

**BUREAU OF SUGAR EXPERIMENT STATIONS
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**FINAL REPORT
SRDC PROJECT BS11S
POPULATION DYNAMICS OF
INOPUS RUBRICEPS IN SUGARCANE FIELDS
WITH EMPHASIS ON BIONOMIC FACTORS
ASSISTING PEST MANAGEMENT**

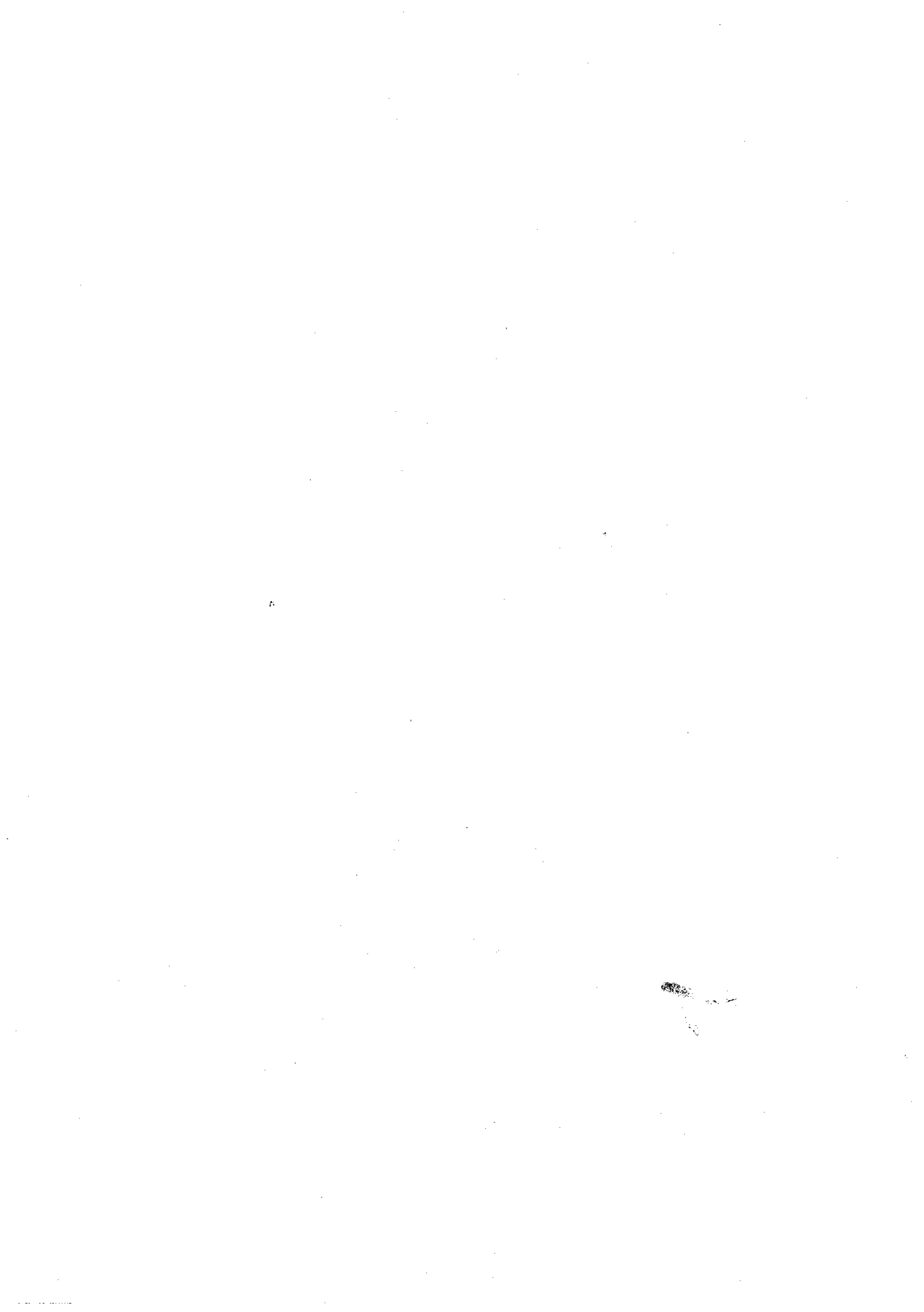
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SUMMARY

Bionomic factors which significantly affected soldier fly populations in the study were predators and the fungal disease *Metarhizium*. No other pathogens were identified. Parasitic wasps that are known to attack soldier fly occurred very infrequently.

Metarhizium affected all developmental stages of soldier fly, but only one epizootic of the disease was observed. Although numbers of soldier fly larvae were reduced immediately afterwards, the population recovered in the following generation. Predation on pupae occurred frequently in the study. Potential predators were mainly predatory beetles and their larvae, including carabids, staphylinids, and elaterids (wireworms).

