgrave (far north Queensland) to Sarina (south of Mackay) showed variable infection rates of the pathogens *Adelina* sp. and *Metarhizium anisopliae*, especially in the area between South Johnstone (south of Innisfail) and Mutarnee (north of Townsville). Neither of the two pathogens was found in

the Burdekin. The impact of soil chemistry, tillage intensity and fallowing strategy on the prevalence of the two diseases was investigated. No clear relationship was detected between disease incidence and soil chemistry.

Economic analyses of costs and benefits associated with greyback-canegrub control tactics are difficult, as the specific strategies tested in this project form part of a package of strategies now promoted under the *GrubPlan* banner. It is the combination of these strategies that provide the higher economic returns.

1.0 BACKGROUND

Canegrubs, as a group, are the most damaging of the insect pests of sugarcane in Australia. Greyback canegrub (*Dermolepida albohirtum*) is the most destructive of these, and recent and current outbreaks have extended from Mackay to Innisfail. Control of most canegrubs is with controlled-release chlorpyrifos (suSCon® Blue), but this product failed through enhanced microbial degradation in the Burdekin during the mid 1990s. In excess of 20,000 ha of Delta soils are subject to infestation by greyback canegrub in the Burdekin canegrowing area, and incidence of the pest has increased in this district. More recent outbreaks in the Innisfail-Tully area are the worst since 1984, and greyback canegrub has resurfaced as a pest in Mackay and Ingham after 15 years of low numbers. Several diseases have recently been identified from greyback canegrub, and these may be responsible for suppression of pest numbers in some years.

Childers canegrub (*Antitrogus parvulus*) is the major pest of sugarcane on the ferrosols (red volcanic clays and clay loams) and heavy alluvial sodsols of the Bundaberg and Isis areas of southern Queensland (Mungomery 1932; Anderson and Luckett 1960; Smith *et al.* 1963; Cherry and Allsopp 1991; Allsopp *et al.* 1993). The species has a 2-year life cycle, with two allochronic populations (development separated by 12 months) often existing in the same field (Allsopp *et al.* 1993; Logan *et al.* in press). Adults usually emerge in November-December (Allsopp and Logan 1999), eggs hatch by January and larvae are first instars until March-April. Second-instar larvae moult to third instars in late winter or spring and then feed through spring, summer and early autumn, pupating the following spring. Fully fed third-instar larvae move deep into the soil to pupate during their second winter; during their first winter, third-instar larvae remain close to the soil surface (Logan 1995; Logan *et al.* in press). Neither sex feeds as adults, and adult males are strongly attracted to light (Allsopp and Logan 1999). Females are poor fliers, emit pheromones to attract males (Allsopp 1993), mate on the ground near where they emerge, and usually oviposit in the soil close by (Logan 1997a).

Feeding by third-instar larvae in spring and summer destroys the roots of sugarcane, stunting cane growth and reducing yield (Allsopp *et al.* 1996). Heavy feeding may kill the sugarcane plant, although lightly damaged plants can partially recover after the main feeding period. Damage to sugarcane usually occurs in patches, with most eggs and first-instar larvae of one generation found on the edge of the damaged patch and 12-month-old third-instar larvae more evenly distributed across the patch (Logan 1997a). Larvae are traditionally controlled with two types of insecticides. A controlled-release formulation of chlorpyrifos (suSCon® Blue; CropCare Australasia) (Allsopp *et al.* 1996) is applied prophylactically at or soon after planting and can give up to three years' control. A more transient insecticide, cadusafos (Rugby® 100 G, FMC), can be applied in spring to infested ratoon crops and will control young third-instar larvae then present in the crop (Allsopp and McGill 1997). A formulation of imidacloprid (Vitelli *et al.* 2001) (Confidor® Guard, Bayer Australia) has recently been registered for use in a similar way.

Canegrubs caused losses estimated at $4.51m in the 1994 crop, and estimates for 1995 were higher due to further outbreaks of greyback canegrub. In addition, in excess of $5m is spent each year on insecticides, mostly suSCon Blue, to control canegrubs. Losses to growers through premature ploughout, and losses to millers through excessive soil entering the mill with damaged cane, have not been quantified but are probably

significant. Failure of control by the current insecticide through development of resistance in a key pest, through enhanced microbial degradation, or through loss of the insecticide by legislation would expose the industry to losses by canegrubs of up to 12% of the crop, worth $150m. Alternatives to the current insecticidal control are urgently needed, to reduce the risks inherent in almost total reliance on one product for canegrub control.

The Australian sugarcane industry has been working towards broadening and integrating control options for canegrubs. The general philosophy has focused on three strategies: improve the efficiency of current controls; develop substitute controls using biologicals and novel chemistry; and change farming practices so that canefields are less attractive to canegrubs (Robertson *et al.* 1995). Modelling (Logan *et al.* 2000) and experience with other canegrub species (Samson *et al.* 1998) indicate that different farming practices could impact significantly on numbers of Childers canegrubs.

2.0 OBJECTIVES

- Survey farm management practices in endemic canegrub areas, and determine factors that may predispose farms to outbreaks.
- Determine effects of cultural practices (tillage intensity, GCTB) on Childers and greyback canegrub population levels.
- Monitor effects of farming practices (tillage intensity, GCTB, insecticide use) on incidence of diseases in canegrubs.
- Evaluate economics of alternative farming systems for management of canegrubs.
- Demonstrate and promote cultural and natural control of canegrubs.

3.0 RESEARCH METHODOLOGY, RESULTS AND DISCUSSION

3.1 Childers canegrub

Our study tested the impact of faming practices on Childers canegrubs and associated entomopathogens using two approaches: a survey to relate numbers of larvae in infested fields to farming practices in those fields; and a field experiment to determine the impact of combinations of insecticide application, intensity of cultivation before planting, and retention of the previous crop's residues on numbers of larvae and associated entomopathogens in successive crops. The survey was run over five sampling years between 1996-2001 and the field trial over four years between 1997 and 2001. We also evaluated thee economic benefits derived from the combinations of treatments in the field trial.

3.1.1 Materials and methods

3.1.1.1 Field survey

We approached this survey knowing that there are two allochronic populations of *A. parvulus* and that there are differences (even on the same farm) between fields in planting times, crop age, cultivar and management practices. Hence, each field-year combination represents a unique set of conditions that could affect population numbers of *A. parvulus*. We sampled larvae of *A. parvulus* in 441 field-year combinations from 58 farms over each August-February from 1996-97 to 2000-01. All farms were in the general area in which *A. parvulus* could be expected on the basis of soil type (Cherry and Allsopp 1991). Third-instar larvae and most of the second-instar larvae of *A. parvulus* are in the upper 40 cm of soil between July and February (Allsopp *et al.* 1993; Logan 1999), so we counted the numbers of these stages in randomly distributed soil samples 30 cm by 30 cm and 40 cm deep centred over a sugarcane plant. We used the sequential sampling plan of Allsopp and Bull (1989) to sample fields with similar precisions (the standard error:mean ratio was about 0.1) by taking samples until we reached a cumulative total of 28 larvae. Larvae were hand sorted from each sample and identified using the raster pattern (Miller and Allsopp 2000).

A sample of soil was taken from each hole to form an aggregate sample for each field. We determined the fraction analysis of sand, silt and clay composition using the method of Piper (1942). Soil pH was determined by mixing 20 g of air-dried soil with 100 g of deionised water, stirring for 1 h, allowing the sediment to settle, and then taking a reading with an ion analyser.

Information on farming practices and field conditions in the current crop and during the previous break was gathered by interviewing the growers responsible for the care of the fields surveyed. We used 14 variables in further analysis, those in Table 1 and soil pH, previous application of transient insecticides for control of *A. parvulus* (no fields were sampled where these insecticides had been used that year), application of chlorpyrifos-based insecticides at planting for control of wireworms, and time of planting or harvest the previous year.

To link larval numbers and farming practices and field conditions, we either used the field data for continuous variables or first converted interview responses to numerical categories. Mean numbers of larvae in each field were categorised into four levels of infestation (not infested; low, < 3 larvae per sample; medium, 3-8 per sample; high >8 per sample), based on crop responses to larval numbers detailed by Allsopp *et al.* (1996) and Allsopp and McGill (1997). We then used logistic regression using both forward and backwards stepwise techniques (SAS 1988) to determine the significance of the field variables on the proportions of the four levels of larval infestation. Logistic regression provides a method of examining the relationships between the logistic transformation of the proportions and linear combinations of the predictor (independent) variables. To determine the differences between levels of each of the variables contributing significantly to the logistic regressions, we used the Kolmogorov-Smirnov test (Analytical Software 2000). This is generally preferable to the alternative chi-square test, because it exploits the information in the ordering of the categories. However, a limitation is that probability values should not be computed if there are few observations in any of the two levels being compared; therefore some categories had to be grouped for analysis and others could not be considered.

3.1.1.2 Field trial

We tested the effects of application of suSCon® Blue, pre-planting cultivation and trash management on numbers of larvae and crop yield in a split-split plot randomised-block trial with three replications at South Isis, near Childers in south-eastern Queensland. The main-plot factor was insecticide application, the first split was pre-planting cultivation and the second split (imposed after the harvest of the plant crop) was crop-residue management. The area was planted to cultivar Q138. The site was previously infested with *A. parvulus* and each main plot was 11 or 12 rows wide and 60 m long.

The previous ratoon crop was harvested in August 1996. Two pre-planting cultivation treatments were applied. In the intensively cultivated plots, the previous crop was destroyed by cultivation using two passes with offset discs, one ploughing and two rotary hoeings during December 1996. In minimum-tilled plots, the previous crop was sprayed with Roundup® herbicide in November 1996 and crop residues were burnt in December 1996 after the above-ground parts of the existing plants were dead. Just prior to planting in February 1997, a single ripper tine was used to cultivate a narrow strip of earth to a depth of about 30 cm to provide a bed for planting and the plots were rotary hoed to a depth of 15 cm to allow for a change in row locations in the new crop.

At planting, we applied suSCon® Blue at 315 g product per 100 m of row (the registered application rate; Allsopp *et al.* 1993) in half of the main plots and left the other half untreated. After the harvest of the plant crop and each of the ratoon crops, harvest residues were retained on the surface of one half of the subplots and raked and removed in the other half; the latter simulated residue removal through preharvest burning.

We harvested the plant crop in 1998, the first-ratoon crop in 1999, and the second-ratoon crop in 2000 using a commercial cane harvester and recorded crop yields with a weigh truck. Preharvesting samples were taken from each plot for determination of CCS (commercial cane sugar) levels using a small mill and standard formulae (Mackintosh 2000).

The trial was sampled for *A. parvulus* larvae 14 times from March 1997 to April 2001. This regime allowed us to track differences in larval number for the two allochronic populations (termed ‘A’ and ‘B’ populations). At planting, the ‘A’ population was third-instar larvae > 1 year old, whereas the ‘B’ population was first- and second-instar larvae derived from eggs laid a few months earlier. In each sub-sub plot we dug five holes each covering an area of 30 by 30 cm and to a depth of 40 cm, spaced at random. All undamaged larvae were collected and sent for monitoring of diseases at CSIRO in Canberra. They were held in a mixture of sterilized potting soil and peat moss, fed carrot, and examined for the presence of microorganisms (particularly the protozoan *Adelina* sp. and the fungus *Metarhizium anisopliae*) when they died (Lai-Fook *et al.* 1997).

Numbers of larvae at each sampling were transformed by $x^{0.44}$ (Allsopp and Bull 1989) and they and yield data were analysed by analysis of variance. The proportions of larvae from each treatment at each sampling that subsequently died with infections of *Adelina* sp.

and *M. anisopliae* were calculated, transformed with the inverse-sine transformation and analysed by analysis of variance. All means were compared with the protected least-significant-difference test.

3.1.1.3 Economic analysis

We used costs representative of various farming practices in the Isis district in mid 2002 to compare the economic return from each combination of treatments in the field trial.

3.1.2 Results

3.1.2.1 Field survey

We collected 9527 *A. parvulus* larvae from the 441 field-year combinations; 2618 were second instars and 6909 were third instars. Of the sites, 131 had no infestation, 102 had low infestations, 123 had medium infestations, and 85 had high infestations.

Logistic regression using both forward stepwise techniques gave the same model, with 10 variables contributing significantly (Table 1). Four factors, soil pH, previous application of transient insecticides for control of *A. parvulus*, and application of chlorpyrifos-based insecticides at planting for control of wireworms, and time of planting or harvest the previous year, did not contribute significantly ($P > 0.05$) to either model.

Table 1 - Factors contributing significantly to the logistic regression model for data from the field survey during 1996-2001.

Variable	Df	*P*
Year sampled	4	<0.0001
Percent sand in soil	1	<0.0001
Crop age	1	<0.0001
Cultivar	10	<0.0001
SuSCon® Blue use	1	0.0165
Crop-replacement strategy used	3	0.0318
How the previous crop was destroyed	6	0.0210
Number of times break was ripped	5	<0.0001
Number of times break was rotary hoed	4	0.0443
Irrigation type	2	0.0002

There were significant differences in the distribution of infestation levels among some of the years sampled, both consecutive years and alternate years (Figure 1). In the first four years, there is a higher proportion of medium and high infestations in 1997-98 and 1999-2000 than in 1996-97 and 1998-99 but this pattern of alternate medium-high years did not continue into 2000-01.

Sand content of the soil at the site was negatively correlated with numbers of larvae (Spearman's rank correlation -0.22, $P < 0.0001$) (Figure 2).

