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FINAL REPORT
SRC/SRDC PROJECT BS36S
BIONOMICS AND IMPORTANCE OF THE FROGHOPPER *EOSCARTA CARNIFEX* (F.) (HEMIPTERA: CERCOPIDAE), A NEW PEST OF SUGARCANE

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1.0 SUMMARY

Southern and Central American and Caribbean froghoppers are well-known pests of sugarcane. The first record of sugarcane infested by the native Australian froghopper *Eoscarta carnifex* was confirmed at Tully and Ingham in 1987, but symptoms had been recorded since 1983. These infestations coincided with trends to harvesting cane unburnt and retaining crop residues as a surface blanket. This project commenced in anticipation of further outbreaks, to provide basic information with which to develop suitable pest management practices.

I developed methods for estimating froghopper adult numbers and for assessing the intensity of froghopper-induced symptoms on leaves. The maximum population of adults detected during this study was only 0.4% of that commonly reported from Trinidad, where the most definitive froghopper population studies have been carried out.

The life cycle of *E. carnifex* in sugarcane is similar to that of the Caribbean froghoppers, with at least three generations during the `wet' summer and autumn months, and diapausing eggs which survive in the soil over the `dry' winter and spring months.

In Trinidad, soil temperature and moisture regulate survival and hatching of diapausing eggs and young nymphs. At Tully, the practice of crop residue retention reduced potentially lethal soil temperatures and enhanced soil moisture and the numbers of surface roots. The effect of these changes on froghopper survival and population growth was not quantified. Infestation patterns suggest that crop residue retention did not predispose crops to infestation.

Crop losses were not measurable at the low population density and symptom expression experienced during this study. Some cultivars are more attractive to *E. carnifex* and more prone to severe symptoms than others.

Infestations appear static and are localised within the Tully and Ingham region. In sugarcane, *E. carnifex* infestations are associated with alluvial clay loam soils in regions of high rainfall and humidity. It is unlikely to become a pest in other sugarcane producing regions.

2.0 INTRODUCTION

In Central and South America and the Caribbean, indigenous froghoppers (Hemiptera: Cercopoidea) adapted to and became the major pests of sugarcane (Fewkes, 1969a). Froghoppers damage sugarcane in tropical and subtropical regions of western and southern Africa, India, South-east Asia, Taiwan and the Philippines (Fewkes, 1969a).

The froghopper *Eoscarta carnifex* (F.) is indigenous and widespread throughout tropical and subtropical Australia (Qld Department of Primary Industries Collection, Brisbane). `Blighting' symptoms on sugarcane leaves were first noticed at Tully and Ingham in 1983-84 and symptoms associated with *E. carnifex* in 1988 (Magarey *et al*, 1988).

This project was initiated because cultural changes to harvesting unburnt cane and retaining trash residue on the soil surface may have created an environment favouring *E. carnifex*, and

also similar changes in other areas could expand the range and pest status of this insect.

3.0 OBJECTIVES

(i) Develop methods for sampling all stages of *E. carnifex* and the symptoms on sugarcane plants.

(ii) Define the biology and population dynamics of *E. carnifex* on sugarcane.

(iii) Determine the relationship between *E. carnifex* numbers and crop losses, and develop pest management practices.

(iv) Identify other potential *E. carnifex* outbreak areas.

4.0 BACKGROUND

Efficient sampling and monitoring methods are necessary for studying population dynamics (Southwood, 1978; Evans 1971, 1972, 1974) and for pest management (Evans and Buxo, 1972; Norton and Evans, 1974). I developed sampling plans to estimate *E. carnifex* distribution and symptom dispersion.

The phenology of froghopper infestation in sugarcane environments depends on egg diapause over the `dry' season, and timing of egg hatch at the beginning of the following `wet'. Soil temperature and moisture patterns are key factors in egg and nymph survival (King, 1975). I measured soil temperature under conventional bare soil cultivation and under crop residues to estimate the influence of this change in cultural practice.

The nature and extent of loss due to froghoppers are not well known (Fewkes, 1969b; Norton and Evans, 1974; Batterby, 1982). I attempted to quantify losses as a pre-requisite to further work on *E. carnifex*.

Geographic distribution of froghoppers was studied throughout sugarcane producing regions to identify areas prone to outbreaks.