Soldier fly larvae were able to avoid harmful effects of weather by vertical movement in the soil. Larvae went deeper in summer, so avoiding high surface temperatures that may be lethal. This knowledge should be used to guide the nature and timing of control procedures, including cultural practices such as soil cultivation, as larvae are likely to be most vulnerable when close to the surface.

Differences in climate between sugarcane-growing districts affected the timing of specific events in the soldier fly life cycle. Larvae pupated earlier in the year in New South Wales than Queensland, but the length of time to complete a generation was the same.

Life table analyses were not able to distinguish any one factor capable of regulating soldier fly populations. The most consistent influence on population dynamics was the death of eggs and tiny larvae each winter, which resulted in the largest individual mortality in each generation.

Research conducted elsewhere suggested that predators are potentially able to regulate soldier fly populations but are prevented from doing so by residues of pesticides, especially dieldrin, in the soil (Robertson, 1984). Our study did not support this hypothesis. Numbers of potential predators were actually lower in one field that had no measurable dieldrin residues than in others that had been treated with dieldrin a few years earlier. This is a single instance, and predators may have been absent from the field for other reasons. However, a survey of soldier fly damage did not show any difference in the frequency of damage between untreated and treated fields.

Among cultural practices that might influence the efficiency of pest management, trash blanketing was not shown to increase populations of soldier fly or of its predators. Soldier fly larvae were found to feed on a wide range of alternative host plants that can be grown in rotation with sugarcane, including sorghum, legumes and tomatoes. A survey of commercial crops did not provide any evidence that damage to sugarcane was increased by crop rotations, but this result is not conclusive. On present knowledge, rotating sugarcane with crops which favour soldier fly is not advisable.

Ploughout-replanting was shown to increase the likelihood of soldier fly damage, in comparison with planting in the following year after a fallow or crop rotation. Presumably more larvae survive in the soil to establish in the newly planted cane, resulting in higher populations in subsequent ratoons. Existing BSES recommendations for soil cultivation as a control practice were not confirmed, but they remain intuitively correct and are in agreement with results overseas; they will continue to be recommended.

BACKGROUND

Soldier fly, *Inopus rubriceps* (Macquart), is a serious pest of sugarcane in parts of Queensland and New South Wales. Larvae feed on the roots, resulting in poor growth or complete ratoon crop failure. In Queensland in the late 1950s to early 1960s, crop loss through the activity of soldier fly was estimated to be 80 000 t of cane. Since that time the pest has been controlled by field dressings of dieldrin. However, restrictions were placed on the use of dieldrin in 1987 and its registration for use in the sugar industry lapsed in mid-1991. As no other insecticide is presently available to replace dieldrin, there is an urgent need to develop alternative control strategies.

Robertson (1984) identified organisms predatory and parasitic on the pupal stages of soldier fly as exerting significant population control. A detailed study of the effect of biological control agents and cultural conditions may enable an effective pest management program to be developed for soldier fly.

The economic benefits of an effective, biologically- and culturally-oriented, pest management program for soldier fly are likely to far exceed any cost or disadvantage, both in the immediate and longer-term.

OBJECTIVES

- Assess the potential of biotic and weather factors to regulate soldier fly populations in sugarcane in Queensland and New South Wales.
- Use this information to select cultural practices which will maximise the efficiency of pest management strategies.

RESEARCH METHODOLOGY AND RESULTS

Research was carried out in four broad areas as follows:

1. The population dynamics of soldier fly and its biological control agents
2. The effect of weather on the behaviour of soldier fly populations
3. Factors influencing carryover of soldier fly from previous cropping cycles of sugarcane
4. Influence of cultural practices on soldier fly damage in commercial sugarcane crops

Methodology is provided and results are discussed below within each of these four areas.

1. Population dynamics

1.1 Aims and methodology

This work aimed to determine what factors may regulate soldier fly populations and how these factors differ between study sites with various cultural histories.

Four major study sites were chosen in southern Queensland, comprising sugarcane planted in 1987; these included burnt and green cane harvesting procedures, and a range of dieldrin residue levels. Additional study sites were chosen at Harwood, Mackay and Innisfail. Details are given in Table 1.