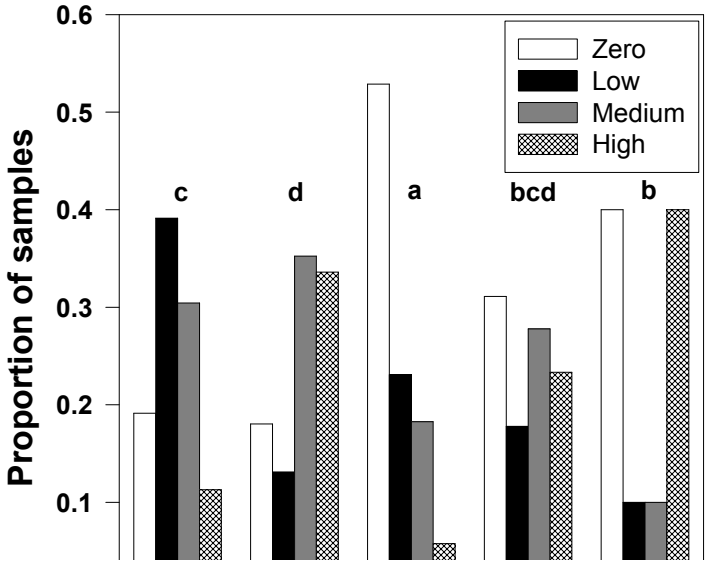

Figure 1 - Levels of infestation of *Antitrogus parvulus* in each of the 5 years of sampling. Distributions marked with the same letter are not significantly different at the 5% level.

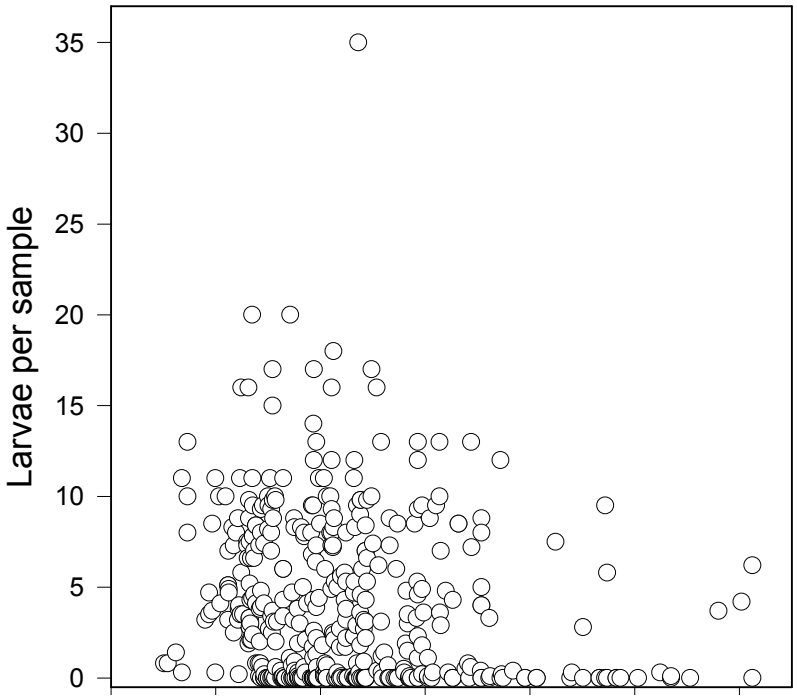

Figure 2 - Correlation between numbers of larvae of *Antitrogus parvulus* and sand content of the soil.

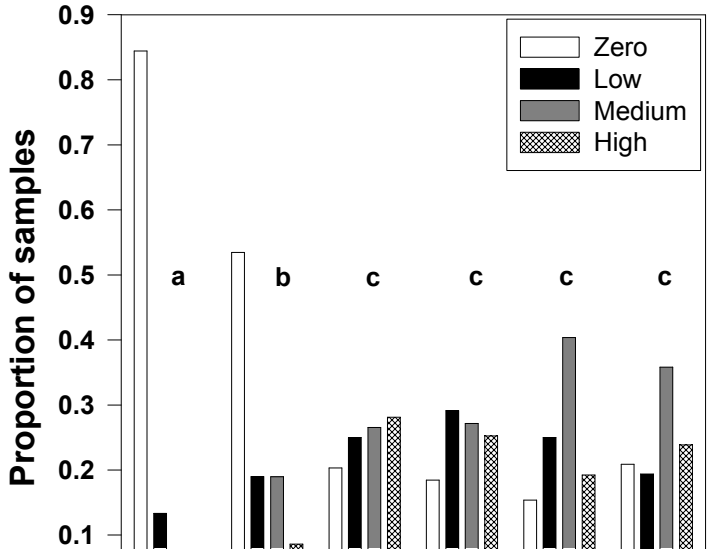

Figure 3 - Levels of infestation of *Antitrogus parvulus* in crops of different ages. Distributions marked with the same letter are not significantly different at the 5% level.

There were significant differences in the distribution of infestation levels among crops of different ages (Figure 3), with first-ratoon and, especially, plant crops having higher proportions of zero and low infestations than later ratoon crops.

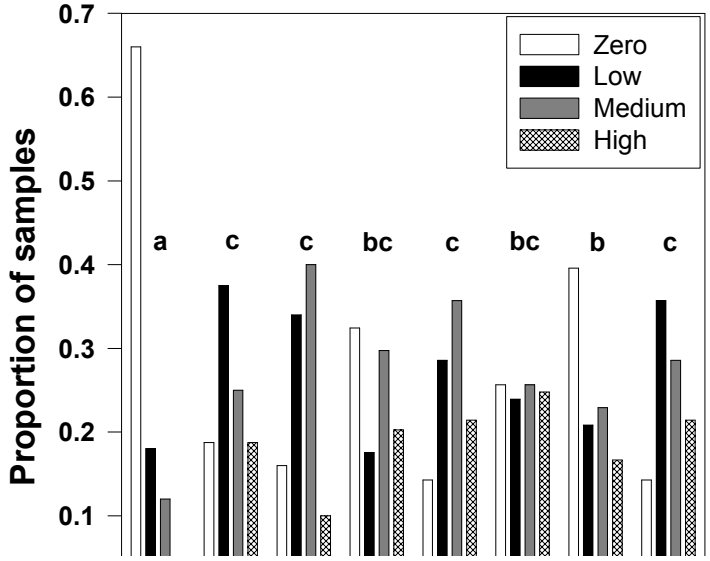

Figure 4 - Levels of infestation of *Antitrogus parvulus* in crops of different cultivars (three cultivars each had too few samples for analysis). Distributions marked with the same letter are not significantly different at the 5% level.

There was a significantly higher proportion of lower levels of infestation in crops of Q124 than in any other cultivar, and a significantly similar proportion in crops of Q155 than in crops of Q137, Q138, Q146 and CP51-21 (Figure 4).

Crops where suSCon® Blue had not been applied in the plant crop had a significantly (P = 0.034) different distribution of infestation levels (more zero and low levels) than crops where suSCon® Blue had been applied (Figure 5). However, 41% of the fields with high levels of infestation and that had suSCon® Blue applied were in the third ratoon or later when the insecticide would no longer be active.

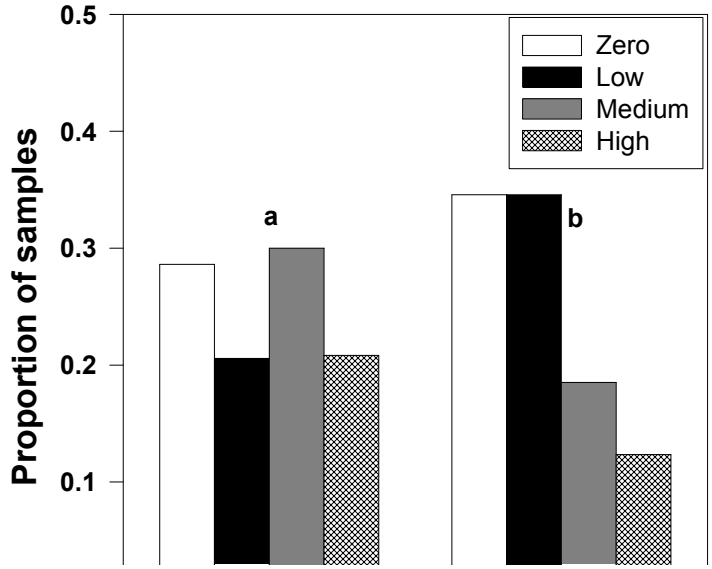

Figure 5 - Levels of infestation of *Antitrogus parvulus* in crops where suSCon® Blue was applied or not applied. Distributions marked with the same letter are not significantly different at the 5% level.

There were significant differences in subsequent infestation levels among fields that had different crop-replacement strategies (Figure 6). The trend was for highest infestation levels in fields that had previously been ploughed out and replanted immediately, with lower levels in fields that had been fallowed, independent of the weed control in the fallow. How the previous crop was destroyed affected subsequent population levels (Figure 7). Crops planted following a herbicide spray-out had significantly lower populations than those following mechanical destruction of the previous crop. Of the single mechanical treatments, populations were generally higher in the order plough-out, rotary hoeing or power harrowing, discing. Combinations of at least two of these methods resulted in the lowest subsequent populations (there were too few samples in any of the separate combinations to allow analysis). The frequency of ripping (Figure 8) or rotary hoeing (Figure 9) fields during the previous break was also related to subsequent population levels. In general, the more frequent the action, the lower the subsequent populations.

The type of irrigation was related to population levels (Figure 10), with fewer larvae in fields with drip irrigation than in those with overhead irrigation, and with irrigated fields having fewer larvae than rain-fed fields. There were too few fields using furrow irrigation (4) to allow comparison with other methods.

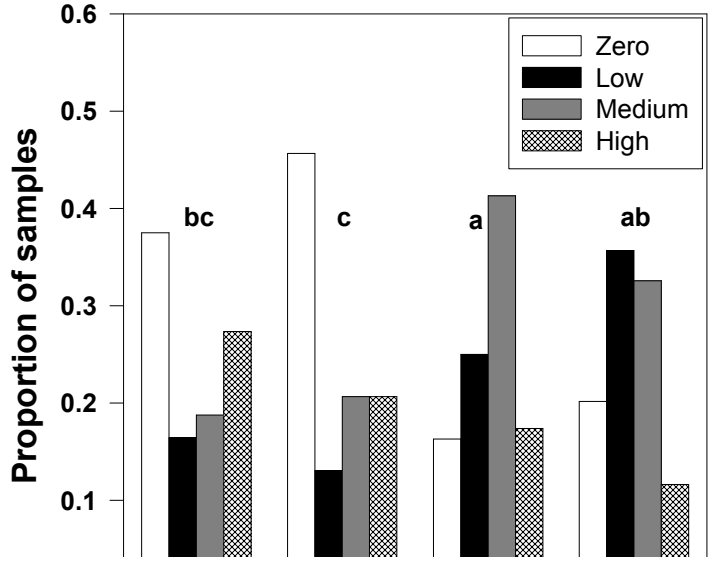

Figure 6 - Levels of infestation of *Antitrogus parvulus* in crops following replacement strategies of fallowing with good weed control, fallowing with poor weed control, ploughout and immediate replant, and a rotation with a cover crop. Distributions marked with the same letter are not significantly different at the 5% level.

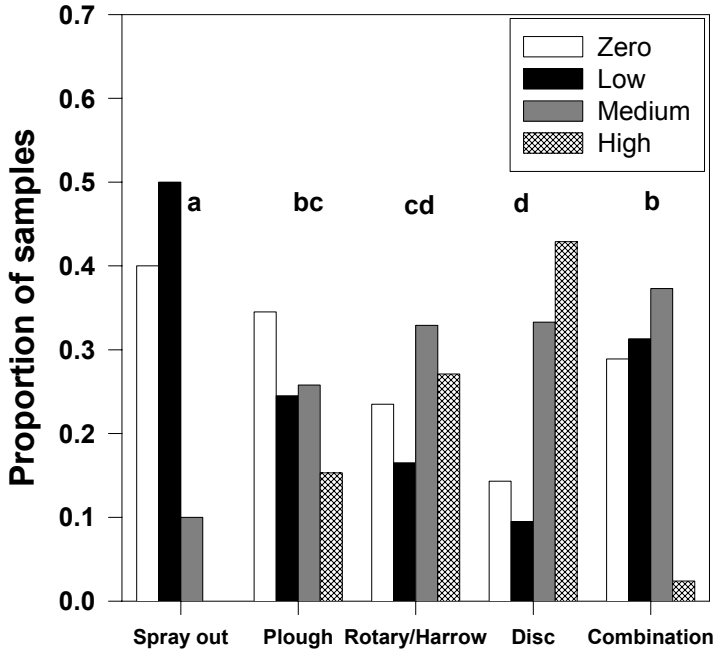

Figure 7 - Levels of infestation of *Antitrogus parvulus* in crops following destruction of the previous crop using herbicides (Spray out), ploughing (Plough), rotary hoeing or power harrowing (Rotary/Harrow), discing (Disc), or a combination of mechanical methods (Combination). Distributions marked with the same letter are not significantly different at the 5% level.

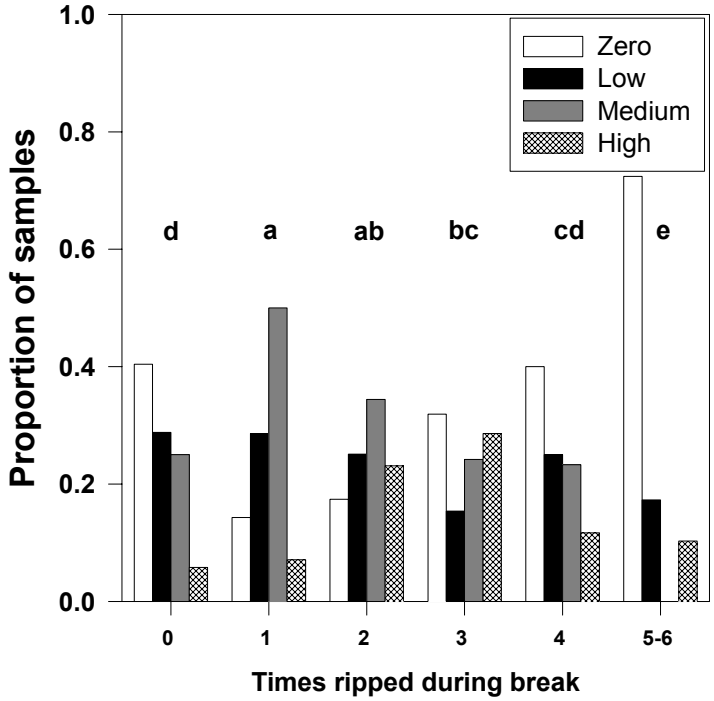

Figure 8 - Levels of infestation of *Antitrogus parvulus* in crops following different intensities of ripping during the break between cane crops. Distributions marked with the same letter are not significantly different at the 5% level.

