BUREAU OF SUGAR EXPERIMENT STATIONS

QUEENSLAND, AUSTRALIA

FINAL REPORT

SRDC PROJECT BS61S

MAXIMISING THE RESISTANCE OF SUGARCANE TO SOLDIER FLY

by

P R Samson

SD96002

Principal Investigator:

Dr P R Samson
Senior Research Officer
BSES
PO Box 651
BUNDABERG Q 4670
Phone (071) 59 3228

This project was funded by the Sugar Research and Development Corporation during the 1991/92, 1992/93, 1993/94 and 1994/95 financial years.

BSES Publication
SRDC Final Report SD96002 **June 1996**

CONTENTS

Page No

1.0 SUMMARY

This project aimed to understand the interaction between soldier fly larvae (*Inopus* spp.) and sugarcane varieties, as affected by environmental conditions, and to identify varieties and agronomic practices that would minimise losses caused by the pest. All studies were carried out using the sugarcane soldier fly, *Inopus rubriceps*.

The effect of soldier fly larvae on germination of sugarcane setts was investigated in pots (Appendix I). Shoot elongation was inhibited when setts were exposed to larvae, although buds often expanded initially. Elongation was resumed when larvae were removed, indicating that larval feeding may not cause permanent harm to setts. Infested setts produced a greater weight of roots than uninfested setts. Similar effects were induced by mechanical root pruning, suggesting that the effect of soldier fly larvae may be due to a redirection of growth from the shoot to roots as a consequence of root damage. Large larvae were more harmful to shoot production than smaller ones, and larvae had a greater effect on shoot production at lower temperature. At 18°C, larvae were more harmful to variety Q151 than to the faster-germinating CP44-101. At 25°C, however, both varieties produced shoots in a similar time and the effect of larvae was similar on each. Larval size, temperature and variety may all influence the harmful effect of soldier fly larvae on sett germination by changing the differential rates of plant growth and larval feeding.

The effect of soldier fly on growth and ratooning of sugarcane plants was measured in pots, using variety CP44-101 (Appendix II). Infested plants were slightly smaller at harvest and produced many fewer ratoon shoots than uninfested plants. Ratoon shoots tended to arise from buds nearer the soil surface on the stubble of both infested and uninfested plants, but a greater proportion of buds failed to sprout on the infested plants. Shoot elongation from buds was also inhibited in setts cut from infested stalks and planted in uninfested medium. Analysis of nutrient levels in plants did not indicate the mechanism for ratooning inhibition, as levels of the 10 elements analysed were at least as high or higher in infested plants. Infestation was associated with an increased level of sucrose and a reduced level of fructose in stalks, and a higher level of soluble solids in juice (brix), but the implication of these measurements is unknown. The effect of larval feeding on ratooning was not reversed if larvae were removed from pots 9 - 10 weeks before harvest. However, new stubble produced from infested plants was unaffected by prior infestation when the new roots were not attacked. Large larvae were more harmful to ratooning than smaller individuals; this could influence damage in commercial crops as the mix of larval sizes at time of harvest varies between canefields and years. Infestation had a greater proportional effect if plants were grown under dry conditions or without fertiliser, and crop response in the field is likely to be affected by any environmental conditions that reduce growth and ratooning vigour.

Potted plants of 22 sugarcane clones were artificially infested with soldier fly larvae (Appendix III). Three experiments of 10 clones each were carried out, with several clones repeated as standards in each experiment. Soldier fly infestation reduced the number of ratoon shoots produced by all clones, in comparison with uninfested pots. However, some infested clones were able to produce more ratoon shoots than others. A rating system was developed based on the number of ratoon shoots produced by infested plants. Of the clones tested, Q135, Q144, and 77N330 performed the best. Ratings of the standard

clones were generally consistent, although the ratings for one clone (H56-752) differed markedly between two experiments. Differences in ratooning between infested plants were due to tolerance alone; growth and survival of larvae were usually the same on all clones. In one experiment, the most tolerant clones were also the ones that had the most underground buds and that produced the most ratoon shoots in the absence of soldier fly. However, this did not explain different levels of tolerance in the two other experiments. Levels of tolerance were not correlated with other characteristics that were measured for uninfested clones - above-ground weight, root weight, root/top ratio, brix, proportion of underground buds that ratooned, or days to appearance of the first ratoon shoot.

Four field trials were established, each with ten commercial sugarcane varieties in ten replicate plots (Appendix IV). Trials were monitored for three harvests. Numbers of soldier fly larvae differed slightly between varieties, but probably not enough to provide useful control. Larval weights were the same on all varieties, showing that antibiosis was not involved. The effect of soldier fly on varietal performance in each trial was examined by regression of numbers of ratoon shoots and subsequent numbers of mature stalks and crop yield on larval numbers during summer-autumn within each crop class. Each increase in soldier fly density of 100 m^{-2} was associated with a yield reduction of 1.2 - 6.5 tonnes cane ha^{-1}, or 3 - 20% of the predicted yield of uninfested plants. In general, the slopes of regressions were the same for all varieties, indicating no differential response to soldier fly infestation. Despite differing soldier fly populations in the different trials, there was no substantial difference in relative performance of the varieties. These results conflict with results of an earlier detailed study of one commercial and one experimental clone (81S595), and with the conclusions of the glasshouse screening in this project (Appendix III). Routine selection of commercial varieties for vigour may confer some tolerance of soldier fly. Differences between the commercial varieties tested may have been more apparent at higher infestation levels, or under different management strategies such as early harvest that would place greater stress on the plants.

Soldier fly damage in fields harvested as second ratoons in 1991 was surveyed in the Bingera Mill area in 1992 (Appendix V). The status of fields was determined by consultation with growers. Apparent damage was then analysed in relation to the history of farming practices in each of 194 fields. Damage was most frequent in fields that had a history of damage in the previous cropping cycle. Damage was also most frequent in fields that had been ploughed during fallows. However, ploughing was itself most frequent in those fields that had suffered previous damage, and so the apparent relationship between ploughing and subsequent damage may be spurious. No other cultural practices seemed to influence damage, including length of fallow which was expected to be significant. The frequency of damage differed significantly between varieties, the percentage of fields damaged for each of the main varieties being: Q141, 20%; H56-752, 29%; Q144, 36%; CP51-21, 43%; CP44-101, 44%; Q110, 61%. This ordering of damage does not agree with expectation based on pot comparisons or anecdotal evidence of tolerance. It is possible that growers may not have correctly identified soldier fly damage, particularly in 1991 when effects of drought and soldier fly could have been confused. It will be difficult to separate cause and effect in any survey because of interrelationships between farming practices and damage in previous cropping cycles.

In summary, the study determined that larval size, temperature and variety influence the harmful effect of soldier fly on shoot production by cane setts. The symptoms of larval attack on setts can be explained by plant growth processes induced by damage to roots. Soldier fly larvae also cause some enduring decline in the ability of sugarcane stubble to ratoon. The effect of larval infestation on bud activity extended to buds on the stalk, with the greatest effect in basal buds. Response of ratoons will be affected by the population structure of larvae in the field, which varies between canefields and years, and by environmental conditions that reduce crop growth and ratooning vigour - dry conditions, inadequate fertiliser, and harvest during cool conditions. In pots, some clones were able to produce more ratoon shoots than others when attacked by soldier fly larvae. This was due to tolerance alone, and a rating system for tolerance was developed from these pot experiments. However, a selection of these varieties did not show significant variation in response to soldier fly in field trials. This conflicts with anecdotal accounts of differing varietal responses to soldier fly in commercial canefields, and the unequivocal demonstration of variation in tolerance in an earlier study of two clones (Samson *et al.*, 1993). Possible reasons may be that the commercial varieties chosen for field testing already possess considerable ability to ratoon under stress, and the trial conditions may not have applied sufficient pressure to the plants. It would still be worthwhile to compare the yields of promising newer varieties in occasional field trials in affected areas.

2.0 BACKGROUND

Infestations of soldier fly (*Inopus* spp.) cause losses to sugarcane in areas from Innisfail to New South Wales. Cane losses attributable to soldier fly in Queensland in 1995 were estimated at 24 000 t, and the annual cost of soldier fly infestations to farmers and millers probably exceeds $1M. The number of farms affected by soldier fly at Mackay is increasing, and the pest has recently appeared at Ayr where it has not been recorded previously. During the late 1950s and early 1960s, losses attributable to soldier fly in Queensland were up to 80 000 t of cane per year on a much smaller assigned area. The pest was subsequently controlled by the application of dieldrin, but this chemical is no longer available and alternatives have not been found. With the loss of dieldrin, there is a high potential for a disastrous increase in losses.

Cane losses could be reduced by agricultural practices that maximise the resistance of sugarcane to soldier fly attack, eg growing varieties that are inherently resistant to soldier fly and managing conditions for crop growth.

Past observations suggest that varieties of cane may respond differently to soldier fly (Moller, 1965). In a previous glasshouse experiment, two clones responded differently when exposed to a range of densities of soldier fly larvae (Samson *et al.*, 1993). This indicates that screening commercial varieties for resistance may be feasible, and varieties could be recommended for planting in soldier fly-prone areas.

Environmental factors also may influence the response of cane to soldier fly. Untested observations suggest that germination of cane setts is more likely to be affected if autumn-planting is late, and ratooning is more likely to be affected if harvesting is early (Moller, 1968). Such changes may reflect different effects of temperature on development rates of

plants and insects, as has been measured in some other agricultural systems (eg Samson and Geier, 1983). Planting or harvesting date, soil moisture content, and fertiliser application could be manipulated to reduce cane losses, if their effect on the interaction between soldier fly larvae and cane was understood.

The development of practices for maximising the resistance of sugarcane to soldier fly would have multiple benefits within an integrated pest management program. Not only would crop losses be reduced directly, but additional time would also be available for natural enemies of soldier fly to build up and exert control before crop damage reached unacceptable levels.

3.0 OBJECTIVES

- To determine the response of sugarcane to different developmental stages of soldier fly larvae feeding at different stages of plant growth, in laboratory and glasshouse experiments.

- To determine the effect of soil temperature, moisture content, and fertiliser applications on varietal responses to soldier fly in pot trials.

- To compare the resistance of current and potential commercial varieties to soldier fly in glasshouse and field experiments.

- To attribute plant resistance to one or more of the components - nonpreference, antibiosis, or tolerance, and to understand the interaction between larvae and plants and the mechanism of resistance.

- To survey existing varieties and agronomic practices for their influence on soldier fly damage.

- To update pest management strategies for soldier fly in sugarcane, and assess the feasibility of screening sugarcane varieties for resistance.

4.0 ANALYSIS OF OBJECTIVES AND RESEARCH OUTCOMES

- Large soldier fly larvae were more harmful than smaller ones to both germinating setts (Appendix I) and ratooning stubble (Appendix II). This may influence the risk of damage to setts planted in different seasons; eg larvae will usually be larger in autumn fallow plants than in spring replants, although in this case the effect of larval size is likely to be outweighed by the effect of fallow length on pest numbers. Damage to ratoons may depend on the proportion of infesting larvae that are in their second year of development, and this will vary between canefields and years (Samson and McLennan, 1995).

- Low soil temperature exacerbated the effect of larvae on both setts (Appendix I) and ratoons (Appendix II), and both dry conditions and inadequate fertiliser increased the effect of larvae on ratoons (Appendix II).

- A rating system was developed for the ability of 22 sugarcane clones to ratoon despite the presence of soldier fly (Appendix III). Ratings were generally consistent between three glasshouse experiments. Of the clones tested, Q135, Q144 and 77N330 performed the best. However, strong varietal differences did not show up in field trials (Appendix IV).

- No antibiosis was shown in either the glasshouse experiments (Appendix III) or the field trials (Appendix IV). Differences in varietal responses in glasshouse experiments were due to tolerance alone. Some evidence of slight nonpreference was obtained in field experiments, but the level was probably too low to be of significance and damaging soldier fly populations developed on all varieties.

- A survey of varieties and agronomic practices gave equivocal results because of difficulties with both methodology and interpretation (Appendix V). Variety Q141 showed the lowest frequency of damage and Q110 the highest among six main varieties. Ploughing was positively correlated with damage but this may have been due to ploughing being undertaken as a control response to infestation in the previous crop cycle.

- Pest management strategies being promulgated include recommendations based on the effect of agronomic conditions on damage, and glasshouse ratings for tolerance are being used as a guide to planting in soldier fly-prone areas. The results do not support an intensive program of screening sugarcane varieties for resistance, but it would be worthwhile to compare the yields of promising new varieties in occasional field trials in affected areas.

5.0 INTELLECTUAL PROPERTY ARISING FROM THE RESEARCH

No commercial developments, patents, or licences will arise from the research in BS61S.

6.0 REFERENCES

Moller, R B (1965). The soldier fly pest of sugar cane. Bureau of Sugar Experiment Stations, Brisbane.

Moller, R B (1968). Soldier fly - past, present and future. *Proc. Queensl. Soc. Sugar Cane Tech.* 35: 53-55.

Samson, P R and Geier, P W (1983). Induction of crop damage by the cabbage white butterfly, *Pieris rapae* (Lepidoptera: Pieridae), on cabbage. *Prot. Ecol.* 5: 199-233.

Samson, P R, Hansen, P B and Mullins, R T (1993). Tolerance of sugarcane clones to feeding by *Inopus rubriceps* (Macquart) (Diptera: Stratiomyidae). *J. Aust. Entomol. Soc.* 32: 37-42.

Samson, P R and McLennan, P D (1995). Timing of pupation of *Inopus rubriceps* (Macquart) (Diptera: Stratiomyidae) in sugarcane fields. *J. Aust. Entomol. Soc.* 34: 37-41.

APPENDIX I

EFFECT OF SOLDIER FLY ON GERMINATION OF SUGARCANE SETTS

INTRODUCTION

Damage by soldier fly (*Inopus* spp.) to sugarcane is mainly seen as an inhibition of ratooning after harvest. However, larvae may also inhibit germination of cane planting pieces (setts) if present in sufficient numbers at planting.

The interaction of soldier fly larvae and sugarcane setts is poorly understood. Larvae are attracted to the developing roots of the setts, and feed particularly near the junction of the root and the sett piece (Moller, 1965). The mechanism whereby this may prevent germination of the shoot bud is unknown. Damage is said to be greater under cool conditions that retard sett germination (Moller, 1968), but this has not been verified experimentally.

I investigated some of the factors that may influence the harmfulness of larvae of the sugarcane soldier fly *Inopus rubriceps* to sugarcane setts. The effects of different sizes of larvae and of different soil temperatures and moisture contents were compared using several varieties. I assessed whether larvae have a lasting effect on setts by allowing only a short period of larval feeding. In addition, the effects of larval feeding were compared with those induced by simple root pruning.

MATERIALS AND METHODS

Effect of larval size

The effect of soldier fly on sugarcane setts was compared between larvae in four size classes: Small, 0.05 - 3 mg (mean 2.0 mg); Medium, 3 - 8 mg (mean 5.4 mg); Large, 8 - 20 mg (mean 12.2 mg); Very Large, 20 - 90 mg (mean 35.2 mg). Larvae were collected from sugarcane fields near Bundaberg in December. They were allowed to burrow into 400 g of sieved krasnozem soil, 26% moisture content (MC, dry-weight basis), in plastic cups; any that failed to bury themselves were replaced. Cups were infested with 0, 6, 10, 15, 25, or 40 larvae of one size, with 7 - 20 replicates of each size-density combination depending on larval availability. Three days later a single-bud sett of variety CP44-101 was planted in each cup, by tipping out soil so that about 2 cm remained in the bottom, placing the sett bud-uppermost, and replacing the soil. Cups were stored at 25°C and checked for shoot emergence above the soil surface after 6 weeks. Setts were then removed from the soil, the length of unemerged shoots was measured, and surviving larvae were counted and weighed. Roots were cut from setts infested with Large larvae and weighed after drying at 100°C for 2 days.

Effect of soil conditions

The effect of soil temperature on germination was compared between five sugarcane varieties, in the absence of soldier fly. The varieties chosen were CP44-101, H56-752, Q136, Q150, and Q151. Stalks of these varieties were cut from second ratoon crops in July. Single-bud setts were then cut and planted in cups as described above, in krasnozem soil of 26%MC. Cups were stored at 16, 20, or 25°C, with 10 replications at each temperature. Emergence of shoots was recorded over 14 weeks, daily at first but less frequently later.

The effect of soldier fly on germination was examined under several soil conditions using varieties CP44-101 and Q151, which were chosen from the previous experiment because of their different responses to temperature (see later). Soldier fly larvae were collected from sugarcane fields in January, and were used to infest cups containing krasnozem soil of 18 or 26%MC (mean larval weight was 21.1 mg). After several days, some larvae in soil at 18%MC were not burrowing so moisture content was increased to 20% by adding water to each cup. Stalks were cut from an autumn-planted crop in February. Single-bud setts were then cut and planted in each cup. Cups with soil at 20%MC were stored at 25°C and cups with soil at 26%MC were stored at either 18 or 25°C. Each combination of variety, larval density, soil moisture and temperature was replicated 12 times with uninfested controls double-replicated. Emergence of shoots was recorded over 5 weeks at 25°C and 10 weeks at 18°C. Cups at 25°C containing unemerged setts were watered up to their original weight after 3 weeks; cups lost negligible weight at 18°C. At the end of the observation period, setts were removed from the soil, the length of unemerged shoots was measured, and surviving larvae were counted and weighed. Roots were cut from setts and weighed after drying at 100°C for 2 days.