Table 1

Details of farms used for soldier fly population studies

Farm	Harvest procedure	Dieldrin residue (mg/kg soil)	
		1988	1990
Southern Queensland - frequent monitoring : planted 1987			
Cordalba	green	<0.01	-
Wallaville	green	0.66	0.44
Yandaran	burnt	0.65	0.33
Walker's Point	burnt	1.1	0.55
Other sites : planted 1988 except Innisfail (1983)			
Harwood 1	burnt	ND	-
Harwood 2	burnt	ND	-
Cattle Creek	burnt	0.25	0.22
Seaforth	burnt	ND	-
Innisfail	green	ND	-

Study sites were sampled regularly for soldier fly, by collecting groups of four soil cores from around each cane stool - 40 stools were sampled at each site in southern Queensland and 20 at the other sites, on each occasion. Soldier fly and other invertebrates were separated from the samples by wet-sieving. Soldier fly larvae were grouped into weight classes, counted, and then incubated at 25°C for four weeks to check for the presence of diseases or parasites. Pupal cases were examined microscopically and classified as either normal or damaged by predators or parasites.

A subsample of soil was checked for the presence of spores of the fungus *Metarhizium*, by incubation on medium and subsequent counting of fungal colonies.

Ten pitfall traps were operated continuously at each site in southern Queensland. Predatory invertebrates falling into the traps were preserved for subsequent identification.

1.2 Precision of soldier fly counts

The efficiency of extracting soldier fly larvae from samples varied depending on larval size. We could find only about 14% of those larvae in the smallest weight class that were actually present in the samples. Efficiency of extraction increased to 100% when larvae weighed more than 15 mg. Estimates of larval density in sugarcane fields were corrected for inefficient recovery.

The distribution of larvae between sugarcane stools was aggregated, not random. The relationship between the variance and mean of soldier fly counts on each sampling occasion was examined using Taylor's power law, by regression of the log-transformed values. The parameters for Taylor's power law were almost identical for soldier fly larvae sampled either in the first or the second half of each year, and for pupal cases. Therefore a combined regression was calculated for all soldier fly stages. This regression, $\ln(\text{variance}) = 1.345 + 1.54 \times \ln(\text{mean})$, accounted for 95% of the variation in the log-transformed variance between sampling occasions (ie $R^2 = 0.95$).

The regression was used to estimate the precision of soldier fly counts. This showed that low density populations were poorly estimated, but precision increased as density increased; it could be improved further by sampling more stools on each occasion. A sample of 40 stools, the number routinely taken at sites in southern Queensland, gave a standard error within 25% of the mean, provided the mean was more than 2.5 larvae per stool or 167 larvae/m². This sampling occupied about one person/week. We concluded that it is difficult to study low density populations of soldier fly, as the sampling effort required is prohibitive.

1.3 Soldier fly population densities and life tables

Soldier fly larvae were present at all study sites. They were found in the plant crop at the four sites in southern Queensland and also at Cattle Creek. They may have been present at the remaining sites at densities too low to detect with our sampling procedure. There was a rapid increase in population density within the first year of detection at several sites, and there were obvious differences between sites in the rates of population increase. In particular, populations reached high densities very quickly at Wallaville and Walker's Point, so that populations exceeded 1 000/m² two years after planting. At Yandaran and Cattle Creek, however, population densities remained at a low level (less than 50/m²) during three years of sampling.

Life tables were developed to identify what determined population changes at each site, and differences in abundance between sites. The life tables contained estimates of population density at different stages in the life cycle of the soldier fly. Mortality rates were then calculated for different developmental periods within each generation, at each study site in successive years (a single soldier fly generation usually occupies one year).

The importance of mortality factors acting at different times was analysed by regression of total mortality in each generation on the mortalities at different stages within the generation. Three mortality stages, ie missing and dead eggs and newly hatched larvae, missing and dead large larvae, and missing and predated pupae, together accounted for more than 98% of the variation in total generation mortality. Their importance varied between sites and between years. However, mortality during the period of establishment of the new generation of larvae, ie missing and dead eggs and newly hatched larvae, was an important factor at all sites.

1.4 Pathogens

The fungal pathogen *Metarhizium* was identified as infecting some soldier fly at the time of collection from the field, and also as appearing during subsequent incubation of larvae and pupae in the laboratory. The species responsible was mostly *M. anisopliae*, but *M. album* was identified from a few larvae at one study site (Wallaville). The latter species had not previously been recorded in Australia.

Of the nine study sites, infection was not detected at Yandaran, Harwood, or Mackay, probably because only a small number of larvae were collected in samples at these sites. The highest rate of infection on a single occasion was 22%, at Walker's Point. Counts of *Metarhizium* spores in the soil were similar at all sites except Wallaville, mostly being less than 1×10^4 spores/g. The mean spore count at Wallaville was 3.2×10^4 /g, and reached 10.3×10^4 on one occasion. However, high counts at Wallaville were not associated with high infection of soldier fly. Over all sites and sampling occasions, there was no correlation between spore counts in soil and infection rate ($r = 0.05$).