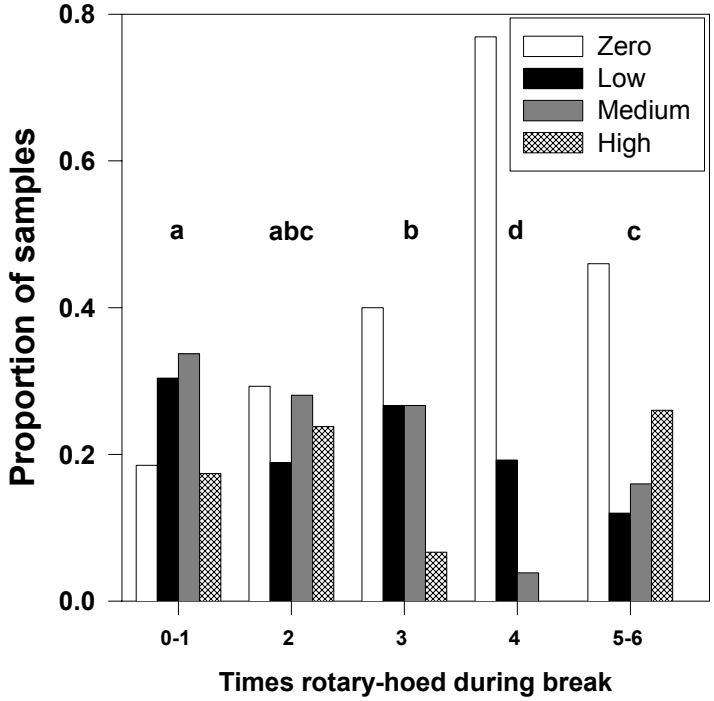

Figure 9 - Levels of infestation of *Antitrogus parvulus* in crops following different intensities of rotary hoeing during the break between cane crops. Distributions marked with the same letter are not significantly different at the 5% level.

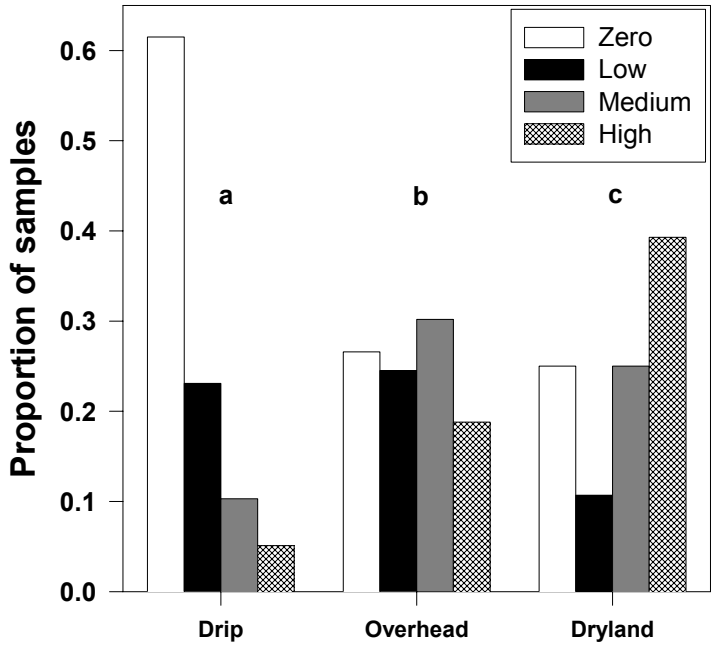

Figure 10 - Levels of infestation of *Antitrogus parvulus* in crops under different irrigation systems. Distributions marked with the same letter are not significantly different at the 5% level.

3.1.2.2 Field trial

Table 2 shows the mean larval numbers for each of the two populations under each of the insecticide-cultivation-residue combinations over the four years of the trial. Overall, numbers of larvae increased until November-February of each year and then decreased as the third-instar larvae aged.

Following planting, there was an immediate effect of suSCon® Blue on the older third-instar larvae of the A population. The insecticide was still active on A-population third-instar larvae in November 1998 in the first ratoon and B-population third-instar larvae in November 1999 to April 2000 in the second ratoon. There was no significant effect of the insecticide on A or B populations in the third ratoon.

For the two months following planting, there were significantly fewer A-population third-instar larvae in the intensive-cultivation plots than in the minimum-cultivation plots. This effect was similar in the same population in the first ratoon in February 1999. In the B population, numbers of third-instar larvae were significantly lower in the minimum-cultivation plots in November 1997 and November 1999, but were significantly higher in February 2001.

The only significant effect of residue removal/ retention was on the A population in February 1999 (early in the first ratoon), when numbers of third-instar larvae were lower in plots where the residues were retained.

Table 2 - Mean (SE) numbers of larvae of *A. parvulus* at each sampling over the plant, first-ratoon, second-ratoon and third-ratoon crops

Management factor	Date sampled													
	Plant crop					First ratoon			Second ratoon			Third ratoon		
	Mar 97	Apr 97	Nov 97	Feb 98	Apr 98	Nov 98	Feb 99	Apr 99	Nov 99	Feb 00	Apr 00	Nov 00	Feb 01	Apr 01
'A' population	Third-instar larvae		Pupae	Second- and young third-instar larvae		Third-instar larvae			Pupae	Second- and young third-instar larvae		Third-instar larvae		
suSCon not applied	16.3 (3.8)	6.7 (2.9)	-	7.2 (1.5)	7.3 (2.6)	8.4 (1.4)	2.5 (0.6)	0.0	-	9.6 (1.8)	8.0 (1.0)	9.1 (1.7)	12.8 (3.3)	0.6 (0.3)
suSCon applied	8.0 (1.3)	2.5 (1.0)	-	4.5 (1.3)	7.8 (2.9)	2.2 (0.6)	1.7 (0.4)	0.0	-	6.6 (1.4)	6.5 (1.0)	7.6 (1.3)	13.4 (2.8)	1.7 (0.5)
P	**0.033**	**0.0099**	-	0.35	0.93	**0.032**	0.51	-	-	0.21	0.43	0.18	0.86	0.27
Intensive cultivation	7.8 (1.3)	0.5 (0.3)	-	6.5 (0.9)	7.3 (2.2)	4.8 (1.4)	1.7 (0.6)	0.0	-	6.8 (1.2)	7.8 (0.9)	7.3 (0.9)	10.7 (2.8)	1.4 (0.5)
Minimum cultivation	16.5 (3.7)	8.7 (2.1)	-	5.2 (1.9)	7.8 (3.3)	5.8 (1.5)	2.5 (0.4)	0.0	-	9.4 (2.0)	6.8 (1.0)	9.3 (1.9)	15.6 (3.2)	0.8 (0.3)
P	**0.022**	**0.0086**	-	0.15	0.84	0.32	**0.024**	-	-	0.46	0.21	0.52	0.052	0.38
Residues removed	-	-	-	-	-	6.0 (1.7)	2.5 (0.5)	0.0	-	7.4 (1.0)	6.4 (0.8)	6.3 (1.1)	10.8 (2.6)	1.2 (0.4)
Residues retained	-	-	-	-	-	4.6 (1.0)	1.7 (0.5)	0.0	-	8.8 (2.1)	8.1 (1.1)	10.3 (1.6)	15.5 (3.3)	1.1 (0.5)
P	-	-	-	-	-	0.74	**0.050**	-	-	0.93	0.39	0.098	0.19	0.90
P - suSCon*cultivation	0.42	0.22	-	**0.039**	0.95	0.52	0.22	-	-	0.35	0.18	0.87	**0.049**	0.67
P - suSCon*residues	-	-	-	-	-	0.095	0.48	-	-	0.26	0.38	0.46	0.70	0.99
P - cultivation*residues	-	-	-	-	-	0.85	**0.015**	-	-	0.91	0.90	0.11	0.27	047

'B' population	Second- and young third-instar larvae		Third-instar larvae			Pupae	Second- and young third-instar larvae		Third-instar larvae			Pupae	Second- and young third-instar larvae	
suSCon not applied	0.0	2.3 (0.9)	3.5 (1.4)	1.0 (1.0)	0.2 (0.2)	-	3.8 (1.0)	15.7 (3.6)	31.0 (6.0)	18.7 (3.5)	6.9 (1.7)	-	17.4 (2.9)	24.3 (2.2)
suSCon applied	0.0	1.8 (0.7)	1.8 (0.9)	0.2 (0.2)	0.2 (0.2)	-	2.2 (0.5)	6.0 (1.4)	9.8 (3.0)	8.4 (1.7)	1.5 (0.5)	-	15.8 (1.5)	18.6 (2.2)
P	-	0.46	0.30	0.73	1.00	-	**0.041**	0.23	**0.020**	**0.043**	**0.0041**	-	0.92	0.41
Intensive cultivation	0.0	3.2 (0.8)	4.2 (1.2)	1.2 (1.0)	0.3 (0.2)	-	3.6 (0.9)	14.7 (3.8)	29.4 (6.5)	17.3 (3.8)	5.0 (1.5)	-	15.4 (2.9)	20.9 (2.5)
Minimum cultivation	0.0	1.0 (0.4)	1.2 (0.8)	0.0	0.0	-	2.4 (0.6)	7.0 (1.4)	11.4 (3.1)	9.8 (1.7)	3.4 (1.5)	-	17.8 (1.5)	22.0 (2.3)
P	-	0.21	**0.024**	0.25	0.23	-	0.18	0.088	**0.020**	0.32	0.16	-	**0.021**	0.75
Residues removed	-	-	-	-	-	-	3.3 (1.0)	10.3 (3.5)	21.8 (6.4)	12.3 (3.5)	3.3 (1.2)	-	17.9 (2.6)	22.2 (2.7)
Residues retained	-	-	-	-	-	-	2.8 (0.6)	11.3 (2.5)	19.0 (4.9)	14.8 (2.7)	5.2 (1.6)	-	15.3 (2.0)	20.8 (2.0)
P	-	-	-	-	-	-	0.91	0.49	0.67	0.25	0.41	-	0.45	0.74
P - suSCon*cultivation	-	0.35	0.24	0.67	1.00	-	**0.021**	0.56	0.50	0.33	1.00	-	0.18	0.92
P - suSCon*residues	-	-	-	-	-	-	0.72	0.74	0.31	0.37	0.86	-	0.24	0.19
P - cultivation*residues	-	-	-	-	-	-	0.066	0.47	0.48	0.93	0.97	-	0.18	0.51

Table 3 - Mean (SE) cane and sugar yields and sugar contents (CCS) of the plant, first-ratoon and second-ratoon crops

Management factor	Cane yield (t/ha)			CCS			Sugar yield (t/ha)		
	Plant crop	First ratoon	Second ratoon	Plant crop	First ratoon	Second ratoon	Plant crop	First ratoon	Second ratoon
suSCon not applied	120.1 (7.5)	117.6 (4.6)	73.0 (5.8)	15.2 (0.1)	15.0 (0.3)	14.9 (0.3)	18.2 (1.1)	17.7 (0.8)	10.7 (0.7)
suSCon applied	142.4 (8.3)	134.6 (4.2)	94.8 (3.0)	15.3 (0.2)	15.0 (0.1)	14.7 (0.4)	21.7 (1.2)	20.2 (0.7)	14.0 (0.6)
P	0.16	**0.023**	0.068	0.70	0.94	0.87	0.18	**0.0006**	0.097
Intensive cultivation	136.9 (6.7)	124.0 (5.2)	81.5 (6.4)	15.4 (0.1)	15.3 (0.2)	14.9 (0.3)	21.1 (1.0)	18.9 (0.7)	12.1 (1.0)
Minimum cultivation	125.6 (10.8)	128.2 (4.9)	86.3 (4.6)	15.0 (0.1)	14.8 (0.2)	14.7 (0.4)	18.8 (1.6)	19.0 (0.9)	12.6 (0.7)
P	0.33	0.23	0.49	0.080	0.074	0.61	0.19	0.70	0.59
Residues removed	-	121.2 (6.0)	75.8 (6.7)	-	14.9 (0.2)	15.3 (0.3)	-	18.0 (0.9)	11.6 (1.1)
Residues retained	-	130.9 (3.4)	92.0 (2.7)	-	15.2 (0.2)	14.3 (0.3)	-	19.9 (0.5)	13.1 (0.4)
P	-	0.24	**0.0091**	-	0.32	**0.0073**	-	0.18	0.082
P - suSCon*cultivation	0.55	0.53	0.97	0.17	0.16	0.91	0.73	0.76	0.84
P - suSCon*residues	-	0.18	0.084	-	0.48	0.32	-	0.17	**0.034**
P - cultivation*residues	-	0.58	0.96	-	0.72	0.92	-	0.56	0.96

Interactions between suSCon® Blue application and cultivation treatments were significant at three samplings. In the plant crop (February 1998), numbers of A-population third-instar larvae were significantly different only in the suSCon-treated plots – lower under minimum cultivation than conventional cultivation. In the first ratoon (February 1999), numbers of B-population third-instar larvae were also lower following minimum cultivation, but only in the plots without suSCon® Blue applied. In the third ratoon (February 2001), numbers of third-instar larvae of the A population were significantly lower in the intensive-cultivation plots than in the minimum-cultivation plots, but only in plots without suSCon® Blue applied.