Duration of larval effect

The duration of the effect of larvae on germination was evaluated at a single larval density of 50/sett. Sixty single-bud setts of variety Q141 were cut in December and planted in krasnozem soil of 26% moisture content held at 20°C, as described previously. Forty cups were infested with larvae on the day of planting. After 3 weeks, all setts were removed from the soil, washed in water and larvae collected from the infested setts. Shoot lengths were measured and the setts replanted in fresh soil. Twenty of the previously infested setts were then reinfested, while the other 20 previously infested setts remained uninfested thereafter. After a further 5 weeks, all setts were again removed from soil, shoot lengths measured, and sett roots weighed after drying at 100°C for 2 d.

Response to root pruning

The effect of root pruning on germination was measured in krasnozem soil of 26% moisture content held at 20°C. Forty single-bud setts of variety CP44-101 were cut in June and planted in individual cups as described previously. Half of the setts were left undisturbed, while the others were regularly tipped from the soil and all visible roots cut from the sett at their base. Roots were pruned six times at weekly intervals starting 16 days after planting. The severed roots were retained. Shoot emergence was observed for a

total of 9 weeks. Roots were then cut from both pruned and unpruned setts, retained roots were added to those from the pruned setts, and total roots weighed after drying at 100°C for 2 days.

Statistical analyses

Percentage failure of sett germination at increasing larval density was analysed as a function of larval density (log-transformed) by probit analysis using *MLP 3.06* (Ross, 1980). Percentage failure in the presence of larvae was first corrected for failure in controls by Abbott's formula (Abbott, 1925). All other analyses were carried out using *Statistix 4.0* (Analytical Software). Numbers of buds that did and did not expand or emerge were compared between treatments by χ^2, with Yates' correction for continuity when only two treatments were compared. The effect of temperature on rate of shoot emergence was described by regression, with the rate of emergence of individual shoots calculated as the reciprocal of days. Linearity of regressions was assessed by the reduction in sums of squares attributable to inclusion of a quadratic term. Results of linear regression were recast as a lower temperature threshold for zero development and required heat units or day-degrees above this threshold determined as slope^{-1}. Time to emergence of successful shoots, shoot length, larval survival and larval weight gain were compared between treatments by the Kruskal-Wallis test. When differences were found ($P = 0.05$), a multiple comparison procedure was used to separate means (Conover, 1980). Root weight was compared between treatments by one-way analysis of variance or *t*-test, and its relationship to shoot length or days to shoot emergence was examined by simple correlation.

RESULTS

Effect of larval size

Emergence of shoots was inhibited by larvae in weight classes of Medium and larger, but not by Small larvae at the densities studied (Table 1). Probit analysis of these results confirmed that there was a significant slope for all density-response regressions except for Small larvae. Parallel line analysis for Medium - Very Large larvae showed no significant differences in slope ($\chi^2 = 2.3$, df = 2, $P = 0.31$) or position ($\chi^2 = 3.4$, $P = 0.18$). A low value of 8.3 for total heterogeneity χ^2 (df = 12, $P = 0.76$) indicated a good fit to the probit model. A pooled response to larvae in these weight classes was therefore calculated with a common slope of 2.1 ± 0.4 se, and indicated that an average of 22 larvae (95% limits 17 - 28) would be required to cause an emergence failure of 50%.

Of 140 failed shoots, 37 (26%) had not expanded from the initial bud. These constituted 4 of 11 failures in control setts. Failure of bud expansion was examined in greater detail for larvae of size Medium and above, that inhibited shoot emergence. Setts that did not produce an expanded bud were 6% of uninfested setts and 10 - 19% of setts infested with different numbers of larvae. Probit analysis showed no significant relationship between larval density and failure of buds to expand initially ($P > 0.05$).

Survival of larvae averaged 67%, 65%, 68%, and 79% for Small - Very Large larvae, respectively. Average weight gain of the different larval weight classes was in the order (mean ± se), Large (5.1 ± 0.3 mg) > Very Large (4.3 ± 0.8 mg) and Medium (3.9 ± 0.4 mg) > Small (2.4 ± 0.3 mg) ($P < 0.05$).

The root weight of setts infested with each density of Large larvae from 6 - 40/cup was greater than that of uninfested setts (mean ± se = 79 ± 15 mg) ($P < 0.05$), with no difference between larval densities (mean ± se = 152 ± 10 mg).

Effect of soil conditions

The rate of emergence of shoots in the absence of soldier fly was reduced at lower temperatures (Fig. 1). Regressions of rate on temperature were non-linear for varieties H56-752 ($P = 0.010$) and Q150 ($P = 0.018$) but not for the other three varieties ($P > 0.05$). Describing the effect of temperature as the average linear effect for each variety, lower thresholds and required day-degrees (d°) were: CP44-101, 9.7°C and 305 d°; H56-752, 11.3°C and 107d°; Q136, 12.7°C and 249d°; Q150, 12.1°C and 104d°; Q151, 14.8°C and 95d°. Because of the considerable difference in thermal requirements of varieties CP44-101 and Q151, these two were chosen for testing of the combined effect of soldier fly and environment.

In the second experiment, the effect of larval infestation on shoot emergence of varieties CP44-101 and Q151 differed between soil conditions (Table 2). Inhibition was obvious at 18°C but less so at 25°C.

The effect of larvae on emergence was examined by probit analysis, excluding variety CP44-101 at 25°C/20%MC where larvae had no effect (Table 2). Analysis of parallelism indicated no difference in slope between lines ($\chi^2 = 1.4$, df = 4, $P = 0.84$), and a low value for heterogeneity χ^2 of 9.0 (df = 15) indicated a good fit to the probit model ($P = 0.88$). The analysis showed a difference in position of lines ($\chi^2 = 61.8$, df = 4, $P < 0.001$). A value for the number of larvae required to inhibit shoot emergence by 50% (LN_{50}) was calculated assuming a common slope for the five lines (2.9 ± 0.7 se). Larvae had greater effect on shoot emergence at 18°C than at 25°C in both varieties, as indicated by non-overlap of the 95% fiducial limits of the LN_{50} values (Table 2). Larvae had a significantly greater effect on emergence of shoots of variety Q151 than CP44-101 at 18°C, but not at 25°C. Soil moisture content did not influence the effect of larvae on emergence.

Time to emergence of successful shoots was the same for all larval densities under each set of conditions ($P > 0.05$). With data pooled over densities, variety Q151 was slower to emerge than CP44-101 at 18°C (mean ± se = 40 ± 3 d and 22 ± 1 d, respectively, $P < 0.001$) but both emerged in a similar time at 25°C/26%MC (mean = 9 d for both varieties, $P = 0.30$). Time to emergence at 25°C was independent of moisture content ($P = 0.064$).

Of 117 failed shoots, 43 had not expanded from the original bud. Bud expansion was examined in greater detail at 18°C, where larvae had a considerable effect on emergence. The percentage of total buds that failed to expand was 15% in uninfested setts and 17 -

38% in infested setts. Probit analysis indicated no significant relationship between failure of initial expansion and larval density ($P > 0.05$).

Larval survival averaged 56% overall. Survival at 25°C was lower at 20%MC (mean ± se = 48 ± 1%) than at 26%MC (mean ± se = 62 ± 2%) ($P < 0.001$). Larval weight gain averaged 2.3 mg and was not affected by any of the treatments.

The weight of sett roots of variety Q151 (mean ± se = 122 ± 8 mg) was greater than that of CP44-101 (mean ± se = 75 ± 8 mg) without larvae present ($P < 0.001$), and there was no difference in root weight between the three environmental conditions for either variety ($P > 0.05$). Root weights were increased by larval infestation at 26%MC but not at 20%MC (Table 3). Infestation sometimes increased root weight even when there was no effect on shoot emergence, for example in CP44-101 at 25°C/26%MC (compare Table 3 with Table 2).

In the absence of larvae, setts of variety CP44-101 that produced an earlier-emerging shoot had heavier roots at 18°C ($r = -0.54$, $P < 0.05$) and 25°C/20%MC ($r = -0.46$, $P < 0.05$). However, there was no correlation between root weight and time to shoot emergence in CP44-101 at 25°C/26%MC ($r = 0.08$, $P > 0.05$) or in Q151 under any conditions.

Emergence times of variety CP44-101 differed greatly between experiments. Mean days to shoot emergence at 25°C averaged 23 days in the first and 9 days in the second. By contrast, time to shoot emergence of Q151 was consistent under the same conditions, averaging 10 days and 9 days, respectively. Factors other than the soil environment, perhaps relating to the plant source from which setts were cut, must also influence time to emergence of shoots.

Duration of larval effect

The initial expansion of buds differed significantly between infestation treatments at both 3 and 8 weeks after planting (Table 4). All uninfested buds had expanded to a length >2 mm by 8 weeks, whereas many buds had failed to expand on infested setts. Shoot elongation differed between all three treatments and was greater if larvae were removed after 3 weeks than if setts remained infested for the whole 8 weeks.

Root weight after 8 weeks was greatest for setts that were infested for only 3 weeks and least for uninfested setts (Table 4). Those uninfested setts with longer shoots had a lesser weight of roots ($r = -0.45$, $P < 0.05$). For setts infested with larvae for 8 weeks, however, root weight and shoot length were positively correlated ($r = 0.57$, $P < 0.05$), and root weight was lower ($P < 0.01$) in setts with unexpanded buds (mean ± se = 218 ± 22 g) than in those with expanded buds (mean ± se = 343 ± 35 g). Corresponding weights for setts infested for only 3 weeks were not significantly different (mean ± se = 322 ± 29 mg and 396 ± 57 mg, respectively, $P > 0.05$) and there was no significant correlation between root weight and shoot length.

Response to root pruning

Emergence of shoots was lower when roots were pruned from setts than when setts were left undisturbed (mean = 55 and 95%, respectively, $P = 0.011$). Pruning did not influence the total weight of roots produced by setts when all setts were considered (mean ± se = 101 ± 7 mg unpruned, 135 ± 20 mg pruned, $P = 0.11$). However, if only successful setts were included, then pruned setts produced a greater weight of roots (mean ± se = 173 ± 27 mg) than unpruned setts (mean ± se = 103 ± 7 mg) ($P = < 0.05$). Earlier-emerging setts produced a lesser weight of roots when intact ($r = 0.52$, $P < 0.05$) but not when pruned ($r = 0.09$, $P > 0.05$).

DISCUSSION

Moller (1965) observed that soldier fly larvae inhibited bud development of sugarcane setts in the field. In the present laboratory study, affected buds often expanded initially but failed to elongate sufficiently to emerge from the soil. Thus the effect of larvae on setts was different from that seen in ratoon stubble, where affected buds tend not to expand at all (Samson *et al*., 1993). In ratoon stubble, however, roots would usually have been exposed to larval feeding for some months before harvest, when the underground buds usually germinate. In one experiment with a heavy larval infestation of setts (*Duration of larval effect*), initial bud expansion was inhibited by larval attack. Shoot growth was resumed when larvae were removed in that experiment, indicating that larval feeding may not cause permanent harm to the setts.

Infested setts produced a greater weight of roots than uninfested setts. Moller (1965) noted that setts affected by soldier fly showed satisfactory root development.

The effect of soldier fly larvae on setts was similar to that induced by root pruning. In both cases, shoot emergence was inhibited and root growth was increased.

Hitchcock (1970) observed that soldier fly larvae excavate cavities in roots, and heavily pitted roots usually died distally. He also observed that small larvae break off root hairs. In maize, the root wound is initially superficial in the cortex but ultimately penetrates the vascular cylinder (Fellowes, 1975). Larvae have the pharynx adapted for sucking (Irwin-Smith, 1921) and the alimentary canal has a filter chamber similar to that found in the Hemiptera (Fellowes, 1975). The mechanism whereby soldier fly larvae affect bud development in sugarcane is unknown. The injection of a growth-inhibiting toxin into roots has been suggested (Moller, 1965) but not confirmed. Fellowes (1975) detected invertase as the only salivary enzyme, and found that a water extract of the salivary glands had no plant growth regulator activity in bioassays. Wilson (1958) reported reduced germination of cane setts injected with a water extract from macerated larvae; however, root growth was also inhibited and this is not typical of the response to larval feeding. The larval extracts were not sterile and microbial infection could have prevented development of injected setts (Fellowes, 1975).

In the present study, the possibility of a growth inhibitor that reduces shoot growth and, directly or indirectly, promotes root growth cannot be discounted. However, the symptoms of attack in cane setts could equally be explained by redirection of energy reserves from shoot to root production. In two experiments, uninfested setts which

produced an earlier shoot or a longer shoot had a lower weight of roots, suggesting that the shoot and roots sometimes compete for energy reserves. Feeding of larvae may cause a redirection of reserves to roots at the expense of shoot growth, as a consequence of larval withdrawal of juice or impaired function of damaged roots. However, root weight and shoot growth were positively correlated in uninfested setts in one experiment (*Effect of soil conditions*), and the two were either independent or positively correlated in infested setts. Variation of energy reserves between setts could be confounded in these relationships.

Infested setts showed pitting at the cut stalk ends, presumably caused by larval burrowing or feeding. This may have encouraged entry of pathogens into the setts and further inhibited shoot growth.

Small larvae were less harmful to sett emergence than larger ones. These small larvae gained less weight and presumably consumed less from the plants during the exposure period. In addition, small larvae may take longer to attach to roots than larger individuals. Therefore, inhibition of sett germination in the field is more likely at times when large larvae predominate in the population.

Larvae had a greater effect on shoot emergence at lower temperature, confirming the field observations of Moller (1965). Gerard and Burton (1983) estimated that larvae of *I. rubriceps* have a temperature threshold for development of 9.5°C, which is less than I estimated for emergence of cane shoots. The influence of decreasing temperature on larval damage was greater in variety Q151 than in CP44-101. This is in accord with Q151 having a higher temperature threshold for development, such that decreasing temperature had a greater proportional effect on the rate of shoot emergence. At any given temperature, larvae are likely to have a greater effect on slower-germinating varieties. No effect of soil moisture was detected. Larval survival was reduced at a lower moisture content and this could have counteracted any tendency for lower moisture to disadvantage the cane setts.

In sum, this study has confirmed that larval size, temperature and cane variety influence the harmful effect of soldier fly larvae on shoot production by cane setts. These factors probably act by changing the differential rates of plant growth and larval feeding. The symptoms of larval attack on setts can be explained by plant growth processes induced by damage to roots.

ACKNOWLEDGMENT

I am grateful to Paul McLennan for technical assistance.

REFERENCES

Abbott, W S (1925). A method for computing the effectiveness of an insecticide. *J. Econ. Ent.* 18: 265-267.

Conover, W J (1980). *Practical non-parametric statistics*. 2nd Edition. Wiley: New York.

Fellowes, R W (1975). Some aspects of the feeding and digestive system of *Inopus rubriceps* (Diptera, Stratiomyidae). M.Sc. thesis, University of Auckland.

Gerard, P J and Burton, G P (1983). Growth and development of Australian soldier fly, *Inopus rubriceps* (Diptera: Stratiomyidae), in New Zealand. *N.Z. Jl Zool*. 10: 75-82.

Hitchcock, B E (1970). The soldier fly pest. *Proc. Qd Soc. Sugar Cane Tech.* 37: 207-216.

Irwin-Smith, V (1921). Studies in life-histories of Australian Diptera Brachycera. Part I. Stratiomyidae. No. 3. On the structure of the mouth-parts and pharynx of the larval *Metoponia rubriceps*. *Proc. Linn. Soc. N.S.W.* 46: 425-432.

Moller, R B (1965). *The soldier fly pest of sugar cane*. Bur. Sugar Exp. Stns, Qld.

Moller, R B (1968). Soldier fly-past, present and future. *Proc. Qd Soc. Sugar Cane Tech.* 35: 53-55.

Ross, G J S (1980). *MLP 3.06, Maximum Likelihood Program*. Rothamsted Experimental Station, UK.

Samson, P R, Hansen, P B and Mullins, R T (1993). Tolerance of sugarcane clones to feeding by *Inopus rubriceps* (Macquart) (Diptera: Stratiomyidae). *J. Aust. Ent. Soc.* 32: 37-42.

Wilson, G (1958). Entomological investigations. *Ann. Rep. Bur. Sugar. Exp. Stns* 58: 79-87.