There were 45 sampling occasions on which *Metarhizium* infection appeared during incubation of soldier fly, resulting in 242 infected individuals. Infection was observed in larvae, pupae, adults that emerged from pupae during incubation, and even in eggs laid by emerging females. Infection was seen in all sizes of larvae. The proportion of infected individuals was similar in each of eight larval size classes and in pupae.

On some sampling occasions, soil cores were sectioned at different depths before soldier fly larvae were extracted. There was a tendency for the rate of infection to be lower in larvae collected within 5 cm of the soil surface than in those collected at greater depth. However, this was not consistent for all occasions, and on some occasions infection was actually highest at the shallowest depth. The vertical distribution of infected larvae probably reflected the past history of infection and consequent distribution of fungal spores in the soil.

1.5 Predators

Potential predators of soldier fly which were collected in soil core samples included larvae and adults of the beetle families Carabidae and Staphylinidae, and larvae of Elateridae (wireworms). All these insects ate soldier fly larvae in the laboratory. Among the Staphylinidae, large adults of the genus *Thyreocephalus* were particularly voracious.

Centipedes were also collected in soil samples; they were not seen to eat soldier fly larvae, but might eat eggs.

Pitfall traps collected similar groups of insects, but were more effective at trapping adult beetles rather than larvae. Spiders were also collected in pitfall traps. Although not likely to prey on soldier fly larvae, they may eat the adult flies.

In southern Queensland, there were differences in the predatory fauna between the four study sites during the first and second ratoon crops. The canefield at Cordalba had few Carabidae and Staphylinidae, but abundant wireworms. Wireworms were also relatively abundant at Wallaville and Yandaran in both the first and second ratoon, and at Walker's Point in the second ratoon despite being scarce in the first. Numbers of staphylinids were similar at Wallaville, Yandaran, and Walker's Point. However, there were fewer carabids at Yandaran than at either of the other two sites. Wireworms were generally the most abundant group of predatory beetles at all sites. Numbers of spiders and centipedes did not differ greatly between sites.

Pitfall trapping was not carried out at those sites outside southern Queensland, and soil sampling was too infrequent to quantitatively compare predatory fauna. However, the same groups of invertebrates were present at those sites.

1.6 Parasitoids

Only one parasitic wasp emerged from many thousands of soldier fly larvae collected from the nine study sites. This wasp was collected at Yandaran. Parasitism clearly was not important in the population dynamics of soldier fly in the canefields under study.

However, parasitoids were reared from soldier fly larvae collected from some other canefields, for other research purposes. Of particular interest was the identification of *Neurogalesus militis* and *N. carinatus* occurring at Yandaran and South Kolan. These parasitoids had not previously been recorded near Bundaberg, although they were known to occur at Mackay and south from Nambour into New South Wales (Robertson 1984).

These parasitoids are apparently distributed throughout the central and southern canegrowing districts. Their infrequent occurrence suggests that they can be disregarded as useful biological control agents. In addition, *N. militis* apparently parasitises only male soldier fly pupae (Robertson 1984) and so is unlikely to affect the rate of increase of soldier fly populations.

2. Effect of weather

2.1 Aims and methodology

Weather is known to influence population dynamics of insects by affecting rates of development, natality, and mortality. Analysis of soldier fly damage shows that outbreaks have followed years of low January-February minimum temperatures and low February

rainfall (Allsopp 1990). Allsopp suggested that these conditions may have inhibited autumn pupation of soldier fly, resulting in many large larvae continuing to feed for a second year of development. Our research aimed to determine the effect of weather on the behaviour and development of larvae in canefields.

The distribution in soil of different-sized soldier fly larvae was measured at South Kolan and Walker's Point during 1989 and 1990. To measure lateral distribution, soil cores were taken in the interspace at increasing distances from sugarcane stools. To measure vertical distribution, cores were taken beside stools and then cut into segments at different depths. Soil temperature and moisture pressure were recorded hourly using data loggers. The relationship between vertical distribution of larvae on each sampling occasion and environmental measurements was examined using correlation methods.

Soldier fly pupation was studied at Yandaran, South Kolan and Walker's Point in 1989, South Kolan and Walker's Point in 1990, and South Kolan, Harwood, Mackay and Innisfail in 1991. Sites were sampled every two to four weeks during the pupation period each year. The proportion of the population that had pupated was calculated on each sampling occasion. Pupae were reared to determine the sex of the adult flies.

2.2 Larval distribution in soil

Larvae were concentrated along the sugarcane rows, with fewer than 15% of larvae more than about 14 cm from the stools. As the row spacing was 1.4 m, the majority of the interrow space had very low larval populations.

Larvae were mostly found near the soil surface. The proportion of the larval population at a depth greater than 15 cm was never more than 40%, and was often negligible.