5.0 DIFFICULTIES ENCOUNTERED

Detecting eggs in soil and nymphs on roots was impractical and inefficient, as concluded by Fewkes (1969a). Egg and nymph sampling was not pursued following the SRDC review in 1991. This review recommended highest priority for measuring crop losses due to *E. carnifex*.

There were too few *E. carnifex* in 1991 and 1992 for further studies of sampling methods, crop losses, and conditions predisposing outbreaks.

This report presents results from 1989-90. **BSES staff expended minimal time and resources on this project in 1991 and 1992 and all unspent funds were returned to SRDC.**

6.0 RESEARCH METHODS

6.1 Monitoring methods

Visual searching is suitable for monitoring the large, orange-coloured, planthopper-like *E. carnifex* adults on sugarcane leaves. Numbers of adults at lights were noted as an indicator of population trends.

Nymphal froghoppers (`spittlebugs') are creamy-yellow and live on roots within crevices and under trash on the soil surface. Nymphs form a frothy mass of bubbles about their bodies resembling spittle, which is a useful guide to finding nymphs. I attempted to find nymphs by visual searching, by slowly flooding soil and forcing insects to the surface, and by washing and sieving.

Adults and nymphs were observed for evidence of predators, parasites and pathogens.

6.2 Sampling methods

Populations: Quantitative estimates of adult *E.carnifex* populations (froghoppers per stem) were obtained by three visual search methods with the same two operators at 42 sites on one transect in the one day. A relative population estimate (froghoppers per unit row length) was obtained by scanning (but not searching) froghoppers on a total of 6 m of row face at each of the 42 sites. I selected a search method which seemed most practical, rapid, and representative of froghopper dispersion.

I counted froghoppers on 60 sets of 20 stems. I then randomly selected data from the set to create a range of sample sizes. Mean and variance were calculated for the different sample sizes. The sample variance:mean ratio was plotted against sampling unit size (1-20 consecutive stems per site) for 10, 15, 20, 30, 40, and 60 sites in the field, and the sample size which minimised population variance identified on the resultant curve.

Leaf symptoms: Symptoms on each of the upper three fully expanded leaves (Magarey *et al,* 1988) were rated as:

0 = healthy leaf tissue, no symptoms;
1 = red feeding scars with slight tissue chlorosis;
2 = red feeding scars plus chlorotic stripes, some reaching the margin and with only slight tissue necrosis;
3 = necrotic stripes to the margins and around the periphery at the tip, with substantial loss of active tissue.

Total symptom expression on the three leaves was summed 0-9. Symptoms were recorded from 10 consecutive stems at 42 randomly stratified sampling sites. Data sets were randomly selected to create a range of sample sizes. The sample variance:mean ratio was plotted against sampling unit size (1-10 stems per site) for 10, 20, 30, and 42 sites in the field, and the sample size which minimised population variance identified from the curve.

6.3 Dispersion characteristics and sampling plans

Populations and symptoms were sampled at four sites at Tully and two sites at Ingham for dispersion analysis.

Regression models for Taylor's power law (Taylor, 1961), Iwao's patchiness regression (Iwao, 1968), and the negative binomial distribution (Southwood, 1978) were applied to sample mean and variance data, using methods described by Chatterjee and Price (1977), to determine spatial characteristics of *E. carnifex* populations and symptoms. Sampling precision of p = 0.25 allows estimation which will detect doubling or halving of a population and is used in assessing large population changes such as in insecticide trials. Precision of p = 0.1 is necessary to detect smaller changes such as in ecological studies and population dynamics (Southwood, 1978).

The expression

$$n = \frac{a.\bar{x}^{(b-2)}}{p^2}$$

was used to calculate the numbers of samples required at the two precision levels, where n is the sample size and p is the required level of precision expressed as a proportion of the mean (Southwood, 1978).

Fixed-precision-level stop lines for sequentially sampling with pre-determined levels of precision were calculated using the formula derived by Green (1970):

$$\ln T_n = \frac{\ln(p^2/a)}{b-2} + \frac{b-1}{b-2}\ln n$$

where T_n is the cumulative number of adults, p is the precision level, and n is the number of samples. Precision levels of 0.10 and 0.25 were considered.

Sampling strategies were derived to estimate froghopper numbers and symptom expression.