Table 1

Emergence from soil of shoots of sugarcane variety CP44-101, after 6 weeks infestation by soldier fly larvae at 25°C in soil of 26% moisture content

Number of larvae	Percentage emergence failure (*n*) with each larval weight class			
	Small	Medium	Large	Very Large
0	38 (8)	13 (15)	10 (20)	29 (14)
6	43 (7)	47 (15)	10 (20)	23 (13)
10	14 (7)	33 (15)	25 (20)	54 (13)
15	29 (7)	40 (15)	55 (20)	62 (13)
25	13 (8)	60 (15)	45 (20)	79 (14)
40	29 (7)	80 (15)	65 (20)	92 (13)

Table 2

Percentage of shoots of two sugarcane varieties that failed to emerge from soil infested with soldier fly larvae, under different combinations of temperature and soil moisture content (MC). Emergence was monitored for 5 weeks at 25°C and 10 weeks at 18°C (*n* = 24 for uninfested setts and 12 otherwise)

Number of larvae	CP44-101			Q151		
	18°C/ 26%MC	25°C/ 26%MC	25°C/ 20%MC	18°C/ 26%MC	25°C/ 26%MC	25°C/ 20%MC
0	25	4	13	25	4	17
10	42	8	17	58	0	17
15	33	0	25	92	17	17
25	75	0	0	92	17	25
40	75	17	0	92	50	33
LN_{50} (95% FI)	24 (15-40)	124 (53-728)	>40	9 (4-15)	48 (32-108)	77 (36-287)

Table 3

Weight of sett roots (mg, mean ± se) of two sugarcane varieties infested with soldier fly larvae under different conditions of soil temperature and moisture content (MC)

Number of larvae	CP44-101			Q151		
	18°C/ 26%MC	25°C/ 26%MC	25°C/ 20%MC	18°C/ 26%MC	25°C/ 26%MC	25°C/ 20%MC
0	75 ± 15 b	80 ± 13 c	71 ± 12	133 ± 15 c	121 ± 15 b	111 ± 14
10	173 ± 17 a	136 ± 18 bc	70 ± 22	207 ± 15 ab	147 ± 17 b	83 ± 17
15	152 ± 20 a	128 ± 27 bc	53 ± 13	178 ± 14 abc	178 ± 34 ab	83 ± 17
25	171 ± 28 a	142 ± 22 b	67 ± 16	164 ± 28 bc	164 ± 16 ab	77 ± 19
40	189 ± 22 a	233 ± 39 a	113 ± 33	239 ± 28 a	231 ± 33 a	108 ± 29
(*P*)	(<0.001)	(<0.001)	(0.32)	(0.003)	(0.012)	(0.56)

Means within columns followed by the same letter were not significantly different by the least-significant-difference test ($P = 0.05$)

Table 4

Effect of continual or interrupted soldier fly infestation on initial expansion and shoot elongation of buds on cane setts

Treatment	No. failed to expand (*n* = 20)*		Shoot elongation 3-8 weeks (mm, mean ± se)	Root dry wt, 8 weeks (mg, mean ± se)
	3 weeks	8 weeks		
Uninfested	1	0	65.2 ± 6.7 a	186 ± 17 c
Infested for 3 wk	14	6	15.3 ± 3.9 b	374 ± 41 a
Infested for 8 wk	14	12	1.5 ± 0.5 c	270 ± 24 b
(*P*)	(<0.001)	(<0.001)	(<0.001)	(<0.001)

* Shoot length ≤ 2 mm

Means within columns followed by the same letter were not significantly different (*P*=0.05)

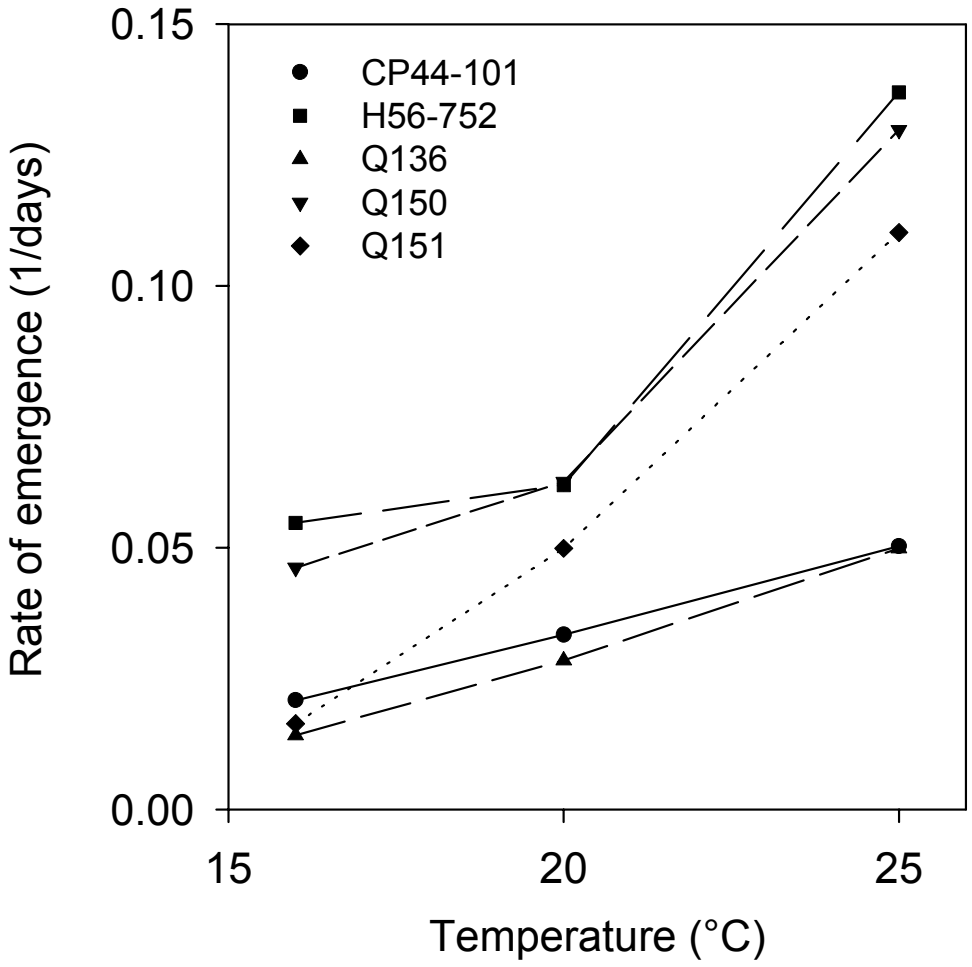

Figure 1 - Effect of temperature on the rate of emergence from soil of shoots of five sugarcane varieties. Means are based on ≥ seven observations, except for variety Q136 at 16°C (four) and 25°C (five).

APPENDIX II

EFFECT OF SOLDIER FLY ON GROWTH AND RATOONING OF SUGARCANE

INTRODUCTION

Larvae of the sugarcane soldier fly feed on the roots of cane plants, leading to ratoon failure after harvest. The nature of the plants' response and its relationship between the number of larvae have not been elucidated. Pot experiments were carried out to describe the response of sugarcane plants to soldier fly larvae, and to determine what factors may influence the harmful effect of infestations on sugarcane yield.

MATERIALS AND METHODS

General methods

Plants were grown in a glasshouse in 10 L or 20 L pots containing krasnozem soil that had been fumigated with methyl bromide. Pre-sprouted single-bud setts of sugarcane variety CP44-101 were transplanted individually into each pot. In standard fertiliser treatments, pots were fertilised with urea and K_2HPO_4 7-8 weeks later, 0.56 g and 1.6 g per 20 L pot, respectively, and with urea again at 1.52 g/pot 13-15 weeks after transplanting; 10 L pots received half quantities. Additional fertiliser (urea 1.52 g and K_2HPO_4 1.6 g) was applied to each pot of ratoons where these were grown through to a second harvest.

Pots were infested by placing field-collected soldier fly larvae on the soil surface; any that had not buried themselves within a few days were replaced. Cane yields were measured by cutting all stalks at ground level. Plant material was weighed after drying at 100°C for 2 days. Where soldier fly were to be recovered from pots, the soil was wet-sieved using a 1 mm screen and larvae separated by hand from roots and debris.

Effect of infestation on plant development

Methods. Sugarcane plants were transplanted into 20 L pots on 8 September 1992. Plants were grown either uninfested or infested 3 days after transplanting with 30 larvae/pot (average larval weight = 1.1 mg). Different times and types of harvest were replicated five times. Pots were harvested for growth measurements on three occasions, at 7, 12, and 18 weeks after transplanting. A sample of juice was collected from stalks just before the harvests at 12 and 18 weeks, and the level of total dissolved solids (brix) was measured using a refractometer. Additional pots were harvested on the final occasion for chemical analysis of elements and carbohydrate and for studies of bud activity. For chemical analyses, material was separated into roots, stubble (the underground basal portion of the stalks), and the lower portion of the above-ground stalks including only the lowermost two nodes. For analysis of elements, samples were dried at 70°C and then ground in a micro hammer mill; nitrogen was determined by a modified Kjeldahl digestion technique while remaining major and minor elements were determined by ICP spectroscopy after digestion with

nitric/perchloric acid. For carbohydrate analysis, samples were frozen immediately after harvest. Concentrations of glucose, fructose and sucrose were determined by standard HPLC procedures, starch was determined enzymatically using an amylase/amyloglucosidase enzyme system, and total soluble carbohydrate was measured by an autoanalyser system based on the standard phenol/sulphuric acid procedure. For studies of bud activity, the time to emergence of shoots from single-node setts cut from the stalks above-ground was measured after planting in fresh soil. The stubble remaining after harvest was examined after 4 weeks and the fate of all underground buds was recorded.

In an additional study of the activity of above-ground buds, stalks were cut from ten varieties that had been infested with 0, 10 or 50 larvae (n = 7; see Appendix III, 1993 experiment). Setts containing successive nodes 1 - 10 from the stalk base were planted in vermiculite and the length of shoots measured after 4 weeks.

Statistical analyses. The time to emergence of shoots from setts and number of ratoon shoots were compared between infested and uninfested pots by the rank sum test. Other measurements were compared between treatments by *t*-test. All analyses used *Statistix 4.0* (Analytical Software).

Effect of timing of larval feeding on plant response

Trial 1. Sugarcane plants were transplanted into 20 L pots on 7 November 1991. The trial was infested with six densities of soldier fly larvae, 0, 5, 10, 20, 50 and 100 larvae/pot, for three consecutive periods. Seven replicates of each combination of density and period were set up as a split-plot, with larval density the main plots and feeding periods the sub-plots, in a randomised complete-block design. Infestations were commenced at 8-week intervals, with the first starting 1 day after transplanting. Average larval weight was 21-22 mg in each infestation. Infestations were interrupted after 8 weeks by either immersing pots in an aqueous emulsion of chlorpyrifos (0.2 ml Lorsban/L) or by flooding pots with 4-6 L of the same chlorpyrifos concentration. Larval survival at the end of each 8-week feeding period and survival 2 weeks after chlorpyrifos treatment were determined in additional pots containing 20 larvae that were set up in each replicate; survival was assessed according to the ability of larvae to bury themselves in fresh soil. Pots were harvested on 11 March 1992, 2 weeks into the final infestation period and 18 weeks after transplanting. Ratoon shoots were counted 6 weeks after harvest. Ratoons were then grown to a second harvest on 30 July 1992, and subsequent ratooning was again recorded.

Trial 2. A second trial was carried out using similar methods to the first but in 10 L pots. Sugarcane plants were transplanted on 30 October 1992. There were only two consecutive infestations, with an additional larval density of 3/pot. The trial was arranged in a randomised complete-block design with five replications. The first infestation started 6 days after transplanting. The second was started 9 weeks later, at which time the first infestation was interrupted by a chlorpyrifos drench (3 L/pot). Average larval weight was 7 mg in each infestation. Pots were harvested on 8 March 1993, 9 weeks into the second infestation period and 19 weeks after transplanting; there was no second harvest. Ratoon shoots were counted after 4 weeks and larvae were then wet-sieved from all pots.

Statistical analyses. Above-ground plant weight was analysed by analysis of variance, and the effect on weight of increasing numbers of larvae added to pots within each infestation period was examined by linear regression. The effect of increasing number of larvae on both the number of ratoon shoots and, in Trial 1, on the increase in ratoon shoots after successive harvests, was analysed by regression with dummy variables representing infestation periods and linear combinations of larval number and infestation period. The number of ratoon shoots was analysed by Poisson regression and the increase in shoots by linear regression. All analyses used *Statistix 4.0* (Analytical Software).

Effect of larval size

Methods. Sugarcane plants were transplanted into 20 L pots on 23 August 1993. Two different size classes of larvae were used for infestations, with mean initial weights of 4 and 22 mg. These larvae were collected from canefields in September 1993, and the two size classes corresponded to progeny of adult flights in 1993 and 1992, respectively. The trial was infested with four densities of each size class, 10, 20, 30, and 50 larvae/pot, plus uninfested controls. Five replicates of each treatment were set up in a randomised complete-block design. Larvae were added 3 weeks after transplanting. Pots were harvested on 25 January 1994, 22 weeks after transplanting, and ratoon shoots were counted 6 weeks later. The soil was then washed from each pot and larvae were counted and weighed.

Statistical analyses. Larval survival was analysed by analysis of variance using *Statistix 4.0* (Analytical Software). Above-ground plant weight and number of ratoon shoots were analysed by *Genstat 5*, with number of ratoon shoots transformed as log(x+1).

Effect of environmental conditions

Methods. Sugarcane plants were transplanted into 10 L pots on 29 September 1993. Pots were distributed among six different treatments (see Table 11). Pots in each treatment were infested with five densities of soldier fly larvae, 0, 10, 20, 40 and 80/pot, with five replications in a randomised complete-block design. Average weight of larvae was 11 mg. Larvae were added to pots 22 days after transplanting. Pots were connected to a drip irrigation system, with pots in the "dry" treatment receiving half quantities of water. Pots in the "unfertilised" treatment received no fertiliser during growth, while other pots received the general fertiliser regime (see earlier) with a double quantity on the second occasion. Plants were harvested on 23 March 1994, 25 weeks after transplanting, or on 4 May 1994, 31 weeks after transplanting, in the"late harvest" treatment. Pots were left in the glasshouse after harvest except in the "warm" and "cool" treatments, which were transferred immediately to either 25°C or 18°C in constant temperature rooms with artificial lighting. Ratoon shoots were counted for at least 7 weeks after harvest. For cool-treatment pots, ratoon shoots were counted for 11 weeks, at which time pots were returned to the glasshouse and ratoon shoots counted for another 3 weeks. The soil was washed from pots containing the two highest larval densities in standard, dry, and unfertilised treatments on 26 May 1994 and live larvae and pupae were counted and weighed.

Statistical analyses. Above-ground plant weight and larval survival and weight were analysed by analysis of variance. The effect of increasing number of larvae on the number of ratoon shoots was analysed by Poisson regression with dummy variables representing

environmental treatments and linear combinations of larval number and treatment. All analyses were carried out using *Statistix 4.0* (Analytical Software).

RESULTS

Effect of infestation on plant development

Plants infested with 30 larvae weighed significantly less ($P < 0.05$) than uninfested plants at 7 and 18 weeks after transplanting (Table 5). Root weight of infested plants was significantly lower at 7 weeks but not later. The juice of infested plants had significantly higher brix at the final harvest.

Soldier fly infestation significantly altered carbohydrate levels ($P < 0.05$) in the basal part of stalks when plants were harvested 18 weeks after transplanting (Table 6). Infested plants had a higher concentration of sucrose, a lower concentration of fructose, and a lower ratio of reducing sugars (fructose and glucose) to sucrose, than uninfested plants. No significant differences were detected in other plant portions, or in levels of total carbohydrate, starch, or glucose. Infested plants had significantly higher concentrations of calcium, magnesium, sulphur, copper, zinc, and manganese in their stubble than did uninfested plants. The concentration of calcium was also higher in the basal stalk of infested plants. No significant differences in concentration of elements were found in roots, or in any plant portions for nitrogen, phosphorus, potassium, or iron.

Ratooning following harvest 18 weeks after transplanting was significantly reduced by infestation (Table 5). Ratoon shoots arose mainly from buds near the surface, in both uninfested and infested plants (Fig. 2). However, a smaller proportion of buds produced ratoon shoots when plants were infested with larvae. Secondary shoots arose mainly from deep buds, with little difference between uninfested and infested plants. Remaining inactive buds were more numerous on infested plants than on uninfested plants.

When single-bud setts were cut from stalks and planted, shoots produced from basal buds were slower to emerge from soil than those arising from buds higher on the stalk (Fig. 3). The increase in time to emergence down the stalk was more pronounced when the setts were cut from plants that had been infested with soldier fly larvae.

In a study of shoot production from setts cut from ten different varieties (1993 experiment, Appendix III), shoot elongation after a fixed time interval varied with position of buds on the stalks (Fig. 4). Average shoot length from previously-infested stalks was reduced at all sett positions. At least part of the difference between infestation levels was due to failure of buds to expand. Expansion failure, defined as shoots less than 2 mm long, was 18 and 10% for uninfested plants, 36 and 16% at 10 larvae/plant, and 64 and 27% at 50 larvae/plant, for the bottom and top setts, respectively.

Effect of timing of larval feeding on plant response

Trial 1. Recovery of living larvae from monitoring pots after successive infestation periods averaged 79%, 51% and 50%, respectively. Corresponding figures for pots 2 weeks after

chlorpyrifos treatment were 6%, 9% and 0%, respectively. Because of the unexpected survival of larvae following chlorpyrifos immersion after the first infestation period, these pots were retreated with a 4 L chlorpyrifos drench. The effect of this second treatment on larval survival could not be determined.

The effect of larvae on above-ground plant weight at the first harvest differed between infestation periods ($P_{interaction}$ = 0.027) (Table 7). There was a significant linear relationship between number of larvae N and weight of the plant crop W_P for the first infestation period, $W_P(g)$ = 301 - 0.98*N ($P < 0.001$) but not for the second and third periods (P = 0.75 and 0.35, respectively). However, infestation period did not influence the effect of larvae on the number of ratoon shoots R_1 after the first harvest (Table 8, $\ln[R_1] = 1.076 - 0.00632*N$, $P_{interaction}$ = 0.70), subsequent above-ground weight of this first ratoon crop (Table 7, $W_1(g) = 120 - 0.56*N$, $P_{interaction}$ = 0.76), or number of ratoon shoots after the second harvest (Table 8, $\ln[R_2] = 1.670 - 0.00368*N$, $P_{interaction}$ = 0.59). The increase in the number of ratoon shoots after successive harvests (Table 8) was not affected by larval number (P = 0.35).