Small larvae (<7.5 mg) were closest to the soil surface in winter. Soldier flies lay their eggs in autumn just beneath the surface, and this may influence the distribution of small larvae. The depth of small larvae was positively correlated with soil temperature, indicating larvae move deeper in summer to avoid high surface temperatures. Their depth was independent of soil moisture pressure.

Large larvae (>7.5 mg) were closest to the surface during the pupation period of March-May. Pupae always occur near the soil surface. The depth of large larvae was not well correlated with temperature but was positively correlated with soil moisture pressure. The latter correlation may have been an artefact of pupation coinciding with autumn rainfall. Depth of large larvae during other months was positively correlated with temperature and independent of soil moisture. Large larvae occurred deeper than small larvae during winter and shallower during spring and summer.

2.3 Pupation

The timing of pupation varied between years at South Kolan. Pupation was later in 1990 than in 1989, and later again in 1991, with an overall difference of about six weeks. In

1991, pupation occurred earlier in New South Wales (Harwood) than at any of the Queensland study sites.

A large proportion of the larval population at South Kolan failed to pupate in 1991. More than half of the larvae continued into a second year of development. In other years, however, and at the other locations, less than 20% of large larvae failed to pupate. During the months of March-April, larvae were smaller on average at South Kolan in 1991 than in previous years and in the same year at other localities. Pupae of each sex were of similar weight during every year and at every locality. At South Kolan in 1991, however, female pupae produced early in the autumn were heavier than those produced later. Male pupae were unaffected. At Harwood, weights of both male and female pupae decreased during the season in 1991.

The results indicate that soldier fly development is similar in all canegrowing districts. Larvae may pupate earlier in New South Wales than Queensland, probably because of the earlier onset of cool autumn temperatures. A complementary laboratory experiment indicated that pupation is inhibited at high temperatures. However, our field studies suggest that generation times are unaffected, a duration of about one year probably being usual in sugarcane.

More importantly, soldier fly development may vary at a given locality, for unknown reasons. At South Kolan in 1991, the continuation of a high proportion of larvae into a second year of development was associated with retarded larval growth earlier in the year. The soil had been dry in 1991 and, in addition, the sugarcane crop was poor, having been affected by drought and by high populations of soldier fly. A combination of weather and host plant factors probably determine soldier fly development.

3. Carry-over of larvae from previous cropping cycles

3.1 Aims and methodology

The source of soldier fly populations in sugarcane may be either larvae already in fields when the cane is planted, adult flies immigrating from neighbouring canefields or grasslands, or both. Adult soldier fly females are not very mobile, suggesting that larvae already present at planting may significantly contribute to population build-up. Therefore, we investigated procedures to minimise carry-over of larvae from the previous cropping cycle.

Bare fallowing and soil cultivation are presently recommended by BSES to control soldier flies before planting. Cultivation is recommended at three strategic times, to kill larvae feeding in the old stools at ploughout, to bury pupae remaining in the soil in autumn, and to damage or desiccate eggs and small larvae in early winter. We carried out an experiment to measure the effect on soldier fly numbers of short and long fallowing (ie autumn and spring planting, respectively), and of different cultivation timings approximating existing recommendations. A sugarcane ratoon infested with soldier fly was killed with glyphosate. The whole trial received the minimum tillage needed for

replanting (ie ripping and discing). Additional workings were then applied to selected plots. Plots were replanted in autumn or spring of the year following ploughout, and numbers of soldier fly larvae were counted the following summer.

Cover crops such as legumes or sorghum are sometimes grown between cropping cycles of sugarcane. Rotation of sugarcane with vegetable crops is becoming more common, particularly near Bundaberg. Numbers of larvae carried-over into newly planted cane may be influenced by the suitability of the alternative crop as a host for soldier fly. Therefore, a pot experiment was carried out to identify crop plants that may be alternative hosts. Thirteen crop plants including sugarcane were compared with a control comprising bare soil. The survival and weight gain of larvae was measured after confinement in the different treatments for 10 weeks. Roots of each plant were then extracted and weighed, to assess any effect of root weight on larval performance.

3.2 Effect of bare fallowing and cultivation

Soldier fly larvae were present in newly planted sugarcane, regardless of a short or long fallow and even with additional cultivation. However, their density was much lower than in the previous cropping cycle, reduced from about 900/m² to less than 20/m². The numbers in the plant cane were too low to detect effects of the different treatments, despite intensive sampling.

This experiment shows that replacing an old cropping cycle of sugarcane with plant cane after a fallow will reduce soldier fly numbers, even without specific workings for soldier fly control. It also indicates the difficulty in eliminating soldier fly from infested fields.