An interaction between cultivation type and residue removal/retention impacted only on the A population in the February 1999 sampling. Where residues were retained, numbers of third-instar larvae were lower in the intensive-cultivation plots than in the minimum-cultivation plots.

Table 3 shows cane and sugar yields and CCS content of cane from the harvests of the plant, first-ratoon and second-ratoon crops. The most significant influence on cane and sugar yield was the application of suSCon® Blue; application increased the total yields of cane by 60.1 t/ha and of sugar by 9.3 t/ha over the three crops. Retention of crop residues increased the total yields of cane by 25.9 t/ha and of sugar by 3.4 t/ha over the first- and second-ratoon crops. The intensity of the tillage before planting did not significantly increase cane or sugar yields. The only significant effect on CCS was 1.0 units higher under the residues-removed treatment in the second-ratoon crop. The only significant interaction was a suSCon*residues effect on sugar yields in the second-ratoon crop, where yields in plots without suSCon® Blue applied were significantly higher when residues were retained than when they were removed.

In larvae taken from the plant crop (March-April 1997 and February-April 1998), the only factor significantly affecting the incidence of *Adelina* infection was the type of preplanting cultivation ($P = 0.048$); observed rates of infection were 24.2 ± 9.5% in intensive-cultivation plots and 14.9 ± 11.8% in minimum-cultivation plots. In the first-to-third ratoon crops, there was a significant suSCon*residue interaction ($P = 0.014$) and a significant effect of the time at which samples were taken ($P = 0.0080$). In plots treated with suSCon® Blue, there was a higher level of infection where residues were retained (23.7 ± 3.6%) than where residues were removed (15.9 ± 3.6%), and, in plots where residues were retained, there was a higher level of infection where suSCon® Blue had been applied (23.7 ± 3.6%) than where suSCon® Blue had not been applied (16.3 ± 3.4%). Over each spring-autumn sampling, there was a trend (sometimes with significant differences in infection levels) to higher infection levels in the April sampling (Figure 11) and higher levels in the older ratoon crops.

In the plant crop there was no significant effect ($P > 0.24$) on levels of *Metarhizium* infection of suSCon® Blue or cultivation type in either of the sampling times – mean infection level 14.2 ± 5.3%. In the first-to-third ratoon crops, there was a significant suSCon*cultivation*residue interaction ($P = 0.020$) and a significant effect of the time samples were taken ($P = 0.034$). Where suSCon® Blue had been applied, there was no significant difference in infection levels among combinations of cultivation type and residue management, and generally lower infection levels than where no suSCon® Blue had been applied (Table 4). Where the insecticide was not applied, infection levels were significantly lower in plots with minimum cultivation and residues removed than in plots with minimum cultivation and residues retained or plots with intensive cultivation and

residues removed (Table 4). Over each spring-autumn sampling, there was a trend (sometimes with significant differences in infection levels) to lower infection levels in February than in November (Figure 11).

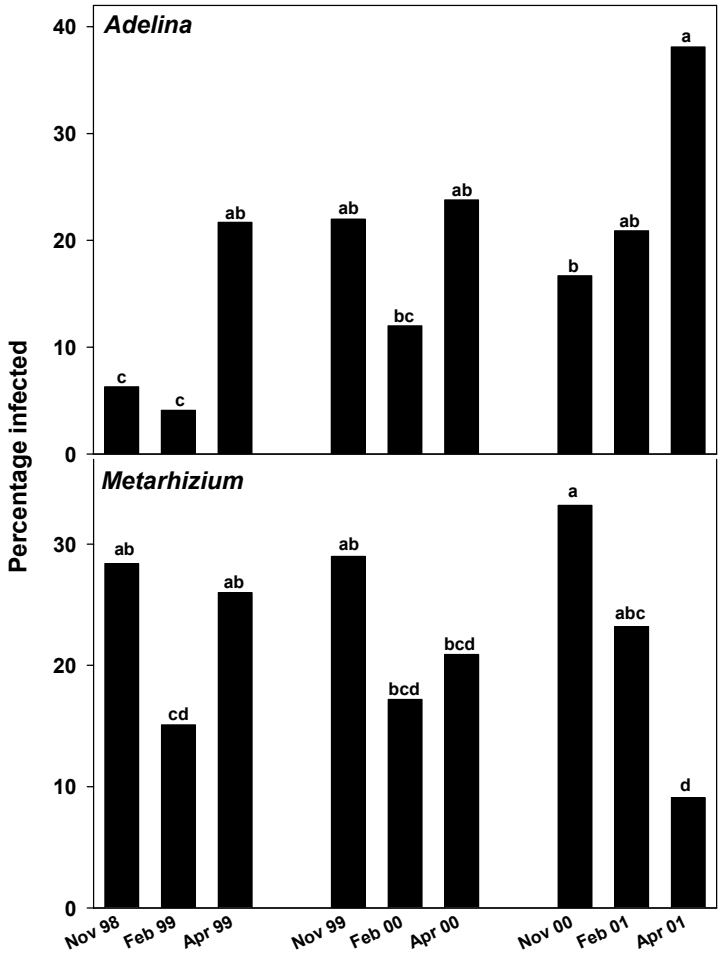

Figure 11 - Mean levels of infection by *Adelina* sp. and *Metarhizium anisopliae* of - larvae of *A. parvulus* collected from the field trial at different times. Within each pathogen type, levels marked with the same letter are not significantly different at the 5% level.

Table 4 - Levels of infection of *A. parvulus* by *Metarhizium anisopliae* in plots with combinations of insecticide application, cultivation type and residue management.

suSCon® Blue	Cultivation	Residues	Mean % infection (SE)*
Not applied	Intensive	Removed	33.7 (5.9) a
		Retained	27.2 (4.3) ab
	Minimum	Removed	15.4 (3.5) bc
		Retained	32.7 (3.2) a
Applied	Intensive	Removed	13.5 (4.0) c
		Retained	16.6 (4.5) bc
	Minimum	Removed	26.2 (5.3) abc
		Retained	14.3 (4.1) c

*Means followed by the same letter are not significantly different at the 5% level – analysis on inverse-sine-transformed data.

3.1.2.3 Economic analysis

The input costs associated with the treatments compared in the Childers-grub farming-system trial are given in Appendix 1 and summarised in Table 5, together with the total sugar yield for each treatment in the trial. The data show the expected profit from each treatment (given a value of sugar to the grower of $150 per tonne) over the plant, first-ratoon and second-ratoon crops. They clearly show the economic benefit to be derived from application of suSCon Blue, minimum tillage and trash retention. In addition, application of suSCon® Blue might (if grub damage was severe) result in at least an extra ratoon crop.

Table 5 - Input costs, value of yield and profit associated with each combination of insecticide application, preplanting tillage and residue management in the field trial.

Combination Insecticide/tillage/residue management	Total input cost ($/ha)	Total sugar yield (t/ha)	Value of yield ($/ha) at $150 per tonne of sugar to the grower	Profit ($/ha)
suSCon, conventional, burnt	7,035	57.3	8,595	1,560
suSCon, conventional, green	6,235	55.7	8,355	2,120
suSCon, minimum, burnt	6,070	55.0	8,250	2,180
suSCon, minimum, green	5,720	55.6	8,340	2,620
No suSCon, conventional, burnt	6,765	44.3	6,645	-120
No suSCon, conventional, green	5,965	51.0	7,650	1,685
No suSCon, minimum, burnt	5,800	41.8	6,270	470
No suSCon, minimum, green	5,450	49.3	7,395	1,945

3.1.3 Discussion

In nature, insect species exist and evolve as components of communities of plants and animals within particular habitats (Clark *et al.* 1974). All species have a limited distribution range, and, characteristically, insect numbers fluctuate in both time and space. In studying these fluctuations, Solomon (1949) emphasised the inseparable existence of a subject population and its effective environment, including both biotic and abiotic agencies. It is the understanding of those interactions that is the key to effective management of pest populations to reduce their economic impact. Our survey and field trial show that some abiotic, human-imposed biotic and natural biotic factors impact on the sizes of populations of *A. parvulus* in sugarcane fields, whilst other factor have negligible impacts. This is similar to impacts on greyback canegrubs, *Dermolepida albohirtum* (Waterhouse), the most important species in northern Queensland (Robertson and Walker 1996; Ward and Cook 1996; Ward 1998; Robertson *et al.* 1999; Ward and Robertson 1999; Horsfield *et al.* 2002). While the factors that are of greatest importance depend on the biology of the target species, manipulation of some of them should reduce population sizes.

The main factor influencing distribution of *A. parvulus* appears to be soil type. Over a wide range of soil types, Cherry and Allsopp (1991) found a negative correlation between abundance of larvae of *A. parvulus* and the sand content of the soil, and a positive correlation with clay and silt contents. They did not find the species in soil with > 54% sand. Our survey results show a similar correlation, even though we sampled only those fields expected to harbour *A. parvulus* and found it in soils up to 61.2% sand. The

mechanism behind this preference is unknown, although the higher correlations with sand content that both Cherry and Allsopp and we found suggest that it is related to the coarser textural components rather than the finer clay and silt components. Soil texture determines the water-holding capacity of the soil and, as Logan (1997b) found, *A. parvulus* adult females prefer to lay eggs in soil at or near field capacity. Soil texture may also influence larval survival and movement in soil insects (Gaylor and Frankie 1979; Gustin and Schumacher 1989). However, from a pest-management perspective, the issue is academic, as soil texture can not be modified appreciably.

Our survey results indicate that the sizes of populations of larvae of *A. parvulus* fluctuate considerably from year to year, with some evidence of higher populations of third-instar larvae in years where the summer starts with an odd number (eg 1997-98) than in alternate years. Given the species' 2-year lifecycle, this suggests that one of the two allochronic populations tends to be larger than the other. This is consistent with anecdotal reports of 'high-beetle' years alternating with 'low-beetle' years and trapping data where numbers of *A. parvulus* beetles in light traps were higher (and by inference numbers of third-instar larvae were lower) in summers commencing in an even-numbered year than in alternate years (Allsopp and Logan 1999). A similar trend is apparent in our field trial, where, in plots where insecticide was not applied, populations of third-instar larvae were higher in November 1999 than in November 1998 or November 2000. This contrasts with cycles of outbreaks of 2-3 years' duration each 10-13 years in greyback canegrub, a species that has a 1-year lifecycle (Robertson *et al.* 1997).

In our survey, infestation levels increased with crop age to the second ratoon, and similar increases were apparent in each population into the third ratoon of the field trial. As the modelling of Logan *et al.* (2000) indicates, this increase could be expected to continue into older crops, given the relative stability of the soil environment and the low dispersion of adult females and consequent oviposition near the emergence point (Logan 1997a). It contrasts with greyback canegrub, where Ward (1998) could show no effect of crop age on numbers of larvae. Adult females of greyback canegrub are strongly attracted to taller crops for oviposition (Ward 1998; Horsfield *et al.* 2002), so damaging populations of larvae appear in different fields each year. The stabilisation of infestation levels that we found reflects a tendency for growers to remove heavily infested and poorly yielding crops. It might also reflect an increase in entomopathogen levels in the later ratoon crops, as appeared to occur with *Adelina* in our field trial.

Application of suSCon® Blue in our field trial significantly reduced numbers of larvae until and including the second-ratoon crop, and significantly increased yields over that period. The increase in yield (about 9 t/ha) would more than pay for the cost of the insecticide (A$280 per hectare). This is consistent with the demonstrated efficacy of the product to *A. parvulus* (Allsopp *et al.* 1996), but appears to contradict the findings in our survey of higher infestation levels where the insecticide was applied. Four factors could contribute to this apparent contradiction. Growers may use suSCon® Blue more often in fields that are more prone to damage, and, hence, higher numbers of larvae. The insecticide does not eliminate larvae, but typically reduces numbers by 70-80% (Allsopp *et al.* 1996), leaving, in some cases, significant populations in treated fields. Secondly, 62% of fields that we sampled were older than the second ratoon, where suSCon® Blue would not be active. Thirdly, the long-term effect of suSCon® Blue depends on planting and application timing relative to the sizes of the two allochronic populations. For crops planted in autumn, suSCon® Blue kills subsequent third-instar larvae of two generations of one population and of one generation of the other population (Logan *et al.* 2000); we

also found that the insecticide could also kill the older third-instar larvae present at planting. If the two populations are of different sizes, the long-term effects will be quite different. Fourthly, our field trial indicates that levels of infection of larvae by *Adelina* and *Metarhizium* may differ between treated and untreated areas. In particular, there were generally lower levels of *Metarhizium* infection where suSCon® Blue was applied than where the insecticide was not applied; this could contribute to population 'resurgence' of healthy grubs once the insecticide was no longer active.

Our survey results also indicate lower population levels in fields growing cultivars Q124 and Q155. Sugarcane clones vary in their resistance to canegrubs (Allsopp and Cox 2002). Tolerance is an important component of this resistance, but would not affect population levels. Either antibiosis or antixenosis (nonpreference) can result in different population levels, but the latter is unlikely given the restricted dispersal of adult females of *A. parvulus* and consequent localised oviposition (Logan 1997a). The former is also unlikely, as, in pot trials, Allsopp and Cox (2002) showed no significant antibiosis effect of Q124 or Q155 on picticollis canegrub, *Lepidiota picticollis* Lea, relative to the other cultivars in our survey. Likewise, in a field trial with southern one-year canegrub, *A. consanguineus* (Blackburn), there were no significant antibiosis/antixenosis effects among a range of cultivars (Allsopp and Cox 2002), and Ward (1998) found no effect of cultivar on the distribution of greyback canegrubs.