Trial 2. Recovery of living larvae from monitoring pots after two consecutive infestation periods averaged 57% and 55%, respectively. The corresponding figure for pots in the first infestation treatment 2 weeks after chlorpyrifos application was 1.3%; the second infestation was continued until ratoon shoots were counted. At that time, recovery of living larvae from all experimental pots averaged 0.3% for the first infestation (previously chlorpyrifos-dipped) and 46% for the second (Table 9).

Analysis of variance of above-ground plant weights and Poisson regression of numbers of ratoon shoots (Table 9) showed no interaction between number of larvae and period of infestation for either measurement ($P_{interaction}$ = 0.60 and 0.19, respectively). The effect of larval number N on the number of ratoon shoots R was described by $\ln[R] = 0.663 - 0.01993*N$ ($P < 0.001$).

Effect of larval size

Larval survival at the completion of the trial averaged 45%, with no difference between size class (P = 0.97) or number of larvae (P = 0.95). The above-ground weight of plants differed significantly between treatments (P = 0.038) but with no consistent effect of either larval size or number (Table 10, lsd (5%) = 70.2). Plants infested with large larvae produced fewer ratoon shoots than plants infested with small larvae, which in turn produced fewer ratoon shoots than uninfested plants (Table 10, $P < 0.05$).

Effect of environmental conditions

Larval survival and larval weight averaged 32% and 20.7 mg, respectively, at the completion of the experiment, with no difference between standard, dry and unfertilised pots ($P > 0.05$). The above-ground weight of plants at harvest was significantly affected by environmental treatments and by infestation ($P < 0.001$ for both), which acted independently ($P_{interaction}$ = 0.68). Weights were lower for unfertilised and dry pots than for other treatments, and tended to be lower for pots infested with more larvae (Table 11). The number of ratoon shoots produced after harvest was influenced by an interaction of environmental treatment and

infestation ($P_{interaction} < 0.001$). Regressions of the number of ratoon shoots R on larval number N within each treatment were as follows:

standard, $\ln[R] = 0.852 - 0.02664*N$, ($se_{slope} = 0.00927$);
late harvest, $\ln[R] = 0.681 - 0.10048*N$, ($se_{slope} = 0.03389$);
unfertilised, $\ln[R] = 0.531 - 0.05059*N$, ($se_{slope} = 0.01855$);
dry, $\ln[R] = 1.397 - 0.06127*N$, ($se_{slope} = 0.01448$);
warm, $\ln[R] = 0.694 - 0.02708*N$, ($se_{slope} = 0.01017$);
cool, $\ln[R] = 0.182 - 0.79837*N$, ($se_{slope} = 1.34033$).

DISCUSSION

Most ratoon shoot arose from shallow buds on stubble after harvest of uninfested plants, as also observed by Ferraris and Chapman (1991). A similar pattern occurred in plants infested by soldier fly larvae, but a greater proportion of buds failed to sprout after harvest. Infestation also inhibited the production of shoots when buds on the above-ground stalk were planted into uninfested medium. These effects are consistent with a toxin injected into the plants, as postulated by Moller (1965), but could equally be explained by unknown effects of the withdrawal of root juices on plant development.

Soldier fly infestation caused changes in the chemical composition of sugarcane plants. Carbohydrate levels were altered in the stalk, with an increase in sucrose and a reduction in the ratio of reducing sugars. Brix was higher in infested plants, and was also increased in three pot experiments comparing different varieties (Appendix III). Levels of some elements were higher in infested plants, perhaps because these plants were smaller than uninfested plants and so had not depleted the nutrient reserves in the pots. There was no evidence that soldier fly feeding caused any chronic nutrient deficiency that may have been responsible for bud inactivity.

In the first pot trial of different times of soldier fly infestation, larval feeding early in plant growth had a greater effect on plant crop yield than later feeding. This was expected, given the exponential nature of plant growth and the fact that a larger proportion of ultimate yield was already produced by the time the later infestations were initiated. However, the inhibitory effect of larvae on ratooning was the same for all infestation periods. The deleterious effect on the plants persisted even after the majority of larval feeding had ceased. A few larvae did survive past the nominal finishing time of the early infestations, but seemingly not enough to cause the observed persistence of inhibition.

The number of ratoon shoots increased by a constant factor after successive harvests, regardless of prior infestation. There was no carry-over of inhibition between ratoon crops, once larvae were removed from the pots. Whatever the reason for reduced activity of underground buds on infested stalks, the effect did not carry over into stalks arising from those buds that did produce ratoons.

In the second pot trial of different infestation times, plants were grown in smaller pots in an attempt to increase the efficiency of the chlorpyrifos drench used to kill larvae. However, a

few larvae still survived after the nominal end of the first infestation period. In this trial, unlike the first, larval feeding had the same effect on plant crop yield regardless of when the infestation was initiated. The first infestation was started slightly later in the second trial (8 days as against 1 day after transplanting), which may have reduced the harm caused by the earlier feeding. Alternatively, the use of smaller pots may have caused a plateauing of yield regardless of treatment. However, the effect on ratooning was similar to that seen in the first trial; larval feeding inhibited ratooning even if virtually all larvae were removed 9 weeks before harvest.

Large second-year larvae had a greater effect on ratooning than small larvae less than 1 year old. Presumably this was related to the rate of larval feeding. The mix of first- and second-year larvae at time of harvest varies between canefields and years (Samson and McLennan, 1995), and this could affect crop damage.

Limited data were obtained on the effect of environment on the interaction between larvae and potted sugarcane plants. It seemed that the harmful effect of larvae on ratooning was increased if harvest was delayed, perhaps because of a longer period of larval feeding or because of a change in the plant. The effect of infestation on ratooning was greater under dry conditions, agreeing with anecdotal evidence that dry conditions accentuate soldier fly losses in the field (unpublished observation). Infestation also had a greater effect on unfertilised plants. Cool conditions may have aggravated the effect of infestation, but this was uncertain as ratooning was very poor even in the absence of larvae. Avoiding early harvest of infested canefields is already an accepted recommendation in the sugar industry (Moller, 1968).

In sum, soldier fly larvae caused some enduring decline in the ability of the infested sugarcane stubble to ratoon after harvest. However, new stubble produced from infested plants was unaffected by prior infestation when the new roots were not attacked. The effect of larval infestation on bud activity extended to buds on the stalk, with the greatest effect in basal buds. Larvae have a facultative life cycle of 1 or 2 years, but the balance of first- and second-year larvae in a field will probably not influence crop response. Response is likely to be affected by environmental conditions that reduce crop growth and ratooning vigour - dry conditions, inadequate fertiliser, and harvest during cool conditions.

ACKNOWLEDGMENTS

I am grateful to Mike Haysom and Graham Leonard for chemical analyses, Joanne Stringer for statistical analyses using *Genstat*, and Paul McLennan for technical assistance.

REFERENCES

Ferraris, R and Chapman, L S (1991). The dynamics of bud development in ratooning stubble of sugar cane varieties. *Proc. Aust. Soc. Sugar Cane Technol.* 13: 164-171.

Moller, R B (1965). *The soldier fly pest of sugar cane*. Bur. Sugar Exp. Stns, Qld.

Moller, R B (1968). Soldier fly - past, present and future. *Proc. Queensl. Soc. Sugar Cane Technol.* 35: 53-55.

Samson, P R and McLennan, P D (1995). Timing of pupation of *Inopus rubriceps* (Macquart) (Diptera: Stratiomyidae) in sugarcane fields. *J. Aust. Entomol. Soc.* 34: 37-41.

Table 5

Plant response to soldier fly infestation (uninfested or 30 larvae/pot) at three times of harvest (weeks after transplanting)

Measurement	7 weeks			12 weeks			18 weeks		
	0	**30**	***P*[a]**	**0**	**30**	***P*[a]**	**0**	**30**	***P*[a]**
Total dry wt (g)	36.3	23.3	**	172	148	ns	362	323	*
Root dry wt (g)	12.7	8.8	*	54.1	41.4	ns	57.6	64.2	ns
Brix	-	-		6.7	6.6	ns	14.3	17.1	*
Ratoon shoots	-	-		-	-		5.8	2.2	**
No. of living larvae	-	12		-	13		-	13	
Av. larval wt (mg)	-	2.7		-	4.9		-	8.5	

[a] ns, $P > 0.05$; *, $P < 0.05$; **, $P < 0.01$

Table 6

Levels of carbohydrate and elements in portions of cane plants grown uninfested or infested with 30 soldier fly larvae/pot

Measurement	Stalk			Stubble			Roots		
	0	**30**	***P*[a]**	**0**	**30**	***P*[a]**	**0**	**30**	***P*[a]**
Carbohydrates [b]									
Sucrose (mg g^{-1})	383	441	**	283	331	ns	28	27	ns
Fructose (mg g^{-1})	19	13	*	14	19	ns	6	2	ns
Reducing sugars/sucrose (%)	12	6	*	8	8	ns	43	28	ns
Elements [c]									
Ca (%)	0.057	0.078	**	0.066	0.087	**	0.13	0.11	ns
Mg (%)	0.13	0.14	ns	0.14	0.16	*	0.25	0.25	ns
S (%)	0.20	0.22	ns	0.27	0.32	*	0.20	0.21	ns
Cu (mg kg^{-1})	3.9	4.3	ns	13	16	*	35	43	ns
Zn (mg kg^{-1})	30	30	ns	84	134	**	128	112	ns
Mn (mg kg^{-1})	81	96	ns	92	113	*	2030	816	ns

[a] ns, $P > 0.05$; *, $P < 0.05$; **, $P < 0.01$

[b] Total CHO, starch, and glucose did not differ significantly between treatments ($P > 0.05$)

[c] N, P, K, and Fe did not differ significantly between treatments ($P > 0.05$)

Table 7

Effect of consecutive 8-week periods of soldier fly infestation (P1, P2, P3) on the mean above-ground dry weight (g) of potted sugarcane plants at successive harvests (Trial 1). The plant crop was harvested 2 weeks into P3

Number of larvae	Plant crop			First ratoon crop		
	P1	P2	P3	P1	P2	P3
0	320	345	327	146	120	140
5	295	285	362	139	104	115
10	300	291	304	121	104	91
20	254	305	290	113	100	91
50	244	295	316	92	61	95
100	211	323	368	73	71	66

Table 8

Effect of consecutive periods of soldier fly infestation (P1, P2, P3) on the mean number of ratoon shoots produced after the first and second harvests of potted sugarcane plants, and on the increase in the number of shoots after successive harvests (Trial 1)

Number of larvae	First ratoon (R_1)			Second ratoon (R_2)			Increase (R_2/R_1)[a]		
	P1	P2	P3	P1	P2	P3	P1	P2	P3
0	3.6	4.0	3.4	7.6	6.7	7.0	2.2	2.1	2.0
5	2.7	2.1	3.1	6.0	5.0	3.7	2.1	2.7	1.4
10	2.4	2.3	3.6	5.1	4.6	3.7	2.4	2.0	1.2
20	1.7	2.0	2.1	3.6	4.6	3.6	2.3	2.2	1.7
50	2.0	1.1	2.9	6.3	2.1	4.3	3.8	1.8	1.7
100	1.7	1.6	2.0	4.1	4.0	4.0	2.3	2.7	2.2

[a] Excluding pots that produced no ratoon shoots after the first harvest

Table 9

Effect of consecutive periods of soldier fly infestation (P1 = 9 weeks, P2) on the mean above-ground dry weight of potted sugarcane plants and mean number of ratoon shoots produced after harvest (Trial 2). Plants were harvested 9 weeks into P2

Number of larvae	Above-ground dry wt (g)		No. of ratoon shoots		No. of live larvae after ratooning	
	P1	P2	P1	P2	P1	P2
0	174	155	1.6	3.8	0.0	0.0
3	163	152	2.0	2.0	0.0	1.0
5	149	153	1.2	1.4	0.0	1.2
10	153	145	0.8	0.6	0.0	4.4
20	154	124	1.6	1.8	0.0	7.0
50	150	122	0.4	1.0	0.4	24.0
100	147	133	0.0	0.6	0.2	48.4

Table 10

Effect of infestations of different size classes of soldier fly larvae on the mean above-ground dry weight of potted sugarcane plants and mean number of ratoon shoots produced after harvest

Number of larvae	Above-ground dry wt (g)		No. of ratoon shoots	
	small larvae	large larvae	small larvae	large larvae
0	367		4.0	
10	330	400	2.8	1.6
20	302	359	3.0	1.4
30	316	287	3.2	2.6
50	351	299	2.2	2.2

Table 11

Influence of different environmental conditions on the effect of soldier fly larvae on the mean above-ground dry weight of potted sugarcane plants and mean number of ratoon shoots produced after harvest

Number of larvae	Standard	Late harvest	Un-fertilised	Dry	Warm	Cool
Above-ground dry weight (g)						
0	491	454	261	211	457	454
10	366	335	206	181	372	376
20	357	311	178	192	337	363
40	313	325	163	191	320	298
80	393	330	170	189	346	289
Number of ratoon shoots						
0	2.8	2.0	2.2	3.6	3.0	1.2
10	1.2	0.6	0.6	2.2	0.8	0.0
20	1.2	0.4	0.6	2.0	0.2	0.0
40	1.2	0.0	0.0	0.0	1.4	0.0
80	0.2	0.0	0.2	0.0	0.2	0.0

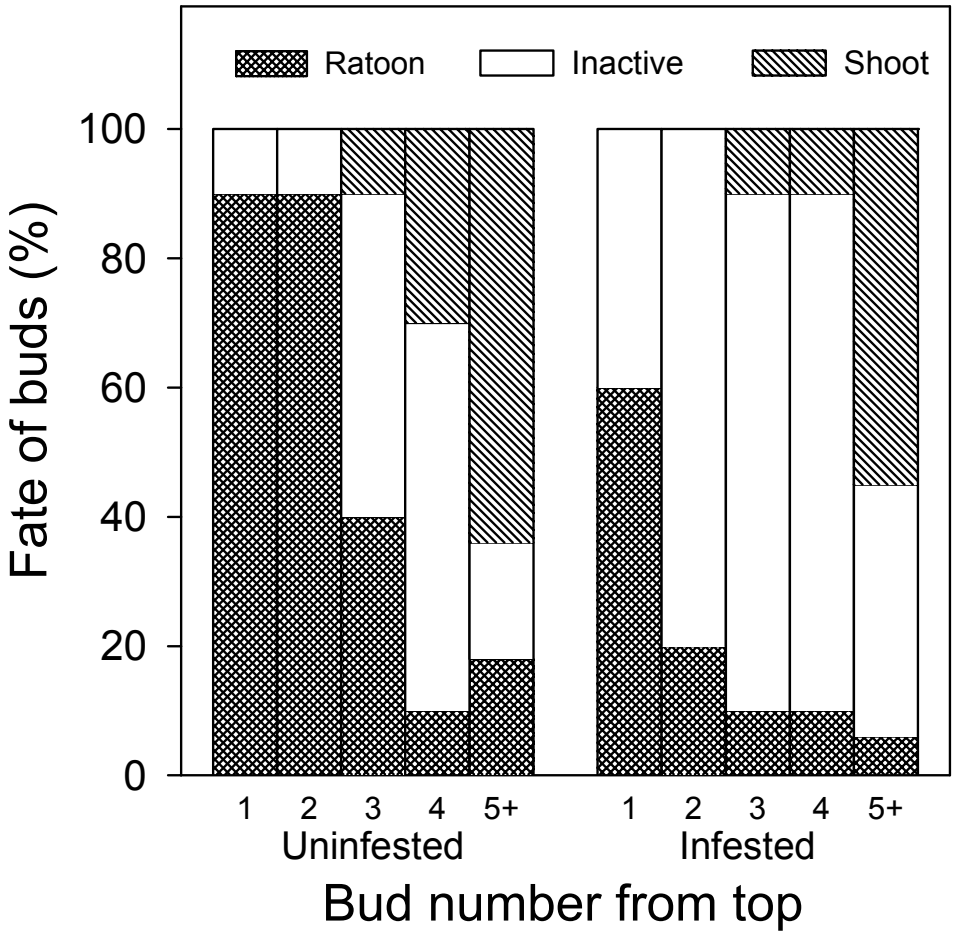

Figure 2 - Fate of below-ground buds on the stubble of primary and main secondary stalks of uninfested and infested (30 larvae) plants, 4 weeks after harvest. (Shoot and Ratoon, shoots that emerged from soil before and after harvest, respectively; Inactive, bud produced no shoot.)