3.3 Alternative host plants

Soldier fly larvae were able to feed and grow on a wide range of plants, but some plants supported better growth than others. Plants which allowed large weight gains of larvae also increased larval survival, in comparison with bare soil.

Larvae grew and survived well on sugarcane and sorghum. They also grew and survived well on four species of legumes, particularly cowpea and lablab. Among the vegetables tested, tomato was particularly favourable for growth and survival. Another solanaceous plant, capsicum, was not as favourable. Three cucurbits allowed little growth of larvae, although only zucchini seemed to prevent growth. Survival on these species was no better than in bare soil. Larval growth occurred on two crucifers, broccoli and radish, with substantial weight gains and increased survival on the latter.

Root weights differed greatly between plant species. There was a positive correlation between larval weight gain and root weight. Plants on which larvae grew poorly, such as zucchini, rockmelon, capsicum and watermelon, had a small root weight.

In sum, larvae fed on many plants that may be grown in rotation with sugarcane. These plants may act as alternative hosts, allowing better survival of larvae in comparison with

fields maintained as a bare fallow. Of the plants tested, the cucurbits were least favourable for soldier fly survival.

4. Influence of cultural practices on soldier fly damage

4.1 Aims and methodology

Soldier fly damage and cultural practices were surveyed on canefarms in the Bundaberg area to assess the effectiveness of cultural control procedures. This survey aimed to relate damage not only to those cultural practices specifically recommended for soldier fly control, ie bare fallowing and cultivation, but also to other agronomic factors. We hoped that this study would suggest additional ways in which damage could be alleviated.

Forty canefarms were surveyed in the Millaquin-Qunaba area. A total of 322 canefields were inspected in November and December by staff of the Cane Pest and Disease Control Board. The presence or absence of soldier fly damage to the new ratoons was recorded. In addition, a questionnaire was completed for each field by interviewing farmers. Information was collected on history of dieldrin use, cane variety, crop age, planting time, pesticide applications, soil cultivation, fallowing practice and crop rotations.

The relationship between cultural practices and damage was examined by logistic regression.

4.2 Survey results

Soldier fly damage occurred in 47 (15%) of the 322 fields surveyed.

Damage was less frequent in first and second ratoon crops than in older ratoons. This probably reflected a build-up of soldier fly numbers with time after planting. An effect of sugarcane varieties was evident, but damage levels were the same for the three main varieties in the district (CP44-101, Q110 and H56-752). No damage was recorded in fields treated with suSCon Blue against canegrubs. Damage was more frequent in canefields that had been replanted immediately after ploughout of the previous crop than in those that had an interval without cane. This interval could have been a bare fallow or a rotation with a vegetable crop. Other factors including rotary hoeing, past use of dieldrin, and use of chlorpyrifos at planting were not shown to affect the frequency of damage.

The findings reinforce a current recommendation for soldier fly control: farmers should avoid replanting fields immediately after ploughout of the previous crop. Older ratoons are more likely to suffer damage than younger ones and may serve as reservoirs of infestation for newly planted fields. Varietal resistance and use of suSCon Blue for control should be investigated further. There is a trend near Bundaberg for sugarcane to be grown in rotation with vegetable crops, but our survey was unable to reliably assess the effect of this on soldier fly damage to cane.

DIFFICULTIES ENCOUNTERED DURING THE PROJECT

The main difficulties encountered were associated with the biology of soldier flies.

Soldier flies have only one generation each year. Therefore, only a small number of generations are possible during a single cropping cycle of sugarcane. Ploughing out and replanting disrupts normal population processes, and soldier fly numbers immediately after planting are too low to measure reliably. Thus, in any given field, population dynamics of soldier fly can only be followed for two or three generations, which is a very short time for developing hypotheses of population regulation.

Soldier fly larvae are also difficult to find in the soil. Sampling methods are very time-consuming, and because the larvae are aggregated in sugarcane fields, many samples must be taken to reliably estimate population densities. This limits the number of populations that can be studied.

Wireworms, which were regularly found in sugarcane fields, could not be identified because the relevant taxonomic studies have not been done. This is discussed under the following section - Recommendations for Further Research.