We found significant differences in population levels following crop-replacement strategies differing in length, and intensity and frequency of operations. Lower populations follow in fields with a long break between sugarcane crops, more intense mechanical destruction of the previous crop, and more frequent ripping or rotary hoeing during the break. These treatments presumably reduce the numbers of larvae carried over from the previous crop cycle, and, because the adult females are poor dispersers, immigration into subsequent crops is low. Mungomery (1932) claimed that *A. parvulus* numbers were reduced by 50% in fields that had been rotary hoed, and ploughing significantly reduces the numbers of noxia canegrubs, *Lepidiota noxia* Britton (Logan 1996). These effects are also consistent with the predictions from population modelling by Logan *et al.* (2000) and the initial effects on the A population in our field trial. The apparent high impact of a herbicide spray-out appears to be anomalous, but this may act by starving the larvae and this treatment is unlikely to be coupled with a plough-out and immediate replant strategy. Logan and Kettle (2002) showed that first-instar larvae of *D. albohirtum* required living roots to develop to later instars, and access to living roots is also necessary for development of other scarab larvae (Milne 1956; Kuniata and Young 1992; Adsule and Patil 1994). Disease data from our field trial show that better conservation of *Adelina* or *Metarhizium* under a herbicide spray-out is unlikely to contribute to the effect, unlike in north Queensland where survival of *Adelina* and subsequent infection levels of greyback canegrubs are thought to be higher under minimum tillage (Robertson *et al.* 1999).

Why there would be fewer larvae in fields with drip irrigation than with overhead irrigation is perhaps related to the soil disturbance necessary to install subsurface drip irrigation (this would have an effect similar to intensive tillage), and/or the more likely longer break between subsequent cane crops necessary to install such irrigation. Fields with drip irrigation may also have younger crops, given that the technique has been adopted in the Bundaberg-Isis area widely only recently. The higher populations in rain-fed fields than in irrigated fields are difficult to explain, but may reflect the higher management inputs, including insecticides, into the higher-yielding irrigated fields.

Our survey showed no significant effects of planting or harvesting times on numbers of larvae. Adults of greyback canegrub are attracted to taller crops for oviposition (Ward 1998; Horsfield *et al.* 2002), making those crops harvested early or planted early in one year more prone to damage in the next year (Ward and Cook 1996). This has been exploited in the management of that species by the use of trap crops (Horsfield *et al.* 2002; Hunt *et al.* 2002). Adult females of *A. parvulus* are much more sedentary, most ovipositing close to where they emerge and creating patches of damage that increase in area over time (Logan 1997a); the beetles appear to show no preference for tall crops.

In our survey there was no significant effect on larval numbers of crop-residue management strategies (green-cane trash-blanket (retention of crop residues as a mulch) or preharvest burning), and, in the field trial, residue management had a significant effect only once, on the A population in February 1999, through an interaction with previous cultivation type. In north Queensland, fields that have residues retained and are minimum tilled have fewer late third-instar greyback canegrubs (Robertson and Walker 1996), possibly because of higher levels of infection by *Adelina* and *Metarhizium* (Robertson *et al.* 1999). We surveyed fields when third-instar larvae were early to mid development, perhaps too early to show an impact of the significant mortality from *Adelina* that we found in larvae collected later (April) from the field trial.

We also did not detect any effect of soil pH on infestation levels. Soil pH is not directly related to incidence of *A. parvulus* (Cherry and Allsopp 1991), but alkaline soils (naturally or induced by application of limestone) more rapidly degrade chlorpyrifos (the active ingredient of suSCon® Blue) (Chandler 1998; Robertson *et al.* 1998) and so might be expected to harbour higher populations of *A. parvulus*.

In each year of the field trial, there was a dramatic reduction in the number of third-instar larvae from November-February to April, similar to the decline seen in other populations of *A. parvulus* by Logan (1998). He thought that, as the decline coincided with late spring and summer, high temperatures may directly stress larvae or increase the development rate of entomopathogens. Dall *et al.* (1995) and Lai-Fook *et al.* (1997) found similar declines in numbers of greyback canegrub, and attributed these to increasing mortality caused by entomopathogens, especially increasing mortality through *Adelina* infections. The trend in our field trial to higher infection levels of *Adelina* in the April sampling and the more even infection by *Metarhizium* across the November-April period are consistent with what happens with greyback canegrub, and suggestive of a direct effect of entomopathogens on third-instar larvae. Ward and Robertson (1999) postulated a density-dependent mortality acting on neonate larvae to stabilise numbers of greyback canegrubs, but Logan and Kettle (2002) could provide no confirmation of this. Our data do not address first-instar *A. parvulus*, but there is no evidence in our field trial of significant mortality on second- and early third-instars during each February-November period.

3.1.4 Conclusions

Overall, our study indicates that farming practices can have significant impacts on populations of Childers canegrubs. Higher infestations are more likely in summers starting in odd-numbered years in later ratoons on low-sand soils that have been established with a plough-out/replant strategy (very short break, minimum tillage disturbance, no drip irrigation installed) without suSCon® Blue applied. Some of these infestations could be reduced through the build up of entomopathogens late in each generation and in later ratoons, but the crops could be so severely damaged in earlier

ratoons that they are ploughed out before significant populations of entomopathogens can develop. Populations of larvae can be reduced and the build-up of damaging populations delayed by use of suSCon® Blue, and this can be cost effective. Longer breaks between successive sugarcane crops, coupled with intensive tillage within that break, will reduce populations carried over from the previous crop cycle (sometimes to extinction; Logan *et al.* 2000) and delay build-up of damaging populations. However, the long-term deleterious effects of intensive soil tillage on other soil biota and on increased soil compaction (Willcox *et al.* 2001; Garside *et al.* 2001) and the cost of such tillage, may negate the economic benefits gained through reduction in numbers of canegrubs. The 'softer' options of destroying the previous crop with herbicides before a long break (one year) with minimum tillage should disrupt the lifecycle of *A. parvulus* to a similar extent, especially if targeted against the larger of the two allochronic populations. Potentially damaging populations that develop can be detected by monitoring in late winter and spring and reduced by application of Rugby® 100 G (Allsopp and McGill 1997) or Confidor® Guard (Vitelli *et al.* 2001). These options will also be cheaper and may better preserve populations of entomopathogens. Our challenge now is to integrate these findings in a package, similar to GrubPlan (for management of greyback canegrub) (Hunt *et al.* 2002) that will appeal to and be implemented by growers.

3.2 Greyback canegrub

Our study used three approaches to determine the impact of farming practices and entomopathogens in greyback canegrub in both northern Queensland (where little previous work had been conducted), and in the Burdekin area (where there had previously been considerable focus on this type of study). We tested the impact of faming practices on greyback canegrubs and associated entomopathogens in a field trial at Tully BSES station and in short-term trials in the Burdekin region. We also surveyed infested fields in northern Queensland to determine factors associated with entomopathogens in commercial fields. The general survey technique used with Childers canegrubs was not used as it had been done in previous projects, eg Andrew Ward's PhD thesis (Ward 1988).

3.2.1 Tully trial

This trial evaluated different combinations of insecticide application trash management and cultivation on the occurrence of greyback canegrubs and entomopathogens.

3.2.1.1 Materials and methods

The trial was conducted in block 26A at BSES Tully, the same block as used by Robertson in BSS120. We compared greyback canegrub populations under:

1. Intensive cultivation + Burnt trash + suSCon Blue.
2. Intensive cultivation + Burnt trash.
3. Minimum cultivation +Burnt trash + suSCon Blue.
4. Minimum cultivation +Burnt trash.
5. Intensive cultivation + GCTB + suSCon Blue.
6. Intensive cultivation + GCTB.

Table 6 - Numbers of greyback larvae at each sampling of the Tully trial.

Treatment	Plant crop		First ratoon		Second ratoon		Third ratoon	
	First sample	Second sample	First sample	Second sample	First sample	Second sample	First sample	Second sample
Intensive cultivation + Burnt trash + suSCon Blue	0.00	0.00	1.00	1.00	2.33	0.33	3.33	2.67
Intensive cultivation + Burnt trash	1.67	1.33	6.00	1.67	0.67	0.33	2.33	0.00
Minimum cultivation +Burnt trash + suSCon Blue	0.67	0.00	6.33	2.00	1.67	0.33	1.00	0.00
Minimum cultivation +Burnt trash	1.33	0.67	2.67	2.67	2.33	1.00	2.67	0.00
Intensive cultivation + GCTB + suSCon Blue	0.33	0.00	3.00	3.00	0.00	0.67	0.33	0.67
Intensive cultivation + GCTB	1.67	1.67	5.67	0.33	1.00	0.33	0.33	0.00
Minimum cultivation +GCTB + suSCon Blue	0.33	0.00	2.67	2.33	2.00	1.00	0.33	0.00
Minimum cultivation +GCTB	0.33	2.33	1.00	0.00	1.00	1.00	0.67	0.33

Table 7 - Harvest yields in each crop of the Tully trial.

Treatment	Cane yield (t/ha)				CCS				Sugar yield (t/ha)			
	Plant	1 R	2 R	3 R	Plant	1 R	2 R	3 R	Plant	1 R	2 R	3 R
Intensive cultivation + Burnt trash + suSCon Blue	79.25	74.39	75.30	70.59	14.55	13.41	15.17	14.25	11.52	9.92	11.40	10.11
Intensive cultivation + Burnt trash	83.09	80.87	79.48	78.27	14.91	13.88	15.34	13.48	12.37	11.28	12.19	10.51
Minimum cultivation +Burnt trash + suSCon Blue	78.65	88.25	81.81	73.68	14.45	13.69	14.69	13.22	11.36	12.09	12.02	9.71
Minimum cultivation +Burnt trash	85.35	80.00	81.47	72.36	14.77	12.28	15.11	14.35	12.62	9.75	12.30	10.42
Intensive cultivation + GCTB + suSCon Blue	77.82	95.82	77.10	55.97	14.25	13.62	15.83	14.39	11.57	13.02	12.18	8.04
Intensive cultivation + GCTB	79.40	88.89	75.07	58.27	15.06	13.26	15.84	14.31	11.96	11.74	11.89	8.32
Minimum cultivation +GCTB + suSCon Blue	86.78	93.34	76.54	56.61	15.09	13.29	15.36	14.11	13.08	12.40	11.76	7.96
Minimum cultivation +GCTB	81.44	93.53	83.85	59.29	15.60	13.65	15.09	14.22	12.70	12.76	12.67	8.43

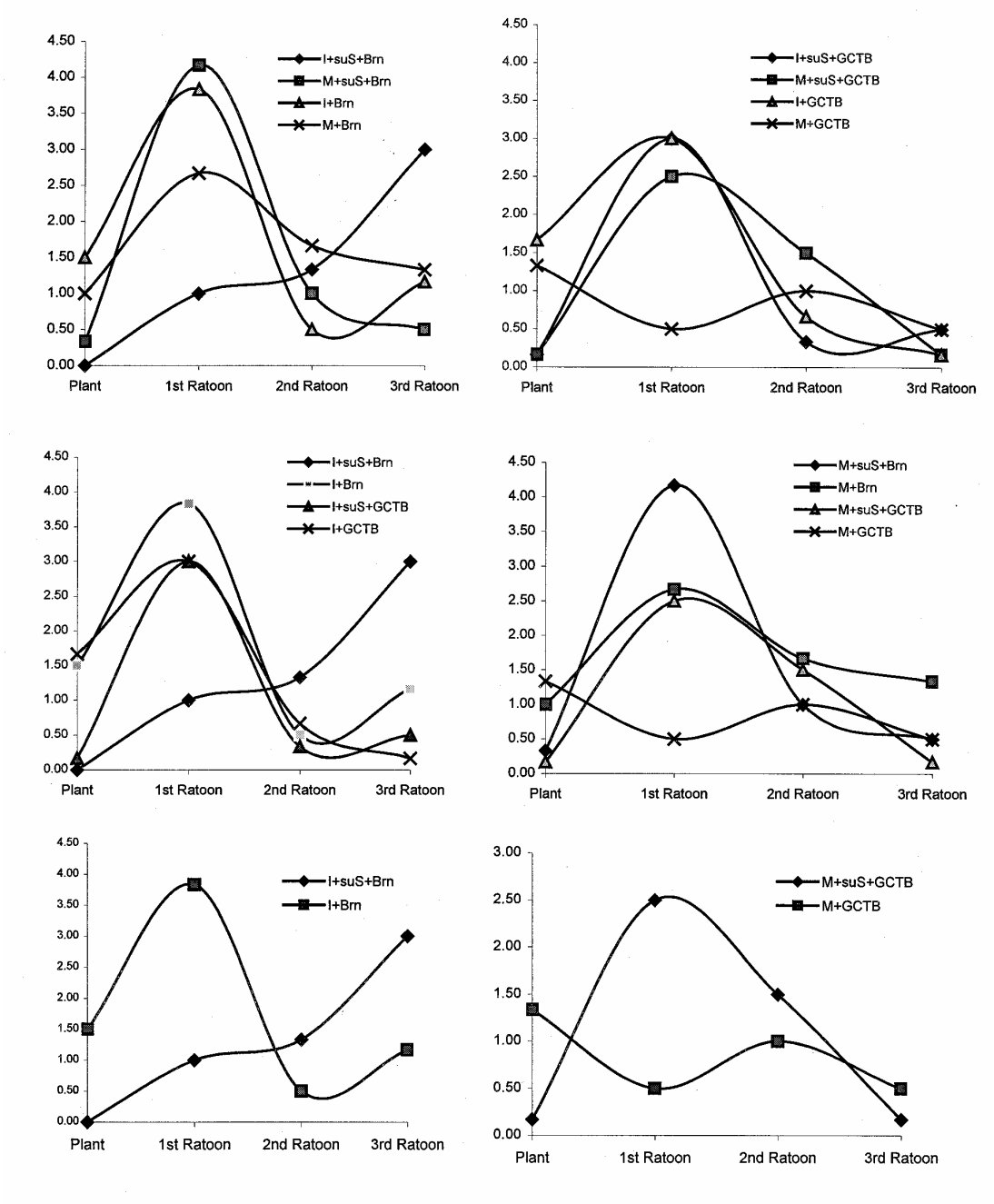

Figure 12 - Summary of mean levels of infestation by greyback canegrub in the Tully trial.