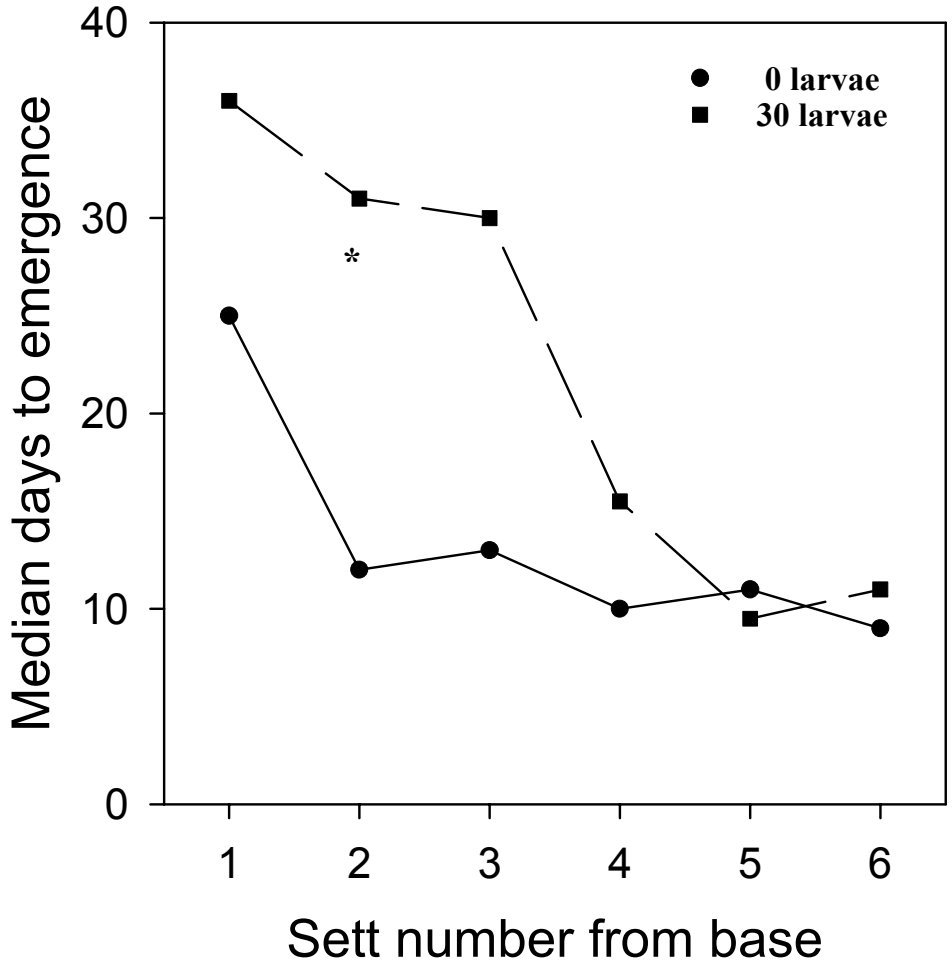

Figure 3 - Days to emergence from soil of setts containing successive nodes cut from uninfested and infested (30 larvae) plants and planted in uninfested soil. (*, time to emergence of sett #2 significantly longer for infested plants).

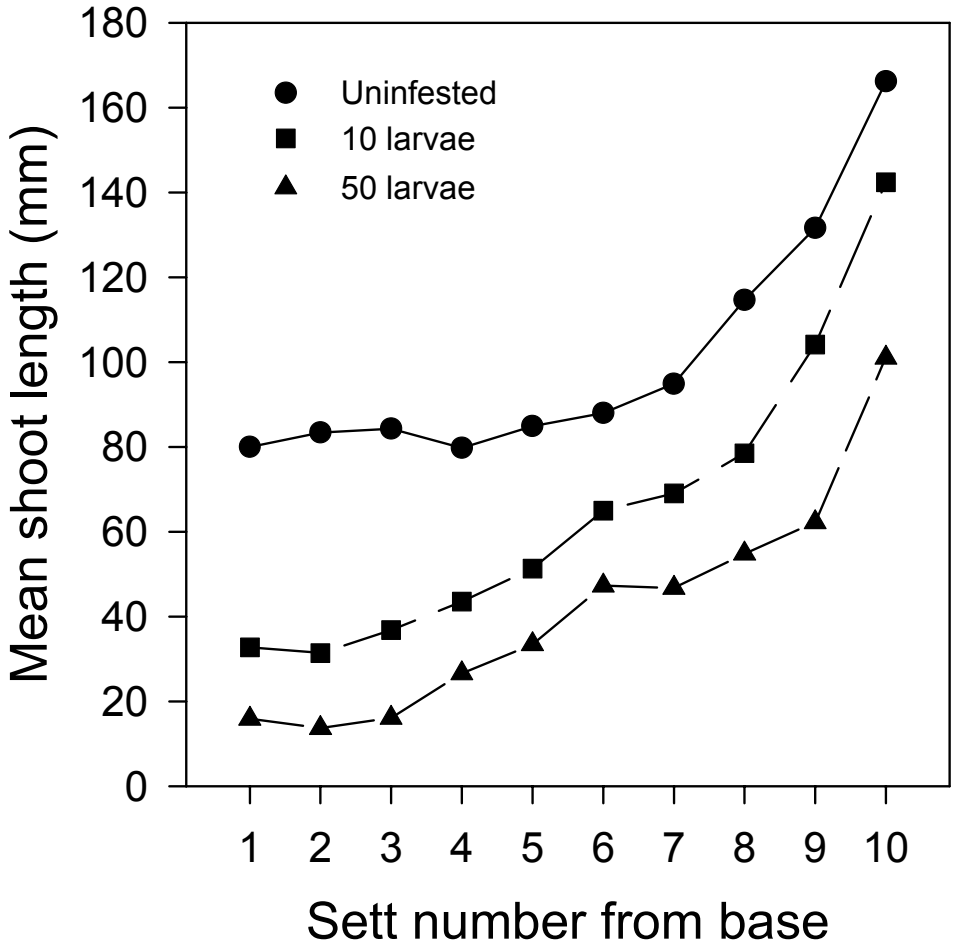

Figure 4 - Length of shoots produced by setts containing successive nodes cut from uninfested and infested plants, 4 weeks after planting in vermiculite.

APPENDIX III

GLASSHOUSE SCREENING OF SUGARCANE CLONES FOR TOLERANCE TO SOLDIER FLY

INTRODUCTION

Larvae of the sugarcane soldier fly suck juices from the roots of sugarcane plants. Affected plants fail to ratoon satisfactorily after harvest, resulting in poor yields and premature ploughout of infested fields.

Previous work on two sugarcane clones showed a difference in their tolerance to soldier fly; 81S595 was much more affected than the commercial cultivar CP44-101 (Samson *et al.*, 1993). Their different levels of tolerance in the field were reproduced when they were grown and infested in pots in a glasshouse. A total of 73 sugarcane cultivars were approved for commercial planting in Queensland in 1995 (Ryan, 1995). In this study, tolerance in some of these cultivars and in several non-commercial clones was compared in pot experiments.

MATERIALS AND METHODS

Experimental methods

Three experiments were carried out in a glasshouse, one in each of 1991, 1992, and 1993. Sugarcane plants were grown in 10 L plastic pots in 1991 and 20 L pots in 1992 and 1993. Pots were filled with krasnozem soil that had been fumigated with methyl bromide. Pregerminated single-bud cuttings of the different sugarcane clones were then planted individually in each pot during mid-September to early October. Pots were fertilised with urea and K_2HPO_4 5-7 weeks later, 0.56 g and 1.6 g per 20 L pot, respectively, and with urea again at 1.52 g/pot 11-14 weeks after transplanting; 10 L pots received half quantities.

Ten sugarcane clones were grown in each experiment (Figs 5-7). Plants were infested with 0, 10, and either 30 (1992) or 50 larvae/pot. Each combination of sugarcane clone and larval density was replicated seven times in a randomised complete-block design. Larvae were added to pots 3-4 weeks after transplanting. They were placed on the soil surface and any that had not buried themselves within a few days were replaced. Sugarcane was harvested at ground level 21-23 weeks after transplanting. Just before harvest, a sample of juice was collected from the main stalk, and the level of total dissolved solids (brix) was measured using a refractometer. Above-ground material (stalks plus leaves) was weighed after drying at 100°C for 2 d. Ratoon shoots were subsequently counted every 2-3 days for at least 5 weeks. The stubble was then removed from the pots and the number of underground buds counted. Soil was wet-sieved using a 1 mm screen to recover roots and soldier fly larvae. Roots were dried at 100°C for several days and weighed. Living soldier fly larvae were counted and the group from each pot

was weighed after surface moisture was removed on absorbent paper. The average weight of living larvae was then calculated for each pot.

Statistical analyses

Average larval weight, larval survival, and the proportion of larvae pupating in each pot were compared between sugarcane clones by analysis of variance, with means separated by the protected least-significant-difference (lsd) test. These measurements had higher variance at the lower larval density in each experiment because averages for each pot were consequently calculated from fewer individuals. Therefore, separate statistical analyses were carried out at each larval density.

The number of ratoon shoots produced in each pot was compared between clones at each soldier fly density by Friedman non-parametric two-way analysis of variance. Measurements of other plant characteristics were compared between larval densities and clones by analysis of variance and lsd test. Measurements of the numbers of buds on stubble and the time for stubble to produce ratoon shoots were transformed as logarithms before analysis. The percentage of buds that produced ratoon shoots was transformed as $\arcsin\sqrt{x}$ in the 1991 experiment only. Relationships between these measurements and ratooning were examined by Spearman rank correlation coefficients. All analyses were carried out using *Statistix 4.0* (Analytical Software).

RESULTS

Larval performance on different clones

Larval survival averaged 47, 48, and 36% in experiments in 1991, 1992, and 1993, respectively. Lower survival in 1993 was probably due to infection by the fungal pathogen *Metarhizium anisopliae*, which was seen on some larval cadavers when soil was sieved after harvest. Some of the survivors had pupated in 1991 and 1993, with 62 and 72% remaining as larvae at the conclusion of the respective experiments. Final weight of larvae and pupae averaged 21.8, 21.8, and 25.9 mg in the three experiments.

Larval survival and the proportion of larvae pupating were the same on all clones in every experiment. Average larval weight differed between clones at the higher larval density in 1993 (Table 12, $P = 0.040$), but no differences were detected at the lower density or in the other experiments.

Ratooning of sugarcane plants

Infested plants produced fewer ratoon shoots than uninfested plants in all experiments (Figs 5-7). The effect of infestation was severe in the 1991 experiment (Fig. 5). Less effect was observed in 1992 (Fig. 6), when plants were grown in larger pots and when the higher larval density was reduced from 50 to 30 larvae in each pot. An intermediate effect was observed in 1993 (Fig. 7), with a higher larval density of 50/pot but with considerable larval mortality (see above).

Clones differed in the number of ratoon shoots that they produced when infested at both low and high larval densities in 1991 ($P < 0.001$ and $P = 0.044$) and 1992 ($P < 0.001$ and $P = 0.0012$) and at the low density in 1993 ($P < 0.001$). Clones also differed in the number of ratoon shoots that they produced when uninfested ($P = 0.027$ in 1991 and $P < 0.001$ in 1992 and 1993).

Rating tolerance of clones to soldier fly

A rating system was developed based on the number of ratoon shoots produced by infested plants of each clone (both larval densities combined, Figs 5-7). After the first experiment, clones 81S595 and Q146 were chosen as representing low and high tolerance to soldier fly with Q141 intermediate (Fig. 5). These clones were carried through as standards in subsequent experiments, although 81S595 was lost from propagation plots in 1993 and could not be included in the final experiment. In 1991 the clones 81S595 and Q146 were given ratings of 1 and 9, respectively. A rating of 3.7 was then applied to Q141 to give a linear relationship with the number of ratoon shoots from infested plants. In 1992 and 1993, these standard ratings were regressed on the number of ratoon shoots produced by the three varieties when infested in each year. In 1993 when 81S595 was absent, a rating of 1 was designated to correspond with assumed zero ratooning. The actual rating applicable to the ten clones in each experiment was then calculated from the number of ratoon shoots produced by each and the regression for the standards in each year.

The resulting ratings are given in Table 13. Of the three standard clones, infested plants of 81S595 failed to ratoon in both 1991 and 1992 (rating ≤ 1.0), Q146 always ratooned well (rating ≥ 7.7), and Q141 was intermediate (rating 3.7 - 5.5). For other clones that were tested more than once, Q144 performed well in two experiments (rating 7.9 and 10.8) and CP51-21 ratooned at an intermediate level in two experiments (rating 3.1 and 5.9). However, inconsistent ratings were recorded for H56-752 (rating 1.0 and 6.3) (Figs 5 and 7).

Effect of infestation on other plant growth characteristics

Infested plants had a lower above-ground weight at harvest than uninfested plants in the 1992 and 1993 experiments but not in 1991 (Table 14). Infested plants had a higher brix in every year. When plants were removed from the pots at the end of each experiment, root weight had been reduced by infestation in 1993 but not in other years. The total number of buds (germinated and ungerminated) present on the stubble below ground was not affected by infestation in 1991 and 1992 and there was not a consistent effect of infestation in 1993. However, infestation did reduce the percentage of these buds that produced a ratoon shoot. Infested plants took longer to produce their first ratoon shoot than did uninfested plants.

All of these measurements differed between sugarcane clones in most years (Table 14). In most cases larval infestation and clone acted independently on these measurements; many interactions were weak and not consistent between years (Table 14). However, the effect of infestation on percentage ratooning of buds differed significantly between clones in 1991. Interactions between infestation and clone were not computed for days to first ratoon, as the data were unbalanced because many infested plants produced no ratoon

shoot. The statistical probability of an effect of clone on this measurement in Table 14 refers to uninfested plants only.

Influence of plant growth characteristics on ratooning

The number of ratoon shoots produced by each clone when infested with larvae was significantly correlated with only two characteristics of uninfested clones, and in only one experiment. In 1992, more ratoon shoots tended to be produced by those clones with more buds on the stubble, and by those clones which produced more ratoon shoots when uninfested (Table 15).

DISCUSSION

The most significant effect of soldier fly infestation observed in these experiments was its effect on ratooning after harvest. Although weights of plant cane at harvest were reduced only slightly by infestation, subsequent ratooning was reduced by up to 100%. Infested plants generally possessed as many buds on the stubble as uninfested plants; however, the expansion of these buds into ratoon shoots was inhibited. A similar effect of infestation on sugarcane has been observed in previous pot experiments and in sugarcane fields (Samson *et al.*, 1993). In a previous study, an extreme effect of soldier fly on yield of the clone 81S595 in comparison with CP44-101 under field conditions was due to a differential effect of larvae on ratooning (Samson *et al.*, 1993). Therefore, ratooning is the most appropriate criterion for assessing sugarcane resistance or tolerance to soldier fly.

The ratooning of all clones was reduced by soldier fly infestation. However, some infested clones produced more ratoon shoots than others. The clone 81S595 performed very poorly, as recorded previously (Samson *et al.*, 1993), and was the least tolerant of all those tested. Ratings of clones tested in two or more experiments were generally consistent, although the ratings for H56-752 varied markedly in duplicate measurements, for unknown reasons.

There was no difference in growth and survival of larvae on different sugarcane clones in two of the three experiments. In 1993, larval growth differed between clones but this was detected at only the higher larval density, the difference in larval weight was small, and survival was unaltered. Antibiosis was evidently not a component of resistance of the clones to soldier fly, and differences in ratooning were due to tolerance alone. The same conclusion was reached in a previous study of clones 81S595 and CP44-101 (Samson *et al.*, 1993).

In 1992, ratooning of infested plants was correlated with ratooning of uninfested plants; those clones that normally produced more ratoon shoots also tended to ratoon better in the presence of soldier fly. However, in 1991 or 1993, when infestation pressure was more severe, the clones that ratooned best when infested were not always the best ratooning varieties under uninfested conditions. Q144, for example, was one of the best ratooning clones when infested but produced fewer ratoon shoots than some other clones when soldier fly were absent (Figs 5 and 7).

In sum, soldier fly infestation reduced the number of ratoon shoots produced by all 22 clones tested. However, some clones were able to produce more ratoon shoots than others when attacked by soldier fly larvae. Of the clones tested, Q135, Q144, and 77N330 performed the best. This was due to tolerance alone; no antibiosis was found. The most tolerant varieties produced the most ratoon shoots in the absence of soldier fly in one experiment. However, this did not explain the difference in levels of tolerance in two other experiments. Levels of tolerance were not correlated with other plant characteristics that were measured. There seems to be no way of predicting the best varieties other than by infesting them with larvae. The relationship between the rating system for tolerance measured in the glasshouse and levels exhibited in the field is investigated in Appendix IV.

ACKNOWLEDGMENT

I am grateful to Paul McLennan for technical assistance.

REFERENCES

Ryan, C C (1995). Approved varieties lists for 1995. *BSES Bull.* 49: 20-21.

Samson, P R, Hansen, P B and Mullins, R T (1993). Tolerance of sugarcane clones to feeding by *Inopus rubriceps* (Macquart) (Diptera: Stratiomyidae). *J. Aust. Entomol. Soc.* 32: 37-42.