RECOMMENDATIONS FOR FURTHER RESEARCH

- Elimination of soldier fly larvae from fields before planting would remove one source of infestation in newly planted cane. Population build-up would then depend on immigration of adult flies, which is likely to be slow. Bare fallowing and soil cultivation are recommended to reduce soldier fly numbers before planting, but the recommendations have little experimental basis. Experiments are needed to compare different lengths and types of fallows (bare, weedy, crop rotations) and different timings and frequencies of cultivation using various implements, for their effect on carry-over of larvae into following sugarcane crops.
- Predators are active in sugarcane fields, and their frequent failure to control soldier fly numbers may be caused by disturbances to the system. Even in the absence of pesticide residues in the soil, predator populations may be harmed by loss of cover and cultivation between cropping cycles of sugarcane. Studies in other agroecosystems have shown that tillage harms populations of some predators, and cover cropping may enhance them. Minimum tillage, cover cropping, green cane harvesting and trash blanketing should be investigated as ways of providing a more stable and genial soil environment than alternative practices in sugarcane. This may lead to a more diverse soil fauna, higher populations of soil predators, and the regulation of soldier fly populations at lower levels.
- The fungal pathogen *Metarhizium* is widespread and may infect a significant proportion of soldier fly larvae at times. Resulting epizootics can cause a large reduction in soldier fly numbers. However, the occurrence of epizootics is

sporadic. Artificial production of *Metarhizium* and its application to soil should be investigated as a method of increasing natural spore concentrations in the soil and increasing infection levels.

- Wireworms are voracious predators of soldier fly larvae in captivity. They were the most abundant and ubiquitous predators that we found during our study. However, wireworms sometimes attack the eyes of cane setts and so are considered pests of sugarcane. At-planting application of chlorpyrifos for wireworm control is routine in some districts, at a total cost in 1990 of more than \$1m. A number of species occur in sugarcane fields. They are difficult or impossible to identify, and the feeding preferences of each are unknown. Research is needed to develop keys to wireworms in sugarcane, to determine the distribution and microhabitat requirement of each species, to investigate the feeding habits and pest status of the main species, and to develop on-farm monitoring systems for major pest species and develop economic thresholds for insecticide use.
- Experimental assessment of cultural control strategies for soldier fly is made difficult by the unpredictable occurrence of soldier fly populations, and by the likely time lag between adoption of strategies and appearance of effects. Also, experimental results may lack generality because only a limited number of experimental sites can be established. Complementary surveys should be carried out of existing cultural practices, soldier fly numbers and damage in commercial sugarcane fields. Survey results could be used to develop working hypotheses for testing by experimental methods.

PUBLICATIONS RESULTING FROM THE PROJECT

Accepted for publication

Samson, P R, Corrie, K D and Dominiak, B C. Influence of cultural practices on damage caused by *Inopus rubriceps* (Macquart) (Diptera: Stratiomyidae) to sugarcane. *Journal of the Australian Entomological Society*, in press.

Submitted for publication

Samson, P R and McLennan, P D. Growth and survival of *Inopus rubriceps* (Macquart) (Diptera: Stratiomyidae) on different crop plants. *Journal of the Australian Entomological Society*.

Samson, P R and McLennan, P D. Distribution of larvae of *Inopus rubriceps* (Diptera: Stratiomyidae) around sugarcane plants. *Journal of Economic Entomology*.

In preparation

Soldier fly distribution and sampling precision.
Infection of soldier fly by *Metarhizium*.
Invertebrate predators in sugarcane.
Life tables for soldier fly in sugarcane.
Soldier fly development and pupation in sugarcane.

REFERENCES

- Allsopp, P G (1990). Use of weather data to forecast outbreaks of soldier fly, *Inopus* spp. (Diptera: Stratiomyidae) in Queensland sugarcane. *Agriculture, Ecosystems and Environment* 30, 61-70.
- Robertson, L N (1984). Effects of natural enemies on population dynamics of *Inopus rubriceps* (Macquart) (Diptera: Stratiomyidae). Ph.D.Thesis, University of Queensland.



APPENDIX

INFLUENCE OF CULTURAL PRACTICES ON DAMAGE CAUSED BY INOPUS RUBRICEPS (MACQUART) (DIPTERA: STRATIOMYIDAE) TO SUGARCANE

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(Short title:- Inopus damage to sugarcane)

Abstract

A survey of damage caused by Inopus rubriceps to sugarcane was carried out in the Millaquin-Qunaba mill area near Bundaberg. Damage was less frequent in first and second ratoon crops than in older ratoons. Damage was more frequent in cane fields that had been replanted immediately after ploughout of the previous crop than in those that had an interval without cane. This interval could be a bare fallow or a rotation with a vegetable crop. There was some evidence that damage was more frequent after weedy fallows than after bare fallows or vegetable crop rotations.

Introduction

The sugarcane soldier fly *Inopus rubriceps* (Macquart) is a pest of sugarcane in central and southern Queensland (Hitchcock 1970) and in northern New South Wales (Osborn and Halbert 1972). Cane is grown by planting pieces of stalk (setts) to produce the first harvestable crop. Subsequent crops are produced by regrowth (ratooning) of the stubble after each harvest. After several ratoon crops the old stubble is ploughed out and the field planted again with fresh setts. The soil-dwelling larvae of the sugarcane soldier fly feed on the cane roots causing poor growth and ratoon failures. Germination of the cane setts can be inhibited in severe infestations. Affected fields are frequently ploughed out prematurely.