7. Minimum cultivation +GCTB + suSCon Blue.
8. Minimum cultivation +GCTB.

Each treatment combination was replicated three times in a split-split plot design with cultivation as the main effect, suSCon application as the first split and trash management as the second split. The trial as planted in 1996 and sampled for third-instar greyback canegrubs in the plant crop on 10 March and 23 April 1997, the first ratoon on 2 February and 19 March 1998, the second ratoon on 2 February and 30 March 1999, and the third ratoon on 17 April and 18 May 2000. At each sample, five standard samples were taken from each plot and the total number of greyback larvae was counted. Each crop was harvested by machine and the BSES weigh-truck in June-July and samples were taken for CCS to allow calculation of sugar yields.

Data were analysed by analysis of variance, in the case of grub counts following transformation by $x^{0.4}$ to stabilise variances. Means were separated by the protected lest-significant-difference test.

When significant numbers of larvae were sampled from each plot, these were reared to when they died or when they emerged as adults. Dead larvae were examined for infection by *Metarhizium anisopliae* or by *Adelina* sp.

3.2.1.2 Results and discussion

Grub numbers

In most treatments, grub numbers were low in the plant crop, increased dramatically in the first ratoon, and then fell in the second and third ratoons (Table 6; Figure 12). The exception appeared to be the Intensive cultivation + Burnt trash + suSCon Blue treatment with apparently high numbers in the third ratoon; numbers at each sampling are analysed more intensively below.

At each the two samplings in the plant crop, there was significantly more grubs in the plots not treated with suSCon Blue (first sampling F=16.4, P=0.016; second sampling F=121.1, P=0.0004). This is consistent with the know activity period of suSCon Blue against greyback canegrub.

At the first sampling in the first-ratoon crop, there were no significant differences among treatments. At the second sampling, there was a significant suSCon*burning interaction (F=7.68, P=0.022), with significantly fewer larvae in the no-suSCon/green-cane plots than in the suSCon-treated or no-suSCon-burnt plots. This indicates that suSCon is no longer controlling larvae, consistent with many other field data, but under green cane and where numbers in the previous crop were higher, there was some reduction in grub numbers, possibly through disease.

In the second-ratoon crop, there were no significant differences among treatments in either sampling.

At the first sampling in the third-ratoon crop, there were significantly fewer grubs were crop residues had been retained (GCTB) than where they were burnt (F=18.9, P=0.0019). In the second sampling, the data are more difficult to interpret, with significant suSCon*cultivation (F=21.9, P=0.0095), suSCon*burning (F=7.2, P=0.025) and

cultivation*burning (F=7.2, P=0.025) interactions. Numbers of larvae were significantly lower in the more 'invasive' treatment combinations of suSCon-burnt, intensively cultivated and burnt, and intensively cultivated and suSCon applied. All are consistent with previous work that showed that grub diseases, particularly *Adelina*, increase under 'softer' treatments of minimum tillage, no insecticide and trash retention.

Crop yields

Cane yields, CCS and sugar yields for each of the four crops are detailed in Table 7. There were significant differences among treatments for each of these parameters in some crops, but the factors associated with these differences and the order of differences among treatments are not consistent. No interactions were significant; significant effects were:

- Cane yield, first ratoon: a significant effect of trash management (F=5.6, P=0.042), with higher yield in the trash-retained plots than in the burnt plots;
- Cane yield, second ratoon: a significant effect of cultivation (F=18.6, P=0.05), with higher yield in the minimum-tilled plots than in the intensively tilled plots;
- Cane yield, third ratoon: a significant effect of trash management (F=22.8, P=0.0010), with higher yield in the burnt plots than in the trash-retained plots;
- CCS, plant crop: a significant effect of trash management (F=10.1, P=0.011), with higher level in the trash-retained plots than in the burnt plots;
- CCS, second ratoon: a significant effect of cultivation (F=28.6, P=0.033), with higher level in the intensively tilled plots than in the minimum-tilled plots;
- Sugar yield, third ratoon: a significant effect of trash management (F=18.5, P=0.0020), with higher yield in the burnt plots than in the minimum-tilled plots (a reflection of cane yields as above).

Levels of entomopathogens

Disease levels were monitored in greyback canegrubs collected from each plot in the Tully trial in February and March 1998; numbers of grubs in 1997 were too low to provide meaningful comparisons. *Metarhizium anisopliae* was the most common pathogen, with relatively low levels of *Adelina* recorded. Incidence of pathogens was higher where insecticide was not used compared to the same treatments where suSCon Blue was applied (Table 8). However, there was much variability between plots and generally low grub numbers that make interpretation of a single sampling difficult.

Table 8 - Incidence of disease (%) (predominantly *M. anisopliae*) in greyback canegrub collected from the Tully trial in March 1998.

Treatment	Insecticide	No insecticide
Early intensive-burnt	40	65
Early intensive-GCTB	31	45
Late minimum-burnt	26	75
Late minimum-GCTB	13	50

Economic analysis

Highest returns were from the minimum-cultivation and GCTB plots, whilst the lowest was from the intensive cultivation/burnt/suSCon applied plots (Table 9; Appendix 2). This is consistent with the relatively low populations of grubs, the input costs and the little difference between treatments in yields.

Table 9 - Total income from treatments in the Tully trial

Treatment	Income ($)
Intensive cultivation + Burnt trash + suSCon Blue	5,195
Intensive cultivation + Burnt trash	5,629
Minimum cultivation +Burnt trash + suSCon Blue	5,355
Minimum cultivation +Burnt trash	5,379
Intensive cultivation + GCTB + suSCon Blue	5,506
Intensive cultivation + GCTB	5,379
Minimum cultivation +GCTB + suSCon Blue	5,494
Minimum cultivation +GCTB	5,730

3.2.1.3 Conclusions

Grub numbers followed a trend of increasing to the first ratoon and then decreasing in most treatments. This is consistent with a slow build-up of entomopathogens, similar to that seen by Robertson *et al.* (1998) in other trials in northern Queensland. The exception was the most invasive treatment, Intensive cultivation + Burning + suSCon use, where numbers continued relatively high in the third ratoon. This is consistent with better survival of *Metarhizium* and *Adelina* under minimum tillage, no insecticide and/or trash retention.

Grub numbers were too low to have significant, consistent impacts on yields. The trial, however, reinforced previous work that the 'softer' treatments did not lead to high grub populations, could be done by growers and did not incur yield penalties. In fact, the 'softer' treatments gave the highest economic returns.

3.2.2 Burdekin trials

Short-term trials were established in the Burdekin area to test, on a large scale under commercial conditions, combinations of pre-planting tillage, insecticide application, and trash management.

3.2.2.1 Experimental

Sgarbossa 1. This trial tested conventional and minimum tillage, application of *Metarhizium*-based insecticide (later BioCane™), and preharvest burning and trash retention in unreplicated strips (no statistical analysis possible).

The first ratoon was harvested in early July 1998 and then ploughed-out. Conventionally tilled areas outyielded minimum-tilled areas, both where *Metarhizium* was applied and where it was not applied (Table 10). Application of *Metarhizium* improved yield in both tillage treatments. Shoot counts taken in the young second-ratoon crop (just before

ploughout) showed no differences between the minimum-tilled area and one of the conventionally tilled areas; the other conventionally tilled area had no shoots. Shoot numbers were improved dramatically where *Metarhizium* had been applied (Table 10).

In a second area planted later, the burnt-cane area outyielded the green-cane trash-blanketed area and had many more shoots in the young second-ratoon crop (Table 10).

Table 10 - Harvest yields in the first ratoon of the Sgarbossa trial

	Cane yield (t/ha)	CCS	Sugar yield (t/ha)	No. of shoots (/m)
Tillage				
Conventional – area 1	129.0	11.4	14.7	0.80
Conventional – area 2	119.7	10.2	12.2	0
Minimum tillage	107.7	10.5	11.3	0.78
Metarhizium *applied*				
Conventional tillage	136.6	13.4	18.3	2.11
Minimum tillage	118.6	14.0	16.6	1.53
Trash management				
Burnt	100.2	13.6	13.6	1.27
GCTB	83.1	16.0	13.3	0.13

McLaughlin. This trial was established in 1998 to monitor the effects of green-cane trash-blanketing (half the field) and burnt cane (half the field) in the Burdekin. The trial was sampled for grubs in February 1999 and green-cane-trash-blanket areas had 0.4 grubs per stool, and burnt-cane areas had 0.2 grubs per stool.

At the 1999 harvest, the trial yielded 99.4 tonnes cane/ha with 13.65 CCS (13.56 tonnes sugar/ha) from the green-cane area and 87.8 tonnes cane/ha with 11.4 CCS (11.4 tonnes sugar/ha) from the burnt area. This shows that green-cane trash-blankets can perform well in the Burdekin.

Lashmar. This trial was established to monitor the effects of green-cane trash-blanketing in the Burdekin. In February 1999, an area trash-blanketed for two years had 0.2 grubs per stool, whilst an area trash-blanketed for one year had 0.4 grubs per stool.

Minimum-tillage comparisons. Six other comparisons of minimum tillage and conventional tillage were established in Burdekin crops during 1998. All sites were sampled in February-April 1999 for greyback canegrubs and two were harvested in 1999.

Sgarbossa 2. Area replanted with minimum tillage had 0 grubs per stool; continuous cane but previously treated with BioCane (*Metarhizium*) had 0.19 grubs per stool in one strip and 2.95 grubs per stool in a second strip.

Rossiter. No grubs. The minimum-tilled area yielded 177.5 tonnes cane/ha with CCS of 13.7 (24.3 tonnes sugar/ha) compared with 160.0 tonnes cane/ha with CCS of 15.2 (24.3 tonnes sugar/ha), showing that minimum-tilled areas can perform well in the Burdekin.

Stevens. No grubs. The minimum-tilled area yielded 115 tonnes cane/ha with CCS of 16.1 (18.5 tonnes sugar/ha) compared with 112 tonnes cane/ha with CCS of 16.7 (18.7 tonnes sugar/ha), showing that minimum-tilled areas can perform well in the Burdekin.

Davenport. No grubs.

Todeschino. Block was previously a BioCane site. One grub with *Metarhizium* found in minimum tillage area.

Pilchowski. No grubs.

3.2.2.2 Grower-based economic evaluation

Costs associated with minimum-tillage planting in the Burdekin have been estimated following trials by Ayr grower Robert Rossiter. Rossiter has experimented with minimum tillage planting since 1997. Prior to this, his conventional land-preparation practices involved a series of heavy tillage passes, including: three passes with offset discs to knock out the old stool after harvest; one pass with a ripper to break up the soil; two passes with offset discs over the fallow period to control weeds; two passes with a ripper to allow the block to dry out; one pass with the rotary hoe; one pass to mark out rows, then finally plant. After consulting BSES extension staff, Rossiter prepared a 2-ha replant block last season using his conventional tillage system, and left 0.4 ha of the old crop on the edge of paddock. This section was used as a 20-drill trial strip of minimum tillage, and was prepared with a total of only two passes. The first pass was with a single tine ripper with a winged tip that was passed through the old stool. The second pass was with a rotary hoe, and involved hoeing only existing drills down to the water furrow depth without disturbing the interrow.

The next season Rossiter prepared a block of 6.6 ha by spraying out the last crop of Q117 with glyphosate. During late May, Rossiter prepared the block using a similar tillage method as the ploughout replant strip the previous year. He started by running a mulcher over the surface to destroy some of the spray-out residue. A single-tine ripper was passed through the old drills only. This was followed by single pass with the rotary hoe resulting in an excellent planting bed, which was planted in early June.

Costs were then calculated in order to compare each system of land preparation, ie conventional versus minimum-tillage fallow plant, or versus minimum tillage replant (Table 11). The costs of the sprayout-minimum tillage are substantially lower than the costs of establishing conventionally tilled crops. Add to this the expected benefits from reduced grub numbers, and the returns and savings are even greater.

Table 11 - Costs associated with land preparation and planting by Rossiter.

Conventional land preparation costs

Operation	$/ ha/ pass	Number of passes	Total $/ha
Offset discs	20	5	100
Ripper	25	3	75
Rotary hoe	25	1	25
Marking out	6	1	6
TOTAL		10	206

Stool spray-out + fallow and minimum tillage planting costs

Operation	$/ ha/ pass	Number of passes	Total $/ha
Ripper	25	1	25
Rotary hoe	25	1	25
Mulcher	18	1	18
Boom spray	6	2	12
Glyphosate	56	1	56
TOTAL		6	136

Minimum tillage ploughout and replant costs

Operation	$/ ha/ pass	Number of passes	Total $/ha
Ripper	25	1	25
Rotary hoe	25	1	25
TOTAL		2	50

3.2.3 Prevalence of soil-borne diseases of greyback canegrub

Two diseases are frequently encountered in greyback canegrub in northern Queensland (Dall *et al.* 1995; Lai-Fook *et al.* 1997). These are caused by the protozoan *Adelina* sp. and the entomopathogenic fungus *Metarhizium anisopliae*. There are other bacterial and viral diseases, but their impact on canegrub populations is unknown. Levels of mortality caused by *Adelina* and *M. anisopliae* vary considerably between areas and over time (Robertson *et al.* 1997). In an analysis of mortality factors, Robertson *et al.* (1998) concluded that *Adelina* acts as a density-dependent mortality factor. As populations of greyback canegrub increase, *Adelina* incidence increases and causes the grub population to crash. The incidence of *Adelina* then declines to a minimum and grub populations eventually rise again. In contrast, *M. anisopliae* did not exhibit any dynamic effect on population density of host grubs, giving constant levels of mortality in consecutive years.

Metarhizium anisopliae grows successfully on rice and is mass produced as the biological insecticide BioCane™ (Logan *et al.* 2000; Milner 2000; Samson *et al.* 2000).