6.4 Field-caging for biology and crop-loss assessment studies

Cages were constructed with a 50 mm diameter PVC centre-pole support and three 900 mm square steel hoop frames, enclosed with green knitted horticultural shadecloth transmitting 50% available light (Figure 1). Cages could be raised to 4 m. The skirt could be elevated to the full cage height by pulling on 3 mm diameter nylon halyard ropes. The lower edge of the shadecloth skirt was buried 10 cm into soil about the base of each cage to anchor the cage and to prevent insect escape.

A 30 x 30 m study area was selected in an existing froghopper infestation. Five stools were selected at random as field controls. A further set of 24 stools with 3-5 stems per stool was selected, and each stool reduced to three similarly sized stems. Four of these were randomly

allocated as uncaged standards. A cage was established over each of the remaining 20 stools on 23 February 1990. The uppermost fully exposed leaf (designated `-1') on each stem in the 29 stools was labelled with an oil marker.

Froghopper adults were captured from wild populations and cages infested with 0, 2, 6, 16, or 40 insects per cage on 23 February 1990. Each treatment was randomly allocated and replicated in four cages. Cages were resupplied with fresh field-collected insects on three occasions up to and including 13 March 1990. The infestation period totalled 20 d. Cages were maintained over plants until 16 May 1990.

Soil about the caged stools was inspected for nymphs in May and June 1990, and in November 1990 and February 1991. New leaf production was progressively recorded in caged and uncaged plants. Froghopper-related symptoms were recorded at four intervals on three leaves below and all leaves above the marked leaf. At crop harvest in July 1990, all stems were removed and taken for sugar content (ccs) and purity analysis in the laboratory.

6.5 Insecticide screening tests

Insecticides were tested against caged froghoppers to identify treatments for keeping plants relatively free of froghopper infestation. Small clip-on PVC cages were constructed to hold froghoppers. Leaves were sprayed to runoff with three concentrations (0.5, 1.0, or 5.0% AI (w/v)) of methomyl (Lannate 225EC), chlorpyrifos (Lorsban 500EC), trichlorfon (Diptrex 625EC), diazinon (Diazamin 200EC), carbaryl (Carbaryl 800WP), or permethrin (Ambush 500EC). A total of 10 insects, in two cages, was exposed to each of the treated leaf surfaces. Twenty insects in four cages were caged on untreated leaves.

6.6 Soil temperature monitoring

Electronic data-loggers (Tain, Melbourne) were installed at three Tully district locations. Temperature was recorded hourly at 1, 7.5, and 15 cm below the soil surface. Measurements were taken under soil with trash residue on the surface and with residue removed.

Mean monthly temperature was calculated for each hour of the day and the diurnal pattern plotted using Sigmaplot (Jandel Scientific).

Figure 1: Field cages for biology studies and crop-loss assessment with caged froghoppers

6.7 Froghopper distribution survey

Froghopper distribution at Tully and Ingham was noted in roadside transect searches for froghoppers and/or their symptoms. Froghopper presence was confirmed where symptoms were located, and populations estimated as froghoppers per 50 m of headland. Twenty-five insects per 50 m transect (~ 3 insects per 6 m row) are equivalent to approximately 1.6 froghoppers per 10 stems (Table 1).

Froghoppers were searched for at Tully and Ingham, and to the south in swampy areas near the Haughton River and to the north in likely environments at South Johnstone and Babinda.

I attempted two surveys to study varietal preference and cultural practices associated with froghoppers. In March 1990, 106 randomly-selected fields at Ingham were surveyed. In early April 1991, 90 fields in the Herbert Valley and 30 fields at Tully were surveyed.

7.0 RESULTS

7.1 Monitoring

Sampling nymphs: All three methods of recovering nymphs were laborious and unproductive. Digging, crumbling and searching soil samples in the field was the most effective method tried. Recovery was time-consuming (0.25-0.5 h for a 400 x 400 mm soil sample) and the counts were of dubious accuracy.

Parasites, predators and pathogens: Two species of predatory bug (Hemiptera: Reduviidae) were often observed stalking and feeding on adult froghoppers. In only one instance, a wasp was seen carrying off a froghopper. Froghoppers killed by fungal disease were common, but no positive disease isolations were made. On one occasion a rat-tailed maggot (Diptera: Syrphidae) was found feeding on a froghopper nymph. An attempt to rear the maggot to the adult stage was not successful.