Table 12

Average weight of soldier fly larvae feeding on sugarcane clones in 1993 (50 larvae/pot)

Clone	Larval weight (mean ± se)
H56-752	29.8 ± 2.3 a
Q146	28.2 ± 1.3 ab
CP51-21	28.1 ± 1.9 ab
Q144	27.3 ± 1.3 ab
Q141	27.0 ± 1.4 ab
NCo310	26.1 ± 1.4 abc
Q153	25.2 ± 1.6 bc
77N330	25.0 ± 1.6 bc
Q155	24.5 ± 1.3 bc
Q136	21.8 ± 1.4 c

Means followed by the same letter were not significantly different by lsd test ($P = 0.05$)

Table 13

Sugarcane clones ranked according to their rating for tolerance to soldier fly, from least to most tolerant

Clone	Repeated inclusion in experiments	Year	Tolerance rating
* 81S595	(2)	1992	0.5
* 81S595	(1)	1991	1.0
H56-752	(1)	1991	1.0
Q143		1992	2.6
CP51-21	(1)	1991	3.1
Q110		1991	3.1
Q136		1993	3.2
* Q141	(1)	1991	3.7
* Q141	(3)	1993	3.7
Q124		1992	3.7
Q150		1992	4.1
Q138		1991	4.2
Q153		1993	4.6
* Q141	(2)	1992	5.5
CP51-21	(2)	1993	5.9
Q137		1992	6.1
H56-752	(2)	1993	6.3
NCo310		1993	6.8
Q155		1993	7.2
CP44-101		1991	7.4
* Q146	(2)	1992	7.7
Q144	(1)	1991	7.9
Q151		1991	7.9
Q147		1992	8.1
Q154		1992	8.6
* Q146	(3)	1993	9.0
* Q146	(1)	1991	9.0
Q135		1992	10.3
77N330		1993	10.3
Q144	(2)	1993	10.8

*, standard clones

Table 14

Effect of soldier fly infestation on characteristics of some sugarcane clones in three experiments

Year	Means at different infestation levels			P_{clone}	$P_{interaction}$
	Uninfested	Light	Heavy		
Above-ground (top) weight at harvest (g, wet in 1993, dry otherwise)					
1991	152 ± 6 a	149 ± 6 a	142 ± 6 a	<0.001	0.046
1992	331 ± 6 a	318 ± 6 a	309 ± 7 b 1705	<0.001	0.49
1993	2002 ± 30 a	1898 ± 28 b	± 27 c	0.032	0.39
Brix at harvest					
1991	12.2 ± 0.3 b	12.9 ± 0.3 a	13.1 ± 0.4 a	<0.001	0.033
1992	18.7 ± 0.2 c	19.2 ± 0.2 b	19.8 ± 0.2 a	<0.001	0.057
1993	14.9 ± 0.2 b	15.4 ± 0.2 a	15.4 ± 0.2 a	<0.001	0.81
Root dry weight (g)					
1991	10.6 ± 0.9 a	10.9 ± 1.2 a	10.4 ± 0.9 a	0.002	0.49
1992	59.5 ± 1.8 a	61.2 ± 2.2 a	60.3 ± 2.2 a	<0.001	0.22
1993	61.2 ± 2.1 a	56.2 ± 2.4 a	41.5 ± 1.8 b	<0.001	0.33
Total below-ground buds					
1991	7.9 ± 0.4 a	7.8 ± 0.3 a	7.6 ± 0.4 a	<0.001	0.040
1992	11.5 ± 0.5 a	11.5 ± 0.5 a	11.4 ± 0.6 a	<0.001	0.89
1993	9.1 ± 0.3 b	10.3 ± 0.4 a	8.5 ± 0.3 b	<0.001	0.069
Percentage ratooning of buds					
1991	37.5 ± 2.1 a	10.3 ± 1.4 b	3.0 ± 1.1 c	0.001	<0.001
1992	34.1 ± 1.3 a	21.8 ± 1.9 b	14.9 ± 1.6 c	<0.001	0.102
1993	29.8 ± 1.5 a	12.2 ± 1.2 b	8.2 ± 1.1 c	0.089	0.054
Days to first ratoon					
1991	11.2 ± 0.4 b	16.2 ± 1.2 a	14.1 ± 2.0 ab	0.007	-
1992	8.6 ± 0.2 b	11.2 ± 0.7 a	12.6 ± 0.7 a	<0.001	-
1993	8.8 ± 0.3 b	12.4 ± 1.0 a	12.8 ± 0.9 a	0.004	-

Means in rows followed by the same letter were not significantly different by lsd test (P = 0.05)

Table 15

Correlations between measurements on uninfested plants of sugarcane clones and the number of ratoon shoots produced by the same clones infested with soldier fly larvae

Measurements on uninfested plants	Spearman correlation coefficients in each year		
	1991	**1992**	**1993**
Above-ground (top) weight	0.365	-0.492	-0.139
Root dry weight	0.614	0.055	0.200
Root/top ratio	0.606	-0.139	0.309
Brix	0.445	-0.152	-0.394
Total below-ground buds	0.160	0.806*	0.316
% ratooning of buds	0.083	0.134	0.370
No. of ratoons	-0.110	0.851*	0.294
Time to first ratoon	-0.546	-0.207	-0.225

*, $P < 0.05$

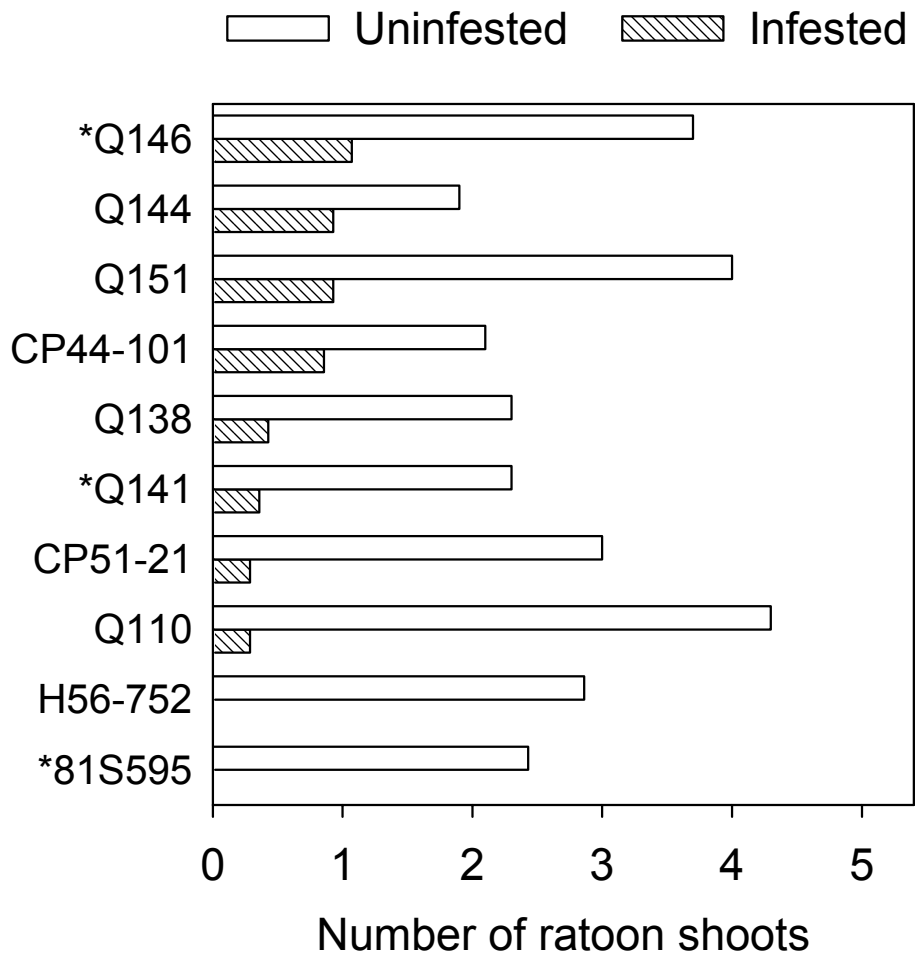

Figure 5 - The influence of soldier fly infestation (combination of 10 and 50 larvae/ pot) on the number of ratoon shoots produced by 10 sugarcane clones after harvest - 1991 experiment. * indicates standard clones.

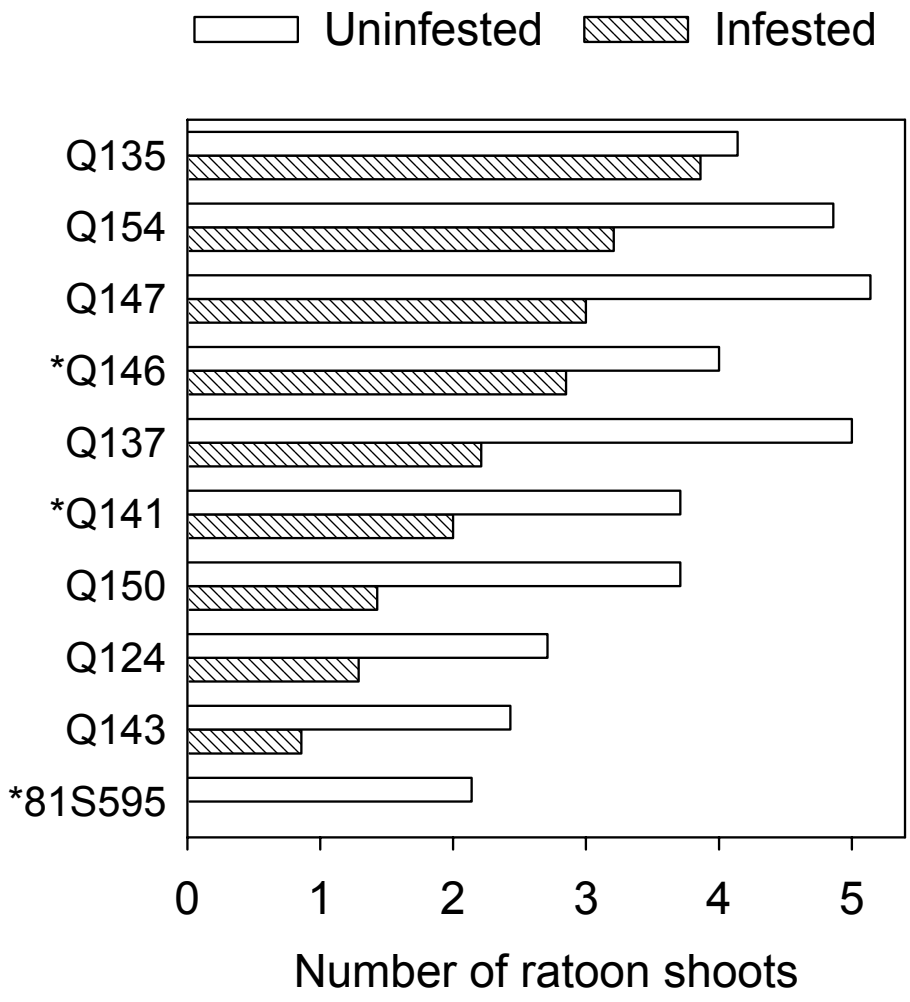

Figure 6 - The influence of soldier fly infestation (combination of 10 and 30 larvae/ pot) on the number of ratoon shoots produced by 10 sugarcane clones after harvest - 1992 experiment. * indicates standard clones.

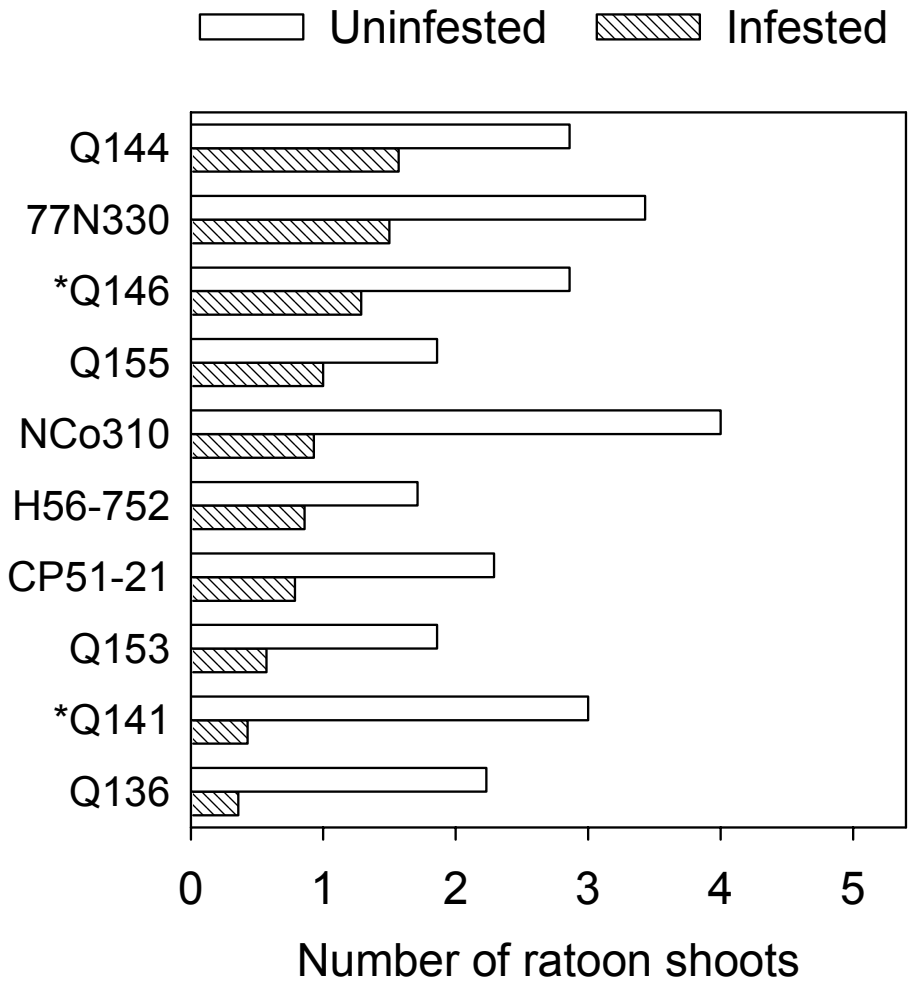

Figure 7 - The influence of soldier fly infestation (combination of 10 and 50 larvae/ pot) on the number of ratoon shoots produced by 10 sugarcane clones after harvest - 1993 experiment. * indicates standard clones.

APPENDIX IV

FIELD COMPARISON OF SUGARCANE VARIETIES FOR RESISTANCE TO SOLDIER FLY

INTRODUCTION

In a glasshouse study, the ratooning of 22 sugarcane clones was compared with soldier fly present or absent (Appendix III). A rating system was developed for their tolerance to infestation. Earlier work indicated that tolerance shown by two clones in the glasshouse reflected their relative tolerance to infestation in the field (Samson *et al.*, 1993). In this study, 10 of the 22 newly screened clones were grown in field plots to determine whether the glasshouse rating system was a useful guide to their field response.

MATERIALS AND METHODS

Experimental methods

Four trials were set up, three in the Bingera Mill area (Bengtson, Laufer and Walker) and one at Maryborough (Doyle). Ten commercial sugarcane varieties were planted at each site in ten plots. Plots measured 4 rows wide by 10-14 m. Trials were laid out in a split plot or split block design, with five bands across each field treated with insecticide (see below) in an attempt to reduce soldier fly populations in those plots.

Cane was planted in August-September 1991. Crops were subsequently harvested annually (Table 16). Crop measurements were taken from the middle two rows of each plot. Numbers of millable stalks were counted shortly before harvest, and levels of CCS were measured in a 6-stalk sample from each plot. Yields were measured with a weighing machine. Numbers of ratoon shoots were then counted 5-15 weeks after harvest, depending on the speed of ratooning in each crop.

Four generations of soldier fly larvae were sampled, in autumn of each year 1992-1994 and in summer of 1994/95 corresponding to the plant and three ratoon crops. Four soil cores each 65 mm diameter by 200 mm deep were taken from the middle two rows of each plot on each occasion. Larvae were wet-sieved from the samples (Robertson, 1984) and collected on a 1 mm punched-hole screen. Living larvae were counted and their total weight for each plot was recorded after surface moisture was removed on absorbent paper.

Ratoon stunting disease (RSD) was inadvertently introduced with planting material in all trials. Its incidence was monitored by collecting the juice from one stalk from at least four stools in each plot. The presence of RSD bacteria was determined by a serological assay, EB-EIA (evaporative-binding enzyme-linked immunoassay) (Croft *et al.*, 1994).

Insecticide treatments

Insecticide was applied to half of each experimental block in each trial. At Doyle, the insecticide then registered for soldier fly control, dieldrin, was applied at 6.7 kg ai/ha. It was applied from a boom spray and incorporated by rotary hoe before planting. This treatment could not be used at the other sites because of possible contamination of neighbouring land, and alternative insecticides were trialled. At Laufer, suSCon Blue containing 14% chlorpyrifos in a controlled-release plastic granule was applied to the drill after planting at 5.7 kg ai/ha. Granules were spread in a band and then covered with soil. At Bengtson and Walker, smaller (1 mm) controlled-release granules containing 10% chlorpyrifos were similarly applied at 5.2 and 6.3 kg ai/ha, respectively. In addition, aldicarb (Temik 150G) was applied at a nominal rate of 2.5 kg ai/ha each year at Bengtson and Laufer followed by irrigation. In the plant crop it was spread across the drill at the same time as suSCon treatment and in ratoons after harvest in 1992 and 1993 it was applied using paired coulters spaced 200-250 mm apart.

Statistical analyses

The effect of insecticide treatment and varieties on the number of soldier fly was determined by analysis of variance over three ratoon crops. Larval counts were first transformed as log(x+1) to stabilise the variance. The average weight of larvae collected from each plot was calculated over all sampling occasions and compared between varieties by analysis of variance within each trial. Relationships between number of soldier fly and crop measurements were tested by linear regression using pest and crop data from individual plots. Analyses were carried out using *Statistix 4.0* (Analytical Software), except that pest-crop regressions for individual varieties were done using *MLP 3.06* (Ross, 1980).