On the other hand, *Adelina* spp. are single-celled protozoans that invade the haemocoel (blood system) of a wide range of scarab beetles and other arthropods. *Adelina* invades the fat bodies of hosts, reducing glycogen accumulation and ultimately destroying the cells (Dolgikh *et al.* 1995; Dolgikh 1998; Paskerova *et al.* 1998). In north Queensland, a

species of *Adelina* is frequently recovered from larvae of greyback canegrub (*Dermolepida albohirtum*) (Dall *et al.* 1995; Lai-Fook *et al.* 1997). The pathogen may be responsible for the cyclic nature of greyback canegrub infestation that is seen in far north Queensland, while grub populations remain high in the Burdekin where *Adelina* is not common (Robertson *et al.* 1997). Unlike *Metarhizium*, *Adelina* requires a living insect to complete its lifecycle, so mass production of the pathogen is less feasible.

Adelina oocysts (spores) remain in the soil over the period when grub hosts are not present. The oocysts are fragile and it is thought that conventional intensive tillage may destroy them. The disease may be absent from greyback canegrubs in the Burdekin because of the farming practices in that district. Therefore, the nature of the disease, its geographical distribution, the influence of farming practices on its incidence, and its impact on canegrub populations in Queensland require more investigation. Better understanding of the disease will lead to improved crop management strategies that aim to maximise the disease impact on grub populations.

Studies showed that high amounts of soil organic matter (SOM) is conducive to the activity of beneficial soil fauna (Rao and Veeresh 1988; Haynes *et al.* 1991). For example, Villalobos *et al.* (1997) showed that the abundance of *Serratia entomophila*, an entomopathogenic bacterium that causes amber disease in *Costelytra zealandica* (Coleoptera: Melolonthinae) in New Zealand, is positively linked to levels of total carbon and nitrogen in pasture soils. Other work demonstrated the importance of added organic matter in possible mitigation of damage caused by scarab larvae (King 1977). In addition, intensive soil cultivation and frequent ploughing may negatively impact on the activity of beneficial soil fauna (Miln 1982; Robertson *et al*. 1997). Our study was conducted to understand the nature and the life cycle of the *Adelina* pathogen and investigate its occurrence in selected canegrowing areas, and to determine the factors governing persistence of cane grub diseases in different localities of central and north Queensland.

3.2.3.1 Materials and methods

We sampled 21 sites from Sarina in central Queensland to Mulgrave in the north to determine factors associated with the distribution of both *Adelina* and *M. anisopliae*. Sites sampled had a range of soil types, climatic conditions and farming practices. Growers were requested to fill a survey form to provide data on farming practices at each site. We collected greyback canegrubs from each site and examined them for *Adelina* as soon as they were collected. Symptoms of *M. anisopliae* infection were monitored later (April-May), when the fungus grows on the outside of the infected grub giving a white cottony appearance and producing green spores.

To establish the role of soil factors on the abundance of grub diseases, a soil sample was taken from a depth of 20 cm at each site. Samples were dried, ground and sent to BSES Indooroopilly for analysis of soil electrical conductivity (SEC), pH, phosphorus, sulfur, soil organic carbon and nitrogen. We ran multiple regression analyses with the square root values of percentages of *Adelina* and *M. anisopliae* infection rates as dependent variables against soil parameters as independent variables.

3.2.3.2 Results

Multiple regression analysis showed that none of the soil factors were significantly related to the abundance of *Adelina*. On the other hand, only sulfur appeared to positively impact on rates of *M. anisopliae* (P=0.04), with none of the remaining factors appearing to influence disease prevalence. This suggests that no single factor governs disease levels. In addition, our results do not support the assumption, based on the absence of *Adelina* in the generally alkaline Burdekin soils, that neutral-to-low-pH soils favour the abundance of the *Adelina* pathogen. Nevertheless, where *Adelina* occurred in soils with pH slightly higher than 6.0 (Table 12), the growers had used either lime (up to 2 tons/acre) or mill mud, which induced higher pH in their soils. High soil moisture appears to favour the persistence of *Adelina* in soil (D. Dall, unpubl. data), and this could explain the abundance of the disease in the 'super wet' belt of far northern Queensland. This, however, does not explain the frequent abundance of *Adelina* at Mutarnee, where very dry seasons occur and soil moisture drops to low levels for an extended period of time.

Table 12 - Incidence of *Adelina* and *Metarhizium anisopliae* in selected locations of central and northern Queensland.

Location	SEC	pH	P	S	C	N	Grubs/stool	% Adelina	% Metarhizium
Mt Sofia - Mulgrave	0.02	5.09	321	20	0.65	0.07	2.5	8.5	0
Innisfail	0.02	5.76	90	22	1.79	0.12	0.5	0	0
South Johnstone-1	0.01	5.22	53	12	2.79	0.14	2.6	50	16.7
South Johnstone-2	0.02	6.13	122	22	2.56	0.19	3.3	10.3	13.7
South Johnstone-3	0.06	4.93	66	277	1.87	0.17	1.6	27.7	16.7
El Arish	0.02	5.93	103	6	1.24	0.12	0.5	0	0
Tully-1	0.01	5.27	46	8	1.56	0.1	2.9	0.6	0
Tully-2	0.04	5.07	19	12	1.49	0.11	2.6	0	0
Tully-3	0.03	5.59	112	25	5.16	0.36	0.4	100	0
Kennedy	0.03	5.38	168	7	1.45	0.12	4.5	25.5	0
Ingham-1	0.03	5.1	81	3	0.58	0.07	2.5	36.5	2.7
Ingham-2	0.03	4.98	31	5	0.92	0.08	2.5	75	0
Mutarnee-1	0.03	6.8	26	4	1.03	0.09	1.4	41.5	2.6
Mutarnee-2	0.02	6	117	3	0.65	0.07	1.2	0	0
Burdekin-1	0.04	6.44	234	30	1.05	0.07	2.5	0	0
Burdekin-2	0.11	7.49	204	16	1.15	0.09	2.9	0	0
Mackay-1	0.02	5.33	125	2	0.6	0.04	2.1	0	1.64
Mackay-2	0.02	5.35	128	2	0.75	0.05	1.1	0	0
Sarina-1	0.01	5.76	14	21	0.79	0.08	2.7	0	15.7
Sarina-2	0.01	5.88	63	2	0.59	0.02	1.2	0	0
Sarina-3	0.04	5.48	84	4	1.44	0.09	1.7	1.61	3.2

SEC = Soil Electrical Conductivity, P = Phosphorus, S = Sulfur, C = Carbon and N = Nitrogen.

The survey revealed that all growers conventionally worked their soils, mainly through ploughing-out/replanting in addition to frequent disking, ripping and rotary hoeing, thus, it was difficult to attribute disease incidence to intensity levels of farming practices. Lands in Kennedy and Mutarnee-1 were previously cattle and timber lands that were cleared to plant cane, while South Johnstone-1 had a legume crop prior to planting cane. Though the survey does not confirm that fairly new cane land, or legume-fallowed land, may have an abundance of naturally occurring *Adelina*, this, however, was encountered in a number of cases.

3.2.3.3 Conclusions on entomopathogens

From our study, it appears that the presence of diseases of greyback canegrubs is governed by a complex set of factors. Further work is also required to test the persistence of *Adelina* oocysts in different soil types, pH and moisture levels, and to investigate the possibility of enhancing the role of *Adelina* in regulating greyback canegrub populations in the north, and in other cane growing areas of Queensland. Factors such as burning crop residues, long-term intensive cultivation, soil temperature, or perhaps changes in soil moisture between seasons could be important in determining the occurrence of *Adelina*.

3.2.4 General economic comparisons

Economic analyses of costs and benefits associated with greyback-canegrub control tactics are difficult, as the specific strategies tested in this project form part of a package of strategies now promoted under the *GrubPlan* banner. It is the combination of these strategies that provide the higher economic returns.

Appendix 3 presents an analysis of costs associated with grub-control scenarios in northern Queensland (especially the Burdekin area).

4.0 OUTPUTS

Our study indicates that farming practices can have significant impacts on populations of Childers canegrubs. Higher infestations are more likely:

- in summers starting in odd-numbered years;
- in later ratoons;
- on low-sand soils;
- in crops that have been established with a plough-out/replant strategy (very short break, minimum tillage disturbance, no drip irrigation installed);
- in crops without suSCon® Blue applied.

These infestations can be:

- reduced through the build up of entomopathogens late in each generation and in later ratoons, but the crops could be so severely damaged in earlier ratoons that they are ploughed out before significant populations of entomopathogens can develop.
- reduced and the build-up of damaging populations delayed by use of suSCon® Blue, and this can be cost effective;
- reduced and delayed following longer breaks between successive sugarcane crops, coupled with intensive tillage within that break, will reduce populations carried over from the previous crop cycle. However, the long-term deleterious effects of intensive soil tillage on other soil biota and on increased soil compaction and the cost of such tillage, may negate the economic benefits gained through reduction in numbers of canegrubs. The 'softer' options of destroying the previous crop with herbicides before a long break (1 year) with minimum tillage should disrupt the lifecycle of *A. parvulus* to a similar extent, especially if targeted against the larger of the two allochronic populations.

- Detected by monitoring in late winter and spring and reduced by application of Rugby® 100 G or Confidor® Guard.

These strategies have been integrated into the *Southern GrubPlan* package.

Our study with greyback canegrubs showed that in north Queensland numbers follow trend of increasing to the first ratoon and then decreasing in most treatments. This is consistent with a slow build-up of entomopathogens. The exception was the most invasive treatment, Intensive cultivation + Burning + suSCon use, where numbers continued relatively high in the third ratoon. This is consistent with better survival of *Metarhizium* and *Adelina* under minimum tillage, no insecticide and/or trash retention. Our work reinforced previous work that the 'softer' treatments do not lead to high grub populations, can be done by growers and do not incur yield penalties. In fact, the 'softer' treatments give the highest economic returns.

Trials in the Burdekin with different tillage and trash-management regimes generally had too few larvae to draw useful conclusions about the effect of these treatments on grub numbers. However, the trials showed that minimum tillage and trash retention were both feasible farming practices in this area and adoption was possible. Both were also considerably cheaper options than either conventional tillage and/or burning trash.

Diseased greyback canegrubs from the area from Mulgrave (far north Queensland) to Sarina (south of Mackay) showed variable infection rates of the pathogens *Adelina* sp. and *Metarhizium anisopliae*, especially in the area between South Johnstone (south of Innisfail) and Mutarnee (north of Townsville). Neither of the two pathogens was found in the Burdekin. The impact of soil chemistry, tillage intensity and fallowing strategy on the prevalence of the two diseases was investigated. No clear relationship was detected between disease incidence and soil chemistry.

Economic analyses of costs and benefits associated with greyback-canegrub control tactics are difficult, as the specific strategies tested in this project form part of a package of strategies now promoted under the *GrubPlan* banner. It is the combination of these strategies that provide the higher economic returns.

5.0 OUTCOMES

Many discussions have been held with grower groups in the Burdekin, northern Queensland and Isis/Bundaberg areas to convey the results of this project and to encourage changes in farming practices. In particular regular contact has occurred between researchers and the Isis CPPB, and researchers and the Childers-grub focus group set up under the IPM coordinator project. The findings of the Childers-grub section of this project have been presented at these meetings. Contact has been continued with the CP2002 greyback canegrub advisory committee. The findings of both sections of the project also form important components of the *GrubPla*n approach used for greyback management and *Southern GrubPlan* developed for southern grub species. The *GrubPlan* program trained 906 growers and CPPB and rural-industry staff through 70 workshops in the north, Burdekin and cental regions in late 2001. Training was an interactive process based on developing understanding and skills, leading to changes in practices. The program has seen 60% of growers implementing 80% or more of the management plans that they developed in the workshops. Visible damage to canegrubs has declined and is

being confirmed by lower crop losses in the 2002 harvest. The technique has assisted BSES extension and research staff and CPPB staff to operate more effectively using appropriate meeting processes, and has served to standardise IPM programs in the industry.

6.0 RECOMMENDATIONS

- Use the *GrubPlan* and *Southern GrubPlan* formats to continue delivery of the outcomes of this project;
- Incorporate these findings into the Macarthur Agribusiness model to make the model more relevant to areas other than the Burdekin;
- Incorporate the findings on Childers canegrub into the Logan population-dynamics model to expand the usefulness of that model.

7.0 PUBLICATIONS

Part of the work on greyback canegrub is reported in the paper:

Sallam MN, Bakker P and Dall DJ. 2003. Prevalence of soil-borne diseases of greyback canegrub with special reference to *Adelina* sp. *Proceeding of the Australian Society of Sugarcane Technologists* **25,** in press.

The work on Childers canegrub is reported in the papers:

Fischer TWA and Allsopp PG. 1997. Farming practices influence populations of Childers canegrub (*Antitrogus parvulus* Britton) in Australian sugarcane: preliminary results. *In* Allsopp, P.G., Rogers, D.J. and Robertson, L.N. (Eds) *Soil invertebrates in 1997*. pp. 48-51. Bureau of Sugar Experiment Stations, Brisbane.

Allsopp PG, Fischer TWA, Bade GS and Dall DJ. 2003. Do farming practices influence the incidence of Childers canegrub, *Antitrogus parvulus* Britton (Coleoptera: Scarabaeidae)? *Australian Journal of Agricultural Research* **54,** in press.

The findings on greyback canegrub form part of the package of management strategies marketed under the *GrubPlan* label. This has seen the production of a brochure for GrubPlan workshops and an ASSCT paper:

Hunt W, Horsfield A, Cocco R and Chandler K. 2001. *GrubPlan.* Bureau of Sugar Experiment Stations, Indooroopilly.

Hunt WD, Chandler KJ, Horsfield A, Cocco R, Sgarbossa PJ (2002) Developing and extending 'GrubPlan' for management of greyback canegrub damage in Queensland sugarcane. *Proceeding of the Australian Society of Sugarcane Technologists* **24,** 207-212.