Preliminary adult sampling: Counts from a series of consecutive stems were preferred. Searching consecutive stems did not cause froghoppers to move as much as searching individual stems. Counts on a set of consecutive stems seemed to account for the loose aggregates of froghoppers on adjacent stems more readily than individual stem counts. Time taken for the three methods was similar in this test (Table 1). However, this consecutive stem search was hindered by the awkward angle of the midday sun, and the method was much more rapid in practice. I abandoned progressive stem searches as it offered little time saving and routine methods of analysis were unavailable.

Table 1

Preliminary survey of 20 sites by absolute and relative estimates of froghoppers on the same sugarcane plants

Method	Population estimate	Time (min)
Search 10 consecutive stems at each site	1.6 . 1.6 per 10 stems	30
Search 10 randomly selected stems at each site	0.9 . 0.6 per 10 stems	28
Progressively search until a froghopper is encountered (abandon count if >50 stems)	8.3 . 9.1 8.8 . 8.5 stems per hopper	30
Scan 6 m of row	3.1 . 3.1 3.7 . 2.8 per 6 m row	10

7.2 Sampling methods

Sampling units - Froghoppers. Population sample variance was minimised with sampling units of 10 consecutive stems (Figure 2). Variance remained similar for 10, 15, 20, 30, 40, or 60 sampling sites per sample. Froghopper number per 10 consecutive stems was used as the sampling unit. Forty-two randomly stratified sampling units were taken in each sample.

Sampling units - Symptoms. Sample variance of leaf-symptom ratings was minimised with sampling units of five consecutive stems and 20 sampling sites per sample (Figure 3). The mean symptom score from five consecutive stems was treated as a sampling unit. Forty-two randomly stratified sampling units were taken in each sample.

Population monitoring: Eleven populations were sampled from six sites between February and April 1990, with 2-4 weeks between samples at any site. Sample mean and variance estimates for froghopper numbers are listed in Table 2. Three peaks of relative froghopper abundance were observed at lights and in headland scans, in both 1988-89 and in 1989-90. General populations were sparse in November 1989, more dense in mid-January 1990, and largest in March 1990. No froghoppers were present after mid-April 1990. Sampling could not be justified in 1990-91 and 1991-92 because of low, sporadic populations.

Leaf symptom monitoring: Eleven sets of symptoms were sampled at six sites between March and June 1990. Sample mean and variance estimates for leaf symptoms are listed in Table 3. Field symptoms became progressively more obvious in February and March. Symptoms remained obvious in April and May, after froghoppers had ceased to emerge.

Figure 2: Sample variance as a proportion of the mean, with counts of the froghopper population on sampling units of 1-20 consecutive stems at 10, 15, 20, 30, 40, and 60 sampling sites in the field

Figure 3: Sample variance as a proportion of the mean, with ratings of symptoms on sampling units of 1-10 consecutive stems at 10, 20, 30 and 42 sampling sites in the field

7.3 Dispersion characteristics

Froghoppers: Taylor's power law gave a significant linear regression ($R5 = 0.930$) when all 11 samples (Table 2) were included. Iwao's model gave a significant linear regression ($R5 = 0.623$) when all 11 samples were included. Regression of the negative binomial parameter *k* on
x

- was not significant ($P = 0.137$) indicating that calculation of a common *k* is valid. Regression of y^1 on x^1 gives a significant relationship ($R5 = 0.817$) and a common *k* of 3.302.

Leaf symptoms: Taylor's power law gave a significant linear regression of symptom estimates (Table 3), with $R5 = 0.572$, but the quadratic term was also significant ($P = 0.038$) and there were significant outliers in the distribution of the standard residuals. Iwao's model gave a significant linear regression ($R5 = 0.988$) with no significant quadratic component ($P = 0.093$) and no outliers or patterns in the distributions of the standardised residuals. Regression of the negative binomial parameter *k* on
x

- was not significant ($P = 0.751$). Regression of y^1 on x^1 did not give a significant relationship ($P = 0.576$), so a common *k* can not be calculated.

7.4 Sampling plans

Froghopper estimation: Fixed-precision-level stop lines for estimating adult populations with precision levels of 0.1 and 0.25 are given in Figure 4. In the field, random sampling units are taken and the cumulative numbers of froghoppers successively plotted against the corresponding sampling unit number until the stop line of the required precision is crossed. The mean density per sample at this point is estimated by T_n/n. Use of these stop lines provides a time-efficient method for estimating froghopper populations at desired levels of precision.