At present (1990), dieldrin ($6.7 \text{ kg a.i. ha}^{-1}$) is the only insecticide registered for soldier fly control, and it is available only on a permit system. Farmers are encouraged to employ cultural control procedures as an alternative to chemical controls. Fallowing and cultivation of ground before setts are planted provides some control of soldier fly (Bell 1934), and these measures are still recommended (Allsopp and Bull 1987).

Soldier fly damage and cultural practices were surveyed on cane farms in the Bundaberg area to assess the

effectiveness of cultural control procedures. This survey aimed to relate damage not only to those cultural practices specifically recommended for soldier fly control, but also to other agronomic factors. We hoped that this study would suggest additional ways in which damage could be alleviated.

Methods

Forty cane farms were surveyed in the Millaquin-Qunaba mill area near Bundaberg. Soils on these farms were mainly krasnozems (known locally as red volcanic soils) or recent alluvia, these being prone to soldier fly infestations (KC pers. obs.). A total of 322 cane fields (average size more than 1 ha) were inspected on these farms in November and December 1989 by staff of the Cane Pest and Disease Control Board. The presence or absence of soldier fly damage was recorded. The inspection included all fields of ratoon cane that had been harvested after June 1989 and that had regrown sufficiently to allow damage to be assessed.

The following data were also collected for each field of inspected cane: history of dieldrin use; cane variety; crop age; planting time; applications of insecticides and nematicides (since ploughout of the previous crop); use of rotary hoe during ground preparation for planting; nature of fallow before planting, if any; and rotation with vegetable crops.

The effect of individual agronomic and cultural variables on the incidence of soldier fly damage was first examined by chi-square tests for independence in two-way tables. Yates' correction for continuity was applied to analyses of 2 x 2 tables (Steel and Torrie 1980). Where interaction between variables was suspected, the independence of damage and the variable of interest, conditional upon levels of a second variable, was tested by a log-linear model. This test produced values for the Pearson (χ^2) and likelihood ratio (G^2) goodness-of-fit statistics (Fienberg 1980) and the statistics were compared with tabulated values of chi-square. All analyses were carried out with Statistix 3.0 (Analytical Software).

Results

Forty-seven (15%) of the 322 fields of cane showed damage by soldier fly.

Effect of Crop age

Incidence of damage varied significantly between different ages of ratoons (Table 1; $\chi^2=32.6$; $P<0.001$). Damage was rare in the first ratoon but became more frequent in older ratoons. The frequency of damage differed significantly between ratoons even when the first ratoon crop was excluded from the analysis ($\chi^2=16.3$; $P=0.003$), but was independent of ratoon age when the first 2 ratoons were excluded ($\chi^2=7.62$;

P>0.05).

Effect of cane variety

The most common variety was CP44-101, followed by Q110 and H56-752 (Table 2). Minor varieties (those represented in 10 or fewer fields) were grown on 35 fields and 83 fields contained a mixture of varieties. The incidence of soldier fly damage was the same for the 3 main varieties and for a grouped classification comprising minor varieties and mixed plantings (Table 2; $\chi^2=0.22$; P>0.05).

There was a change in the predominant varieties in different ratoons. In younger ratoons CP44-101 occurred less frequently but minor varieties or mixed plantings were more common (Table 2). Controlling for ratoon age, frequency of damage was again independent of variety ($\chi^2=13.8$, $G^2=15.1$, df=11 when corrected for zero expectation in 2 cells; P>0.05).

Effect of dieldrin use

Farmers reported that dieldrin had been applied for soldier fly control to 113 fields (35%). Of these fields, 12 had been treated within 5 years of the survey and 101 more than 5 years earlier. Soldier fly had damaged 9.7% of fields previously treated with dieldrin (8.3% of those treated within the last 5 years and 9.9% of those treated more than 5 years earlier) and 17.2% of untreated fields. The frequency of

soldier fly damage was independent of preceding dieldrin usage ($\chi^2=2.73$; $P>0.05$).

Effect of pesticide applications

No insecticides or nematicides had been applied since ploughout of the previous crop of cane in 89 fields (28%). In-furrow applications of chlorpyrifos E.C. (0.75 kg a.i. ha⁻¹) were made at planting for control of wireworms (Coleoptera: Elateridae) in 198 fields (61%). Chlorpyrifos in a controlled-release formulation (suSCon Blue; 3-4 kg a.i. ha⁻¹) had been applied to planting drills as a prophylactic treatment for canegrubs (Coleoptera: Scarabaeidae: Melolonthinae) in 39