The findings on Childers canegrub form part of the package of management strategies marketed under the *Southern GrubPlan* label. This has seen the production of a brochure for GrubPlan workshops:

Hunt W, Allsopp P, Samson P, Fischer T, Chandler K, Agnew J and McGill N. 2002. *Southern GrubPlan.* Bureau of Sugar Experiment Stations, Indooroopilly.

These workshops and the associated brochures are seen as the most effective way to make interested growers aware of the findings of this project and how they relate to management options.

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APPENDIX 1 – Costs associated with different farming scenarios in Childers-grub trial

Assumptions Autumn Plant, Operation costs are a reflection of contract rates (inferred that labour & depreciation costs are included in the cost)

Comparisons
suSCon (**S**) vs no suSCon (**NS**)
Conventional Tillage (**CT**) vs Minimum Tillage (**MT**)
Burning (**B**) ratoon cane vs harvesting ratoon cane Green (**G**)

Cost per ha for All Input Costs Planting, 1R & 2R				
Combinations	**Plant**	**1R**	**2R**	**Total**
1 - S, CT, B	3,305	1,865	1,865	**$7,035**
2 - S, CT, G	3,335	1,450	1,450	**$6,235**
3 - S, MT, B	2,790	1,640	1,640	**$6,070**
4 - S, MT, G	2,820	1,450	1,450	**$5,720**
5 - NS, CT, B	3,035	1,865	1,865	**$6,765**
6 - NS, CT, G	3,065	1,450	1,450	**$5,965**
7 - NS, MT, B	2,520	1,640	1,640	**$5,800**
8 - NS, MT, G	2,550	1,450	1,450	**$5,450**

Details

Combination No.				**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
$/ha	**Fert/Water/**	**Applic/**	**Total Op**	**suSCon**	**suSCon**	**suSCon**	**suSCon**	**No suSCon**	**No suSCon**	**No suSCon**	**No suSCon**
Operations	**Chem Cost**	**Mach Cost**	**Cost**	**Conv. Tillage**	**Conv. Tillage**	**Min. Tillage**	**Min. Tillage**	**Conv. Tillage**	**Conv. Tillage**	**Min. Tillage**	**Min. Tillage**
Planting				**Burnt**	**Green**	**Burnt**	**Green**	**Burnt**	**Green**	**Burnt**	**Green**
Stool Destruction -Offset		150	150	150	150			150	150		
Stool Destruction -Roundup Applicn	55	30	85			85	85			85	85
Ripping		200	200	200	200			200	200		
Square Ploughing		200	200	200	200			200	200		
Rotary Hoeing		200	200	200	200			200	200		
Offset Operations * 2		300	300			300	300			300	300
Bed Forming		100	100			100	100			100	100
Planting		300	300	300	300	300	300	300	300	300	300
Fert at Planting	125		125	125	125	125	125	125	125	125	125
suSCon Application at Planting	270		270	270	270	270	270				
Fungicide Applied at Planting	25		25	25	25	25	25	25	25	25	25
Early Herbicide Applicn	20	30	50	50	50	50	50	50	50	50	50
Fill in Operations * 2		150	150	150	150			150	150		
Side Dress Fert.	225	100	325	325	325	325	325	325	325	325	325

Hilling up Operation		100	100	100	100			100	100		
Herbicide Applicn-Broadleaves	30	30	60	60	60	60	60	60	60	60	60
Irrigation Costs 4 mgl/ha	180	280	460	460	460	460	460	460	460	460	460
Burning		30	30	30		30		30		30	
Harvesting - Burnt		660	660	660		660		660		660	
Harvesting - Green		720	720		720		720		720		720
1st Ratoon											
Raking		75	75	75				75			
Cultivation		150	150	150				150			
Fertilising	320	100	420	420	420	420	420	420	420	420	420
Herbicide Applicn * 3	90	90	180	180		180		180		180	
Herbicide Applic * 1.5	40	45	85		85		85		85		85
Irrigation Costs 4 mgl/ha	180	280	460	460		460		460		460	
Irrigation Costs 3 mgl/ha	135	210	345		345		345		345		345
Burning		30	30	30		30		30		30	
Harvesting - Burnt		550	550	550		550		550		550	
Harvesting - Green		600	600		600		600		600		600
2nd Ratoon											
Raking		75	75	75				75			
Cultivation		150	150	150				150			
Fertilising	320	100	420	420	420	420	420	420	420	420	420
Herbicide Applicn * 3	90	90	180	180		180		180		180	
Herbicide Applic * 1.5	40	45	85		85		85		85		85
Irrigation Costs 4 mgl/ha	180	280	460	460		460		460		460	
Irrigation Costs 3 mgl/ha	135	210	345		345		345		345		345
Burning		30	30	30		30		30		30	
Harvesting - Burnt		550	550	550		550		550		550	
Harvesting - Green		600	600		600		600		600		600
Total Costs - $/ha				7,035	6,235	6,070	5,720	6,765	5,965	5,800	5,450

APPENDIX 2 – Returns from treatments in each crop in the Tully trial

Treatment	Cult Int Min	Trash Brn GCTB	suSCon (+) or (-)

Labour and Machinery	Year	Treatment	Cost/Ha	Average $ Income/Rep
Plot Establishment Cost	1996		$6,013.19	
Labour and maintenance	1997		$2,430.03	
Harvesting cost per treatment	1997	**IB +**		1,410.45
	Plant	**IB -**		1,543.93
		MB +		1,383.18
		MB -		1,565.02
		I GCTB +		1,442.74
		I GCTB -		1,507.11
		M GCTB +		1,647.59
		M GCTB -		1,642.81
Labour and maintenance	1998		$2,278.03	
Harvesting cost per treatment	1998	**IB +**		1,122.02
	1st R	**IB -**		1,330.77
		MB +		1,403.44
		MB -		999.85
		I GCTB +		1,499.76
		I GCTB -		1,315.66
		M GCTB +		1,396.74
		M GCTB -		1,475.59
Labour and maintenance	1999		$2,103.04	
Harvesting cost per treatment	1999	**IB +**		1,441.96
	2nd R	**IB -**		1,557.87
		MB +		1,483.31
		MB -		1,550.94
		I GCTB +		1,589.69
		I GCTB -		1,555.65
		M GCTB +		1,504.59
		M GCTB -		1,600.43
Labour and maintenance	2000		$1,959.04	
Harvesting cost per treatment	2000	**IB +**		1,220.78
	3rd R	**IB -**		1,196.77
		MB +		1,085.13
		MB -		1,263.70
		I GCTB +		973.99
		I GCTB -		1,001.49
		M GCTB +		945.40
		M GCTB -		1,011.35

APPENDIX 3 – Greyback control scenarios

BSES recommends to growers the practices given in bold italics under each situation provided

Farm Size 100 ha

Block layout 400 m long

Crop Class Distribution Early plant rotation (F, P, 1R, 2R, 3R)
Replant rotation (P, 1R, 2R, 3R)

Average Yield (tc/ha)

Early plant rotation		**Late plant rotation**	
Fallow	0	Replant	130
Plant	160	1R	120
1R	130	2R	100
2R	110	3R	90
3R	95		
Avg	123.75	Avg	110

Trap Crops Trap crops are placed every 200 m or 131 rows apart in high risk areas and 400 or 262 rows in low risk blocks. Area under trap are 10 rows or 0.696 ha. Therefore in high-risk areas where blocks are 20 ha, three trap crops would be established. In low-risk areas two trap crops would be established.

Average yield loss from grubs High risk area 35 tc/ha
Low risk area 5 tc/ha

Cost of replanting $182.11/ha (standard cultivation practice) + $468.32/ha (planting costs) + $144.87/ha (planting fertiliser costs)
Total cost = $ 795.30/ha

Insecticide product cost

BioCane (33 kg/ha)	$274.64/ha
suSCon Plus (40 kg/ha)	$392.64/ha
Confidor (2 L/ha)	$358.64/ha
Confidor(3 L/ha) & Trap Crop (high)	$49.63/ha
Confidor (3 L/ha) & Trap crop (high) and BioCane non trap	$252.00/ha

Note: Assume that unless other wise stated that areas treated on farm sustain no yield reduction when treatment is applied.

Early plant farm

High-Risk Area

Management Option for farm	***Total farm cost***	***$/tonne***
Do nothing/ replant	$795.30/ha * 20 = $15,906.00 Lost production (P) = 20 ha * 35 tonne = 700 tonne at 25.34 = $17,738.00 (1R) = 20 ha * 5 tonne = 100 tonne at 25.34 = $2,534.00 **Total cost = $36,178.00**	**3.98**
suSCon plus(P)	Plant cane no damage. Lost production (1R) = 20 ha * 30 tonnes/ha = 600 tonne at $25.34/tcane = $15,204.00 + replant cost of $795.30 *20 = $15,906.00 **Total cost = $31,110.00**	**3.35+**

BioCane (P)	BioCane = $5,492.80 + Lost production (P) 20 ha * 30 tonnes/ha = 600 tonne at $25.34/ tcane = $15,204.00 + replant cost of $795.30 *20 = $15,906.00	
	Total cost = $36,602.80	**3.94+**
suSCon plus (P) & Confidor (1R, 2R)	***$392.64/ha(P) + $358.64/ha(P, 1R)***	
	Total cost = $22,198.40	***2.24***
suSCon Plus (P) in trap crop & Confidor (1R, 2R) in trapcrop	***1.82 ha*392.64 + 1.82 ha*2*358.64***	
	Total cost = $2,020.05	***0.20***
suSCon Plus (P) in trap crop + BioCane in rest of block & Confidor (1R, 2R) in trap crop	***1.82 ha *392.64 +18.18 ha * 274.64 + 1.82*2*358.64***	
	Total cost = $7,013.00	***0.71***

Low-Risk Area

Management Option for farm	***Total farm cost***	***$/tonne***
Do nothing/ replant or ratoon	$795.30/ha * 20 = $15,906.00 (Depending on damage level may or may not replant) Lost production (P) = 20 ha * 10 tonne = 200 tonne at 25.34 = $5,068 (1R) = 20 ha * 5 tonne = 100 tonne at 25.34 = $2,534.00	
	Total cost = $23,508.88 or $7,602.00	**2.44**
	Or	**0.79**
BioCane (P)	***Total Cost = $5,492.80***	***0.55***
BioCane (P) + Confidor (1R)	***5,492.80 +7172.80***	
	Total Cost = $12,665.60	***1.28***
suSCon plus(P)	**Total cost = $7,852.80**	**0.79**
suSCon Plus (P) + Confidor (1R)	7,852.80 + 7,172.80	
	Total Cost = $15,025.60	**1.52**
suSCon Plus (P) in trap crop & Confidor (1R, 2R) in trapcrop	***1.82 ha*392.64 + 1.82 ha*2*542.80***	
	Total cost = $2,682.69	***0.27***
suSCon Plus (P) in trap crop + BioCane in rest of block & Confidor (1R, 2R) in trap crop	***1.82 ha *392.64 +18.18 ha * 274.64 + 1.82*2*542.80***	
	Total cost = $7,675.65	***0.78***

Replant farm

High-Risk Area

Management Option for farm	***Total farm cost***	***$/tonne***
Do nothing/ replant	$795.30/ha * 25 = $19,882.50 Lost production (P) = 25 ha * 35 tonne = 875 tonne at 25.34 = $22,172.50 (1R) = 25 ha * 5 tonne = 125 tonne at 25.34 = $3,167.50	
	Total cost = $45,222.50	**4.52**

suSCon Plus (P) + Confidor (1R, 2R)	392.64*25 +358.64*50 **Total Cost = 27,748.00**	**3.05**
suSCon Plus (P) in trap crop & Confidor (1R, 2R) in trapcrop	***1.82 ha*392.64 + 1.82 ha*2*542.80 Total cost = $2,682.69***	***0.24***
suSCon Plus (P) in trap crop + BioCane in rest of block & Confidor (1R, 2R) in trap crop	***1.82 ha *392.64 +18.18 ha * 274.64 + 1.82*2*542.80 Total cost = $9,048.80***	***0.82***
suSCon Plus(P)	Plant cane no damage. Lost production (1R) = 25 ha * 30 tonnes/ha = 875 tonne at $25.34/tcane = $22,172.50 + replant cost of $795.30 *25 = $19,882.50 **Total cost = $42,055.00**	**4.10**
BioCane (P)	BioCane = $5,492.80 + Lost production (P) 25 ha * 30 tonnes/ha = 750 tonne at $25.34/ tcane = $19,005.00 + replant cost of $795.30 *25 = $19,882.50 **Total cost = $38,887.50**	**3.79**

Low-risk Area

Management Option for farm	***Total farm cost***	***$/tonne***
Do nothing/ replant or ratoon	$795.30/ha * 25 = $1,9882.50 (Depending on damage level may or may not replant) Lost production (P) = 25 ha * 10 tonne = 250 tonne at 25.34 = $6,335.00 (1R) = 25 ha * 5 tonne = 125 tonne at 25.34 = $3,167.50 **Total cost = $29,385.00 or $9,502.50**	**2.77** **Or 0.89**
BioCane (P)	***Total Cost = $6,866.00***	***0.62***
BioCane (P) + Confidor (1R)	***6,866.00 + 8,966.00 Total Cost = $15,832.00***	***1.44***
suSCon Plus(P)	**Total cost = $9,816.00**	**0.89**
suSCon Plus (P) + Confidor (1R)	9,816.00 + 8,966.00 **Total Cost = $18,782.00**	**1.71**
suSCon Plus (P) in trap crop & Confidor (1R, 2R) in trapcrop	***1.82 ha*392.64 + 1.82 ha*2*542.84 Total cost = $2,682.69***	***0.24***
suSCon Plus (P) in trap crop + BioCane in rest of block & Confidor (1R, 2R) in trap crop	***1.82 ha *392.64 +18.18 ha * 274.64 + 1.82*2*542.84 Total cost = $9,048.85***	***0.82***