Generated plans to calculate numbers of samples needed for estimating adult populations with precisions of 0.10 and 0.25 of the mean are given in Figure 5. In operating the plans, it can be seen that more samples must be taken to achieve higher precision, eg 73 samples are required to estimate a mean population of 2.5 adults per 10-stalk sample with 0.10 precision, whilst 12 samples are required for an estimate with 0.25 precision.

Leaf symptom estimation: Iwao's patchiness regression is the only appropriate model for symptom data. The slope indicates that symptoms are distributed uniformly between samples ($\beta<1$) and thus sequential sampling plans can not be developed for estimating *E. carnifex* leaf symptoms on sugarcane.

The usual expression for the number of sampling units (*n*) is:

$$n = (s/p\bar{x})5$$

This expression can be used to determine the number of units necessary to estimate

symptoms with the required degree of precision. Approximately 20 units should be sampled before calculating the number of units necessary. The variance:mean ratio stabilised for most samples at about 20 samplings.

Table 2

Mean and variance estimates of 11 froghopper populations sampled at Tully and Ingham

	J Bosnich Lower Tully			**J DiLorenzo Collins Road**			**Tully River**		**Lower Tully School**	**Halifax Corner**	**Hawkins Creek Corner**
Date (1990)	1/3	15/3	4/4	5/2	5/3	15/3	22/2	13/3	9/3	10/4	10/4
Sample mean (froghoppers/10 stems)	4.12	2.67	0.50	1.40	2.55	0.83	1.46	0.98	2.61	0.02	0.06
Sample variance	8.79	3.44	0.55	2.34	6.81	1.02	2.55	1.44	5.46	0.11	0.06

Table 3

Sample mean and variance estimates of leaf symptom ratings (0-9) per stem

	J Bosnich Lower Tully			**J DiLorenzo Collins Road**			**Tully River**		**Lower Tully School**	**Halifax Corner**	**Hawkins Creek Corner**
Date (1990)	1/3	15/3	4/4	15/3	6/4	15/6	22/2	13/3	9/3	10/4	10/4
Sample mean	3.40	4.78	5.18	2.91	4.07	0.95	1.67	3.20	1.78	0.18	0.50
Sample variance	0.87	0.91	1.27	2.50	2.88	2.23	1.38	1.17	1.58	0.26	0.44

Figure 4: Fixed-precision-level stop-sampling lines for estimating population density with precisions of 0.1 and 0.25 of the mean

Figure 5: Generated plans of number of samples necessary to estimate froghopper populations with precisions of 0.1 and 0.25 of the mean.

7.5 Effect of field-caged populations on plant growth

Froghoppers survived, fed and mated on sugarcane plants in the cages. Adults lived for approximately 7-10 d. At the close of the infestation in March 1990, less than 45% (n = 220) of captured insects remained alive after 5 d. The wild population declined rapidly from 9 March 1990, and very few insects could be captured to supply the cages. The caging period totalled 20 d.

Leaf symptoms: On caged stems, froghopper-related symptoms on leaves designated +1 through +3, which opened during the infestation period, expressed progressively for at least 72 d after infestation commenced (Figure 6). Symptom intensity increased at higher populations (Figure 6). Some symptoms expressed on leaves +1 through +3 in control cages, presumably because these stems had been infested by the wild population prior to caging. Symptoms also expressed on leaves (designated +4 and above) which opened after the froghopper caging period (Figure 7), even as long as 61-91 d post-infestation (mid-June).

A similar pattern was repeated on uncaged stems. Symptom expression on new leaves increased (Figure 8) for at least 20 d from when the infestation ceased, and thereafter declined, but did not disappear.

New leaf development: New leaves developed at similar rates in infested and non-infested stems (Figure 9). Uncaged standard stems produced a similar number of new leaves (13.1 . 2.6, n = 15) to caged uninfested stems (10.5 . 2.5, n = 14) in the 102-day period following caging.

Sugar content: Mean (n = 4) sugar content (ccs) of uninfested, caged stems was less than that of uncaged stems from the control plants and the 3-stalk standard plants (Figure 10). Both sugar in juice (pol) and total dissolved solids in juice (brix) were reduced (Figure 10). Mean juice purity was slightly reduced by the caging effect (Figure 10).