RESULTS

Ratoon stunting disease

In 1994, RSD was detected in almost all plots in the trial at Laufer, half the plots at Doyle and a smaller proportion at Bengtson and Walker. Average levels of absorbance differed significantly between farms, with readings at Laufer being higher than at Doyle which were higher than at Bengtson and Walker. The frequency of detected RSD differed between varieties, with Q138 showing as positive in almost all plots. Absorbance levels differed significantly between varieties ($P < 0.05$), with Q138 having the highest level and Q141 the lowest.

Larval performance on different clones

Populations of soldier fly larvae developed rapidly after planting at Bengtson and Walker and more slowly at Laufer (Table 17). Insecticide treatment did not affect the number of soldier fly on these farms ($P > 0.05$). Population density of soldier fly remained negligible at Doyle for the duration of the trial.

Numbers of larvae differed significantly between varieties at Laufer, with H56-752 and Q144 hosting more larvae than some other varieties such as Q141 and CP51-21 (Table

18). H56-752 and Q144 also ranked high for larval density at Bengtson and Walker with Q141 and CP51-21 ranking low, but differences in numbers between varieties at these farms were not statistically significant. The mean larval density per stool, averaged over the three trials and three ratoon crops, ranged from 4.7 on Q144 to 1.9 on Q141. Varieties and year of sampling acted independently on larval density at all farms ($P > 0.05$).

The average weight of larvae was not influenced by variety at any farm ($P = 0.19$, 0.38 and 0.66 at Laufer, Bengtson and Walker, respectively).

Effect of soldier fly on crop measurements

Significant relationships ($P < 0.05$) between soldier fly infestation and crop growth and yield in individual plots were observed in the first three ratoon crops at Bengtson, the second ratoon at Laufer, and the plant crop and first two ratoon crops at Walker (Table 19). Ratoon shoots were not counted in the first ratoon at Laufer because of low numbers of soldier fly. Soldier fly numbers at Doyle were too low to carry out regression analysis in any crop class.

The number of ratoon shoots was negatively related to soldier fly density in five analyses (Bengtson 2R and 3R, Laufer 2R, Walker 1R and 2R) (Table 19). Each increase in soldier fly density of 100 m^{-2} reduced the number of shoots by 2 400 - 7 100 ha^{-1}, with a greater effect in earlier crop classes. Because the number of ratoon shoots depends in part on ratooning in earlier crops, I also calculated the increase in ratoon shoots over the prior number of mature stalks as an index of the immediate effect of soldier fly on ratooning in the current crop. However, relationships between soldier fly density and this increase factor were no improvement over those using the number of ratoon shoots alone (see R^2 values, Table 19).

Soldier fly infestation reduced the number of mature stalks (Walker P and 1R), the weight of mature stalks (Bengtson 1R and 2R), or both (Walker 2R) (Table 19). In ratoon crops, reductions in numbers of mature stalks were not as pronounced as reductions in earlier numbers of ratoon shoots. Third ratoons were not grown through to harvest so no data are available for mature stalks in those crops.

Cane yield was negatively related to soldier fly density at the harvests of two ratoon crops at Bengtson and of the plant and two ratoon crops at Walker (Table 19). Each increase in soldier fly density of 100 m^{-2} was associated with a yield reduction of 1.2 - 6.5 tonnes ha^{-1}, or 3 - 20% of the predicted yield of uninfested plants, with a greater effect in earlier crop classes. Levels of CCS were related to soldier fly density on three occasions (Walker P, Laufer 2R, Walker 2R) but with contradictory effects (Table 19).

All these regressions used larval density during summer-autumn within each crop class as the independent variable. However, two generations of larvae may feed on stools between harvests. Harvest measurements may be influenced by the new generation of larvae that appears after the autumn emergence of adult flies. Using density of this later generation of larvae as the independent variable in the regressions recorded as significant in Table 19, values of R^2 were lower for all regressions of the number and weight of mature stalks, yield and CCS. In the case of ratoon shoots, ratooning vigour may be influenced by larvae

that had fed up until the autumn prior to harvest of the previous crop. Using larval density of this earlier generation as the independent variable, values of R^2 were lower for four of the five regressions of ratoon shoots and all of the regressions for shoot increase.

Comparative response of varieties within farms

The number of ratoon shoots and harvest yield were chosen as two crop measurements with which to compare varietal response to soldier fly, as both were frequently affected by infestation when examined over the whole trials (see above). Regressions of the two measurements on soldier fly density were examined individually for each variety in the farms and crop classes where significant effects were observed in the whole-trial analyses, ie five analyses of ratoon shoots and five analyses of harvest yield (Table 19).

For the number of ratoon shoots, the displacement of regression lines differed significantly ($P < 0.05$) between varieties at four farm/crop class combinations, with no significant difference in slope. Slopes differed significantly between varieties at Laufer 2R but some unlikely positive regression coefficients in this analysis suggest little confidence can be placed in the result.

For crop yield, the displacement of regression lines again differed significantly ($P < 0.05$) between varieties at four farm/crop class combinations, with no significant difference in slope. A significant difference in varietal response was detected only at Walker in the second ratoon. Varieties ranked according to the slope of regressions, in descending order of magnitude (compare with Table 19), were Q138 (-2.9), H56-752 (-2.8), CP51-21 and Q141 (both -2.5), Q137 (-1.7), Q110 (-1.4), CP44-101 (-0.8), Q146 (-0.7), Q151 (-0.5) and Q144 (-0.2).

Comparative response of varieties between farms

Crop yields remained high at Doyle in both the plant crop and two ratoons (Fig. 8), perhaps reflecting the low number of soldier fly at this farm (Table 17) but perhaps also resulting from better water availability that minimised the deleterious effect of RSD. Yields fell greatly in ratoons at Laufer in comparison with the plant crop, and in second ratoons at both Walker and Bengtson. Part of this fall must have been due to the effect of RSD in addition to that of soldier fly. Despite the differences in soldier fly numbers between farms and crop classes (Table 17), there were no striking differences between the relative yields of different varieties on the different farms.

Numbers of shoots in second and third ratoons were higher at Doyle than at the other farms (Fig. 9). As with yield, the relative ability of varieties to produce ratoon shoots was not greatly different between farms. Q151 seemed to produce good numbers of shoots at Bengtson, which had the highest density of soldier fly, but in the second ratoon at least this was not reflected in increased yield (compare with Fig. 8).

DISCUSSION

The insecticide treatment of controlled-release chlorpyrifos plus annual application of aldicarb did not reduce soldier fly numbers in these trials. Although this treatment was judged as the most promising procedure at the time trials were laid out, subsequent research has shown that controlled-release chlorpyrifos is not effective (unpublished data) and that aldicarb gives inconsistent results, at least in ratoons (Samson and Harris, 1994). In the absence of uninfested control plots in the trials, the effect of soldier fly on crop growth was estimated from the natural variation in population density of larvae between plots.

When calculating regressions of crop growth on soldier fly density, a choice of soldier fly measurements was available. Soldier fly larvae mature to adults in autumn and a new generation of larvae is then present from winter onwards, often in greater numbers than before. Comparison of the variance explained by regression showed that larval density in the early part of a crop class, before the autumn fly emergence, was the appropriate measure of soldier fly infestation as it affected performance of that crop class (assuming annual harvests). Therefore, ratooning is likely to be related to the number of soldier fly present beneath the stools at harvest, even though these larvae will usually be small and will have been feeding on the stool only since the previous autumn. Yield at subsequent harvest of that crop is strongly influenced by larvae that emerged as adults during the growth of that crop, and whose distribution and density may have differed from that of the current larval generation.

Soldier fly infestation not only reduced the number of ratoon shoots, but also reduced both the number and the weight of mature stalks at harvest. Both of these effects could have resulted from reduced number or slower production of ratoon shoots, plus any additional effect of soldier fly on growth.

The regression analyses indicate that larval populations of several thousand per square metre have the potential to completely suppress ratooning of sugarcane and reduce yield to zero. Such densities are rarely reached on average over whole fields, but may occur in localised patches within fields (eg Samson and McLennan, 1993, and this study).

Larval numbers varied slightly between varieties but no difference was detected in larval weights. There is probably no antibiosis, as similarly concluded from pot studies on a larger range of varieties (Appendix III). Certain varieties may favour a more rapid increase of soldier fly populations, possibly because their root systems may be more suitable for larval establishment and survival. However, the range of larval densities across varieties was small, and unlikely to lead to satisfactory population control.

Within each trial, there were differences between varieties in both the number of ratoon shoots they produced and yield. For most measurements and crop classes, these differences were independent of the number of soldier fly measured in plots, i.e. the effect of soldier fly was similarly adverse on all varieties. This result conflicts with the conclusion of a detailed study of two sugarcane clones, a commercial variety CP44-101 and an experimental clone 81S595, where soldier fly had a greater effect against 81S595 in both pots and canefields (Samson *et al.*, 1993). It is possible that clones which are particularly sensitive to soldier fly, such as 81S595, may also have low vigour under other circumstances and may be discarded during the routine variety selection program.

The field result also conflicts with some results from the pot comparison of clones (Appendix III), where clones that ratooned best when infested were not always the best clones when soldier fly were absent. This could be associated with the higher infestation pressure in those pots, where many larvae were confined on a limited root system.

Anecdotal evidence suggests that commercial varieties do differ in their response to soldier fly. Variety CP51-21, in particular, is reported by cane farmers to be particularly sensitive. This did not show up in my field results. Differences between varietal responses observed in commercial plantings are often confounded by differences in agronomic practices applied to each variety. CP51-21, for example, is an early-sugar cane that tends to be harvested early in the season, when the effect of soldier fly may be more apparent due to cool conditions (Appendix II; Moller, 1968).

Based on pot screening of the varieties (Appendix III), it was expected that varieties Q144, Q146, Q151 and CP44-101 would be less affected by soldier fly while CP51-21, Q110 and Q141 would be relatively sensitive. This was not supported by field comparisons of yield either within farms, except perhaps for the individual plot comparison at Walker in the second ratoon, or between farms. Any relative tolerance may have been counteracted by differing infestation levels on some varieties; Q141 and CP51-21 seemed to host relatively fewer larvae than others.

There may be environmental conditions or management strategies that would stimulate varietal differences, eg early harvest when soil temperatures are low may place greater stress on the plants. Varietal differences may also become more apparent at higher infestation levels. However, given the methods of this study, the results provide little evidence that planting commercial cane varieties according to perceived resistance will be a significant strategy for soldier fly control. Choice of varieties most suited to a district is likely to lead to the best results, whether soldier fly are present or not.

ACKNOWLEDGMENTS

I am grateful to Paul McLennan for technical assistance, Barry Croft for RSD analyses, and the cooperating canefarmers.

REFERENCES

Croft, B J, Greet, A D, Leaman, T M and Teakle, D S (1994). RSD diagnosis and varietal resistance screening using the EB-EIA technique. *Proc. Aust. Soc. Sugar Cane Technol.* 16: 143-151.

Moller, R B (1968). Soldier fly - past, present and future. *Proc. Queensl. Soc. Sugar Cane Technol.* 35: 53-55.

Robertson, L N (1984). An extraction method used to study vertical and lateral distribution of soldier fly *Inopus rubriceps* (Diptera: Stratiomyidae) in sugar cane soil. *J. Aust. Entomol. Soc.* 23: 21-24.

Ross, G J S (1980). 'MLP 3.06'. (Rothamsted Experimental Station.)

Samson, P R, Hansen, P B and Mullins, R T (1993). Tolerance of sugarcane clones to feeding by *Inopus rubriceps* (Macquart) (Diptera: Stratiomyidae). *J. Aust. Entomol. Soc.* 32: 37-42.

Samson, P R and Harris, W J (1994). Effectiveness of insecticides against larvae of *Inopus rubriceps* (Macquart) (Diptera: Stratiomyidae) in sugarcane ratoons. *Plant Prot. Quart.* 9: 35-37.

Samson, P R and McLennan, W J (1993). Natural infection of soldier fly *Inopus rubriceps* by *Metarhizium anisopliae* in sugarcane fields. *Proc. Aust. Soc. Sugar Cane Technol.* 15: 231-236.

Table 16

Dates of planting and annual harvests of variety trials on four farms

Operation	Bengtson	Doyle	Laufer	Walker
Planting	26/9/91	5/9/91	29/8/91	20/9/91
Harvest - P	20/10/92	15/10/92	21/10/92	20/10/92
Harvest - 1R	3/12/93	19/10/93	1/12/93	7/12/93
Harvest - 2R	16/8/94	27/9/94	9/9/94	16/8/94

Table 17

Population density of soldier fly larvae (m^{-2} within rows) in successive years at four farms, with and without insecticide treatment (details given in text)

Crop class	Bengtson		Doyle		Laufer		Walker	
	-	Treat	-	Treat	-	Treat	-	Treat
P	38	18	0	0	0	0	30	11
1R	102	77	0	0	44	49	146	209
2R	491	567	0	3	68	92	278	347
3R	502	556	3	8	105	166	157	197

Table 18

Number of soldier fly larvae found under ten sugarcane varieties on three farms, in ratoon crops 1R to 3R

Variety	Mean number of soldier fly larvae/4-core sample (log-transformed)		
	Laufer	Bengtson (ranking)	Walker (ranking)
H56-752	0.38 a	0.63 (3)	0.52 (3)
Q144	0.37 a	0.69 (1)	0.62 (1)
CP44-101	0.29 ab	0.57 (7)	0.45 (5)
Q151	0.25 ab	0.59 (6)	0.55 (2)
Q146	0.24 abc	0.63 (4)	0.42 (7)
Q137	0.21 bc	0.67 (2)	-
Q138	0.21 bc	0.47 (8)	0.35 (9)
Q110	0.19 bc	0.59 (5)	0.48 (4)
Q141	0.16 bc	0.45 (10)	0.39 (8)
CP51-21	0.10 c	0.46 (9)	0.44 (6)
$(P)^a$	(0.0071)	(0.14)	(0.19)

[a] By analysis of variance

At Laufer, means followed by the same letter were not significantly different by the least-significant-difference test ($P = 0.05$). Numbers in brackets at Bengtson and Laufer are the ranking of each variety for number of larvae, in descending order.

Table 19

Crop measurements in relation to density of soldier fly larvae during the summer-autumn period within each crop class, at three farms

Crop measurement	Regressions[a] on larval density *x* as 100s/m^2 in rows (R^2)		
	Bengtson	**Laufer**	**Walker**
Plant crop			
Mature stalks (10^4 ha^{-1})	-	-	3.4 - 0.56*x* (0.05)
Wt mature stalks (kg)	-	-	-
Yield (t ha^{-1})	-	-	32 - 6.5*x* (0.10)
CCS	-	-	16.0 - 0.43*x* (0.05)
First Ratoon			
Ratoon shoots (10^4 ha^{-1})	-	n.a	11.5 - 0.71*x* (0.16)
Increase[c]	-	n.a	-
Mature stalks (10^4 ha^{-1})	-	-	8.2 - 0.20*x* (0.05)
Wt mature stalks (kg)	0.85 - 0.063*x* (0.17)	-	-
Yield (t ha^{-1})	82 - 6.4*x* (0.23)	-	70 - 2.5*x* (0.06)
CCS	-	-	-
Second Ratoon			
Ratoon shoots (10^4 ha^{-1})	16.8 - 0.49*x* (0.16)	13.5 - 0.51*x* (0.05)	15.0 - 0.40*x* (0.07)
Increase[c]	1.76 - 0.053*x* (0.20)	1.65 - 0.062*x* (0.05)	1.96 - 0.060*x* (0.10)
Mature stalks (10^4 ha^{-1})	-	-	8.9 - 0.19*x* (0.08)
Wt mature stalks (kg)	0.38 - 0.009*x* (0.25)	-	0.38 - 0.008*x* (0.12)
Yield (t ha^{-1})	44 - 1.3*x* (0.25)	-	33 - 1.2*x* (0.22)
CCS	-[b]	14.9 - 0.24*x* (0.07)	12.5 + 0.17*x* (0.09)[b]
Third Ratoon			
Ratoon shoots (10^4 ha^{-1})	14.9 - 0.24*x* (0.08)	-	-
Increase[c]	1.40 - 0.025*x* (0.10)	-	-