Sugar content and purity of uncaged stems from 3-stalk plants were only slightly lower than from randomly selected stools which had not been reduced to three stems (Figure 10). Sugar content (laboratory ccs - 1.5 units) of uncaged, randomly selected canes was 13.64 (0.34), an acceptable outcome for variety Q107 in mid-June at Tully. Sugar content and purity varied slightly between infested and non-infested, caged stems. All values were within the same fiducal limits (Figure 10).

7.6 Insecticide screening tests

Carbaryl and methomyl were the most effective insecticides. Chlorpyrifos and diazinon were slightly effective, and trichlorfon was ineffective (Table 4). Permethrin was evaluated separately from the other compounds because of insufficient test insects on the originally scheduled date; control group mortality was excessive and the results are not reported.

Figure 6: Symptoms expressed on leaves +1 through +3 artificially infested in cages, at post-infestation intervals of 18, 42 and 72 d

Figure 7: Symptoms expressed on uppermost leaves of caged plants opening in the post-infestation period

Figure 8: Symptom expression on the three uppermost leaves of uncaged plants relative to froghopper population

Figure 9: New leaves produced by caged stems 18-102 d after infestation with 0-13 froghoppers per stem for 20 d

Figure 10: Mean and fiducial limits of estimated sugar content and purity of first expressed juice from uncaged stems in 3-stalk standard plants and in randomly selected plants, and of caged stems from 3-stalk plants subjected to 0-13 froghoppers per stem.

Table 4

Percentage mortality of froghoppers exposed to dried insecticide residues on sugarcane leaves

Insecticide	% AI (w/v)	% mortality and insect condition		
		2 h	3 h	20 h
methomyl	0.5	0	0	90 (S)
	1.0	0 (S)	30 (S)	100
	5.0	100	-	-
chlorpyrifos	0.5	0	0	80 (S)
	1.0	0	0	50 *
	5.0	0	0	50 *
trichlorfon	0.5	0	0	0
	1.0	0	0	20
	5.0	0	0	50 *
diazinon	0.5	0	0	80 *
	1.0	0	0	70 *
	5.0	0	0	100
carbaryl	0.5	0	0	90
	1.0	0	30 (S)	100
	5.0	70 (S)	100	100
control (+)	0	0	0	46

(S) = sick insects.
* = ants removed some (dead?) insects overnight; value calculated on remaining insects.
\+ = mean of 40 insects.

7.7 Soil temperature monitoring

Soil temperature gradients and diurnal patterns: Monthly mean diurnal soil temperature patterns, for paired sites with and without crop trash residue, are given for October 1989 and January 1990 at Tully Sugar Experiment Station (Figure 11). Monthly mean diurnal soil temperature patterns under a crop residue blanket at the caging site are given for October 1989 and January 1990 (Figure 12). Data-loggers suffered many malfunctions due to moisture invasion, rat damage to cables, machinery damage and battery failures, and so much of the data are of limited value.

Soil surface changes under trash residue: Paired observations during the early summer period, October to December 1989, showed that the surface soil was moist and contained many actively growing and functional roots under crop-residue blankets, whereas bare-cultivated soil was mostly dry and contained relatively few surface roots.

7.8 Froghopper distribution survey

Tully region: Scattered froghopper infestations in sugarcane were found on alluvial loam soils from Liverpool Creek to the Tully River. The insects were most prevalent on clay-loam soils along the Tully River. In 1988, a dense population occurred on clay-loam soil west of Feluga.

Ingham region: Froghoppers and their symptoms were most prolific on alluvial clay-loam soils either side of the Herbert River downstream from Ingham township. Low density populations and light symptom expression were detected throughout the Herbert valley canegrowing region. Froghoppers occurred infrequently on sandy-loam soils. Moderate populations were seen on clay-loam soils west of Ingham, at Stone River and towards Abergowrie. Moderate populations occurred in three successive years (1989-1992) at two sites on poorly drained duplex soils at Yuruga and Murtarnee, on the southern extremity of the Herbert Valley.

Other areas: A heavy population was reported (M Ward, BSES, Innisfail) from grassland west of the canegrowing region at Abergowrie. Other populations were reported in grassland at Ravenshoe (D Rodman, James Cook University, Townsville) on the Atherton Tableland.

Conditions and varieties associated with froghoppers: Froghopper populations in March 1990 and April 1991 were insufficient to develop conclusions from surveys of factors associated with infestation.

Cultivars Cassius, Pelorus, Triton, Q107 and Q99 all showed severe symptom expression on occasions. Q117 was not frequently infested. Froghoppers infested Cassius in preference to Q117 in one field at Ingham, with far more severe symptoms in Cassius. One field of Q117 at Lower Tully developed a heavy infestation, and moderate-severe `blight' symptoms. Other cultivars, including Q115, Q120, Q119, Q124, Q128 and Q134, were occasionally infested.

Soil type seems to be an important factor in determining *E. carnifex* infestations. Alluvial clay-loam soils in `wet' or poorly drained areas support higher froghopper populations than sand and silt-loams and schist-derived loams, especially at Ingham. Sugarcane froghoppers in Trinidad prefer heavy clay-loam soils (Fewkes, 1969a). At Tully, the cracking soils may allow nymphs to gain access to roots near the soil surface, because these insects are not capable of excavating their own burrows. Also, clay soils retain more moisture than others, perhaps aiding egg survival in the dry season (King, 1975).

There was no evidence to suggest that trash blanket retention is associated with an increase in froghopper densities. Crops with both management practices supported high populations.

Figure 11: Monthly mean diurnal soil temperatures for paired bare-earth-cultivated and crop-residue-blanketed sites at Tully

Figure 12: Monthly mean diurnal soil temperatures for October 1989 and January 1990 at a crop-residue-blanketed infestation at Tully

8.0 DISCUSSION

8.1 Biology, population dynamics and symptom expression

There are insufficient data to quantify the number of generations in the annual cycle, the interval between population peaks, or the multiplication potential of *E. carnifex*. Observations suggest three generations through the summer at approximately 6 week intervals, and a 120-fold population density increase between the first and third generation. Egg diapause is the `dry-season' survival mechanism.

Symptom expression does not readily relate to froghopper population density. Symptoms become more obvious through the infestation period, and express progressively over at least four weeks. The most reliable symptom of froghopper activity seems to be the transitional stage where the reddened feeding scar on an upper leaf is associated with a developing chlorotic stripe. Rodman and Miller (1992) described the salivary enzymes probably associated with the leaf scorch symptoms caused by *E. carnifex*.

Leaves not visible at the time of froghopper feeding also express symptoms once they open. This suggests that some *E. carnifex* may probe their mouthparts through the spindle and into the rolled leaves, or even into the leaf primordia at the growing point. Alternatively, there may be other causes of symptoms which resemble *E. carnifex* feeding effects. Other leaf-sucking insects such as *Lophops* spp. (Hemiptera: Lophophidae) are suspected of causing similar symptoms in PNG sugarcane (Chandler, BSES, Gordonvale). *Lophops* spp. are common in northern Australian sugarcane fields. Chlorotic streak disease is common in the same areas where froghoppers occur, and symptoms could be confused. Likewise, natural leaf senescence, and extremes of yellow-spot disease, can both cause necrosis which resembles extreme froghopper feeding effect.

8.2 Dispersion of froghopper populations

Based on the R5 values, Taylor's power law is the preferred model for froghopper populations. Slopes from Taylor's and Iwao's models indicate an aggregated spatial pattern for froghopper adults ($b>1$). The derived sampling plan (Figure 5) indicates the relative ease of estimating froghopper adult populations with precision of 0.25, with only 10 samples being necessary in a moderately infested field. The number of samples necessary for more precise studies increases 6-10 fold at similar population densities.

8.3 Dispersion of foliar symptoms

Symptoms are uniformly distributed. This is probably a reflection of the continually moving population, coupled with the long period of symptom expression. A fixed sampling size plan of 20 samples is adequate for estimating symptom expression.

8.4 Effect of caged infestation on sugar content and plant growth

There was no reduction of sugar content due to caged *E. carnifex* at the populations tested. The highest number of *E. carnifex* (13 insects per stem) was approximately 100 times the field population density (1.3 insects per 10 stems). However, the maximum population of *E. carnifex* is well below populations of 100 *Aeneolamia* spp. per stem in Trinidad (Fewkes, 1969a), and it is probable that crop losses will occur at higher *E. carnifex* populations.

Sugar content was significantly reduced due to caging. The caging effect may have obscured any yield depression due to *E. carnifex*, and any further caging studies will need to address this issue.

New leaf production was unaffected by caged froghoppers. Caged plants produced as many leaves as uncaged plants. Caged stems collapsed easily, perhaps due to reduced fibre content of stems and/or softer rinds.

Caging to confine known froghopper populations on stems seems useful for estimating froghopper-induced sugar loss, despite the caging effect on sugar production. Estimates of economic injury thresholds are possible with a range of population densities created by caging, whereas insecticide disinfestation allows only a single estimate of the effect of the field population. The caging effect could be lessened by having cages in non-infested sites and removing cages as soon as the infestation period was complete.

8.5 Insecticide screening test

The carbamate insecticides carbaryl (Carbaryl) and methomyl (Lannate) are the most effective insecticides tested. Neither are registered for use in sugarcane. Carbamate insecticides were initially the most effective compounds applied in Trinidad (Fewkes, 1969b), before resistance developed (R Manuel, Carapachima Research Station, Trinidad). None of the compounds registered for sugarcane in Queensland appear promising. Permethrin (Ambush), which is registered in sugarcane, should be tested again if the need for an insecticide arises. Methomyl is a far more hazardous to humans and animals than carbaryl, and so carbaryl is preferred.

8.6 Crop-residue-blanket effects

In October, maximum temperatures 1 cm below the soil surface under a blanket of crop residue were at least 10□C less than under bare, cultivated soil, and the duration of maximum soil temperature (37□C) was reduced by at least 2 h/d. The effect of crop residue retention on soil temperature diminished at 7.5 and 15 cm depth. Surface zone root growth was visually greater under crop residues. Surface soil moisture was also slightly higher under the crop residue blanket. Surface humidity increased slightly during early mornings under trash residues, but differences were only slight when trash heated, and at night.

Crop-residue blanket retention reduces potentially lethal soil temperatures and maintains higher moisture at the soil surface during the `dry' season. These changes could increase egg survival through diapause, and bring forward the breeding period. The greater quantity of

active roots at the surface under a residue blanket could create more feeding sites, increasing nymph survival. Some or all of these changes are likely to increase population density. However, there was no evidence of increased populations in crop-residue retention fields.

8.7 Froghopper distribution

E. carnifex populations did not develop in regions other than Tully and Ingham during the project. The distribution seems to be confined to suitable clay-loam alluvial soils in relatively wet production environments.

Varietal preference: E. carnifex appears to prefer certain sugarcane varieties; however, it will infest most. Once infested, a `non-preferred' cultivar such as Q117 can express severe symptoms. Highly significant, family related differences in symptom expression between varieties occurred in a variety trial at Tully (N Berding, BSES, Gordonvale). However, these differences could have been wholly or partly due to preferential feeding behaviour. Varieties Cassius and Q117 both showed only very slight symptoms in this trial, which contrasts with several field observations of these varieties.

9.0 OUTCOMES

Relatively efficient and reliable field sampling techniques are now available should further research be necessary.

Froghopper infestations in the 1980s probably caused only minimal loss.

Tully and Ingham populations have not expanded geographically in five years. There is a historical suggestion that leaf symptoms from *E. carnifex* have been a regular feature at Tully and Ingham for many years prior to recognition of *E. carnifex* as the causal agent.

At Tully, crop-residue retention alters soil temperature and moisture patterns and root growth in a manner which could increase populations.

There is no evidence that populations escalated at Tully or in any other area due to the adoption of crop-residue retention practices.

Field populations of *E. carnifex* at Tully would need to increase up to 700-fold to equal population densities of recognised froghopper pest species in Caribbean countries.

No significant intellectual or financial property was created or developed during this project.

10.0 RECOMMENDATIONS

There is little justification for further research on this insect.

In any future work, highest priorities should be afforded to assessing economic injury level.

The caging technique seems to offer the best opportunity for estimating economic injury levels.

11.0 TECHNICAL SUMMARY

A generated sampling plan for estimating *E. carnifex* populations with predetermined levels of precision was produced. A standard sampling procedure for estimating symptom intensity has been validated.

Field cages for use over sugarcane plants were developed and successfully used under tropical conditions. The caging equipment and method of monitoring plant development may be useful in other insect-pest-related studies of sugarcane.

Diurnal soil temperature data generated in this project have potential for research on insecticidal and biological control of cane pests.

12.0 PROPOSED PUBLICATIONS

Chandler, K J and Allsopp, P G Sampling adults of *Eoscarta carnifex* (Hemiptera: Cercopidae) and their associated symptoms on sugarcane. Submitted to *Journal of Economic Entomology*.

Influence of trash residues on soil temperatures.

Description of the large field cages.

13.0 ACKNOWLEDGMENTS

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