[a] $P < 0.05$

[b] Variety Q144 omitted due to frost damage

[c] Number of ratoon shoots/number of mature stalks at previous harvest

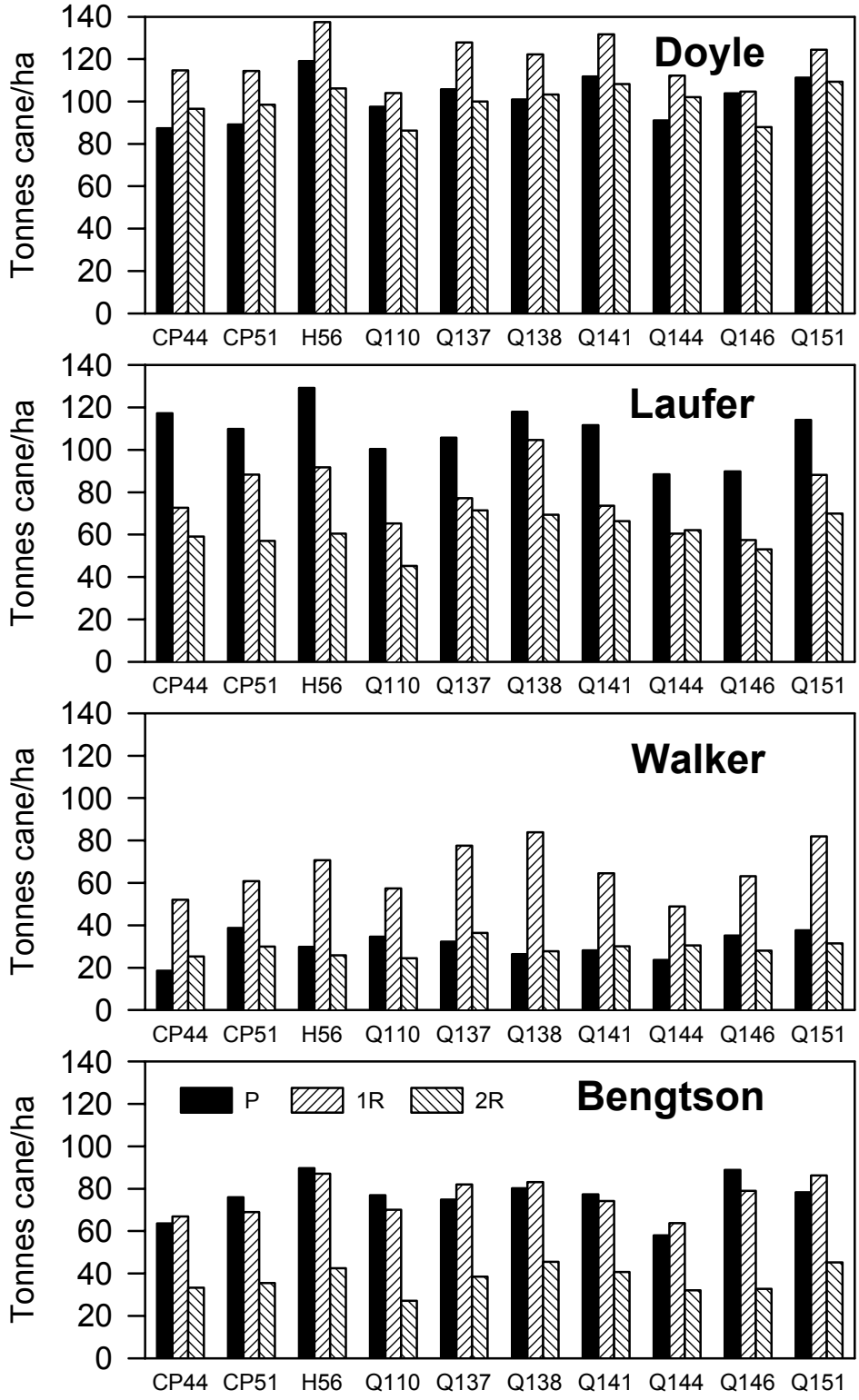

Figure 8 - Yield of sugarcane on four farms at successive harvests (P - 2R).

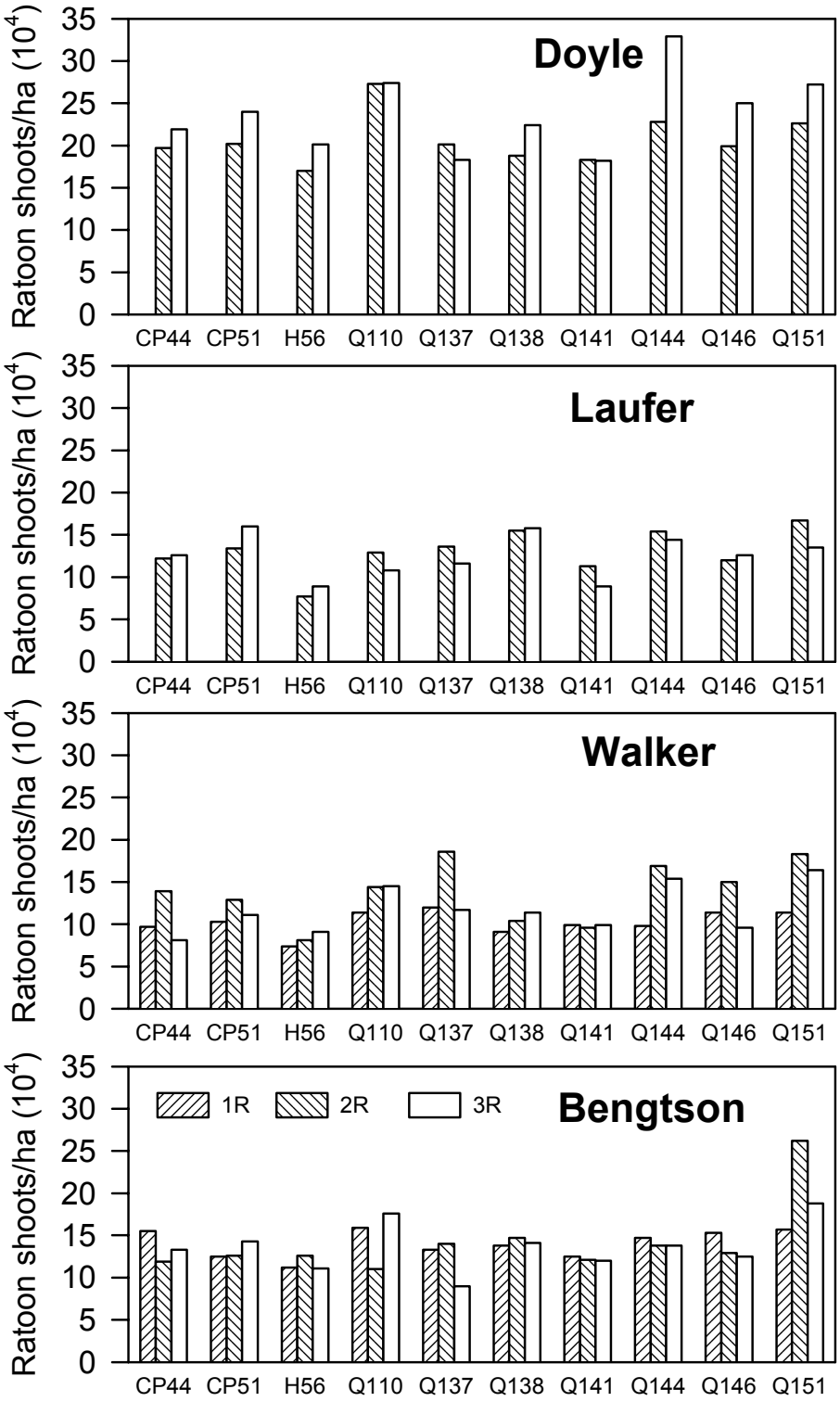

Figure 9 - Numbers of ratoon shoots (1R - 3R) on four farms at successive harvests.

APPENDIX V

A SURVEY OF SOLDIER FLY DAMAGE AND ASSOCIATED FARMING PRACTICES AT BINGERA

INTRODUCTION

The occurrence of sugarcane soldier fly varies between farms and canefields, with some fields suffering chronic infestations. It is likely that certain environmental conditions or farming practices predispose some farms and canefields to high soldier fly levels. A survey of soldier fly losses and associated farming practices was carried out in 1992 in an attempt to identify critical factors that may reduce soldier fly losses.

METHODS

The Bingera Mill area was chosen for the survey, as it has many farms affected by the pest. A questionnaire was completed for individual canefields on 58 canefarms, in consultation with growers. Farms with a history of soldier fly were targeted. On each farm, records were obtained for every field harvested as second ratoons in 1991. This crop class was chosen as being sufficiently old to show soldier fly damage (Samson *et al.*, 1991) but not so old as to have lost many fields through plough-out. ('Plough-out' here refers to the destruction of an unwanted crop by any mechanical or chemical method, not necessarily using a plough.) A total of 194 fields were surveyed.

Farmers were asked the incidence of soldier fly damage as shown in the second ratoon harvested in 1991 and also in the previous first ratoon harvested in 1990. In mixed plantings, the incidence of damage was recorded separately for each variety in the field. Other information was obtained concerning soldier fly incidence in the previous crop cycle, ground preparation for planting, and farming practices including pesticide use and sugarcane varieties in the present crop cycle. Growers were questioned regarding past use of the organochlorine insecticides dieldrin and BHC, and supporting records of dieldrin use within the previous 12 years were also obtained from the Bingera Cane Protection and Productivity Board. Soil types were determined from farm and soil maps held by the Bingera CPPB (van Wijk, Bundaberg Irrigation Project soil association map).

Associations between the different factors and soldier fly damage, expressed as the number of fields damaged and undamaged, were examined in contingency tables by computing the interaction chi-square using *Statistix 4.0* (Analytical Software). Yates' correction for continuity was applied to 2 x 2 tables. Confidence intervals for the proportion of fields damaged were determined from tabulated binomial confidence limits for given sample sizes (Table A14, Steel and Torrie, 1960).

RESULTS

Influence of soil type

Most fields surveyed were on flood plain alluvia, recent alluvia, yellow brown and dark brown clays, red friable loams to clay loams, and black earths. The frequency of soldier fly damage was the same on the five soil groups ($\chi^2 = 5.0$, $P = 0.29$)

Influence of organochlorine history

Many fields had been treated with dieldrin for soldier fly control, although not in the current crop cycle. Soldier fly damage was independent of growers' recollection of time elapsed since the last use of dieldrin, whether ≤12 years ($n = 55$), 13 - 20 years ($n = 23$), or >20 years or never ($n = 116$) ($\chi^2 = 5.3$, $P = 0.07$). Damage was also independent of dieldrin use from CPPB records, whether used within the previous 12 years ($n = 36$) or not ($\chi^2 = 0.08$, $P = 0.77$). Some fields had also been treated previously with BHC. Damage was independent of growers' recollection of BHC use, whether within the previous 20 years ($n = 32$) or not ($\chi^2 = 0.9$, $P = 0.33$).

Historical effect of soldier fly damage

Damage in second ratoons was more frequent in fields that had been damaged in the previous crop cycle, before it was ploughed out ($\chi^2 = 42.3$, $P < 0.001$). Of previously undamaged fields, only 16% showed damage in the new second ratoon, whereas 63% of previously damaged fields were recorded as damaged in 1991.

Influence of farming practices before planting

Damage was independent of fallow length ($\chi^2 = 3.1$, $P = 0.21$). The proportion of damaged fields was 21%, 35% and 44% in fields that had been replanted in the same year as plough-out or planted in the following autumn or spring, respectively.

The influence of frequency of use of four types of implements before planting was examined. Damage was independent of ripping 0 - ≥3 times ($\chi^2 = 2.9$, $P = 0.41$), discing 0 - 4 times ($\chi^2 = 6.2$, $P = 0.18$), and use of rotary hoes (including power harrows and spade cultivators) 0 - ≥3 times ($\chi^2 = 4.2$, $P = 0.24$), and was independent of the total frequency of use of these three types of implement combined from ≤2 to ≥7 times ($\chi^2 = 4.3$, $P = 0.50$) . However the frequency of damage varied between fields with different histories of plough usage. The proportion of fields damaged was 10%, 38%, 37%, and 53% for fields never ploughed ($n = 31$) or ploughed once ($n = 61$), twice ($n = 82$), or 3 - 4 times ($n = 19$) ($\chi^2 = 11.7$, $P = 0.008$).

Damage was independent of weeds before planting ($\chi^2 = 0.03$, $P = 0.87$) and of crop rotations ($\chi^2 = 0.00$, $P = 1.0$). The latter comprised only 12 fields covering a diverse range of crops - tomatoes, cucurbits, sorghum, and legumes.

Influence of varieties

Two separate analyses were carried out, one using only the main variety in each field with mixed plantings and the second using up to three varieties within fields (Table 20). Analyses were only carried out for varieties represented in more than 10 fields.

The frequency of damage was dependent on the main variety in each field ($\chi^2 = 13.6$, $P = 0.019$). Damage was most frequent in Q110 and least in Q141; the 95% confidence intervals for these two varieties did not overlap with each other but did overlap with the other four varieties in the analysis (Table 20). Damage was independent of varieties when minor varieties in fields were included, according to the chi-square analysis ($\chi^2 = 12.4$, $P = 0.054$). However, binomial confidence intervals again did not overlap for Q110 and Q141.

Influence of farming practices in the current crop

Damage in the 1991 crop was not dependent on pesticide regimes in the plant crop, comprising no treatment ($n = 73$), Lorsban for wireworm control ($n = 46$), suSCon Blue for canegrub control ($n = 50$), or both Lorsban and suSCon Blue ($n = 17$) ($\chi^2 = 4.1$, $P = 0.25$) . Damage was independent of time of harvest in 1990, grouped into five periods of about 1 month each ($\chi^2 = 2.9$, $P = 0.58$), and was independent of a green cane trash blanket after this harvest ($\chi^2 = 1.8$, $P = 0.18$).

Cross associations between factors

The relationship between damage in the previous crop cycle and ploughing was examined, as both were associated with the frequency of damage in the current crop. Of 31 unploughed fields, only 7% were damaged in the previous crop cycle. Of 161 ploughed fields, 43% were damaged in the previous crop cycle. Ploughing was also related to soil type, with 76% of the black earth fields being ploughed 3 or 4 times compared with only 44% of the remaining soil types.

DISCUSSION

Soldier fly damage was strongly dependent on damage noted in the previous cropping cycle. This would support anecdotal evidence that certain fields suffer chronic soldier fly problems. Such fields may offer environmental conditions that are particularly favourable for soldier fly invasion and build up. Alternatively, persistence of infestations across cropping cycles may reflect the difficulty of eradicating larvae during fallows, and larvae which carry over from the previous cycle may be the source of future infestations.

Soldier fly damage appeared to be increased by ploughing. There are plausible biological explanations for this. Ploughing may disturb natural enemies, although other implements would then be expected to do the same. Ploughing may enhance survival of soldier fly larvae if they are buried deep with a living food supply (Wilcocks, 1971). More likely, however, the apparent effect of ploughing is an artefact of its own association with previous

damage. Ploughing is a recommended procedure for soldier fly control during fallows, particularly in late summer-early autumn to bury pupae (Allsopp and Bull, 1987). Therefore, it is likely that fields previously damaged by soldier fly would receive additional ploughing. These same fields may be more prone to infestation in the next cropping cycle, as discussed above, but not because of any effect of ploughing *per se*.

Damage varied between varieties, with Q110 the most frequently affected and Q141 the least. This conflicts with results of a glasshouse comparison of varietal tolerance, in which Q141 was relatively sensitive to soldier fly, whereas other varieties such as CP44-101 and Q144 appeared relatively tolerant. Anecdotal evidence supports relative tolerance of CP44-101 and Q144, yet this did not show up in the survey.

The apparent lack of influence of fallow length was surprising, as replanting immediately after plough-out was expected to increase subsequent damage (eg Samson *et al.*, 1991). Fallowing is presently recommended for soldier fly control (Allsopp and Bull, 1987).

There were drawbacks in the methodology of this survey that bring its results into question. Evidence of soldier fly damage was obtained solely from information supplied by growers, as the presence of soldier fly larvae could not be confirmed or quantified in the time available. It is possible that not all fields were correctly diagnosed. This was particularly so for the 1991 crop, which was affected by dry conditions. Because all information was obtained from growers at the one time, their responses to questions such as the presence of damage in the current crop cycle and the previous crop cycle may not have been independent. Although these problems could be overcome by measuring soldier fly densities, another problem would remain. Interrelationships between factors and historical effects will make the interpretation of any survey difficult, particularly for factors such as use of dieldrin, fallowing and cultivation that were carried out in response to previous soldier fly infestations.

ACKNOWLEDGMENTS

I am grateful to Bill Harris for technical assistance, and to Roy Sinnamon and Bruce Quinn of the Bingera Cane Protection and Productivity Board for their help with data collection.

REFERENCES

Allsopp, P G and Bull, R M (1987). Cultural methods for soldier fly control. *BSES Bull.* 20: 20-21.

Samson, P R, Corrie, K D and Dominiak, B C (1991). Influence of cultural practices on damage caused by *Inopus rubriceps* (Macquart) (Diptera: Stratiomyidae) to sugarcane. *J. Aust. Entomol. Soc.* 30: 289-294.

Steel, R G D and Torrie, J H (1960). *Principles and procedures of statistics*. McGraw-Hill: New York.

Wilcocks, C R (1971). Review of control measures for the Australian soldier fly. *Proc. NZ Weed Pest Control Conf.* 24: 155-159.

Table 20

Frequency of soldier fly damage in second ratoon fields containing different sugarcane varieties

Variety	Main variety		All varieties	
	% damaged (95% CI)	*n*	% damaged (95% CI)	*n*
CP44-101	44 (26-64)	34	41 (27-56)	41
CP51-21	43 (17-73)	14	40 (21-61)	25
H56-752	29 (13-48)	28	28 (14-44)	36
Q87	-	4	-	7
Q103	-	2	-	4
Q110	61 (39-82)	18	58 (33-80)	19
Q125	-	7	36 (11-67)	11
Q137	-	2	-	5
Q140	-	3	-	7
Q141	20 (11-32)	60	21 (12-32)	71
Q144	36 (17-58)	22	30 (16-48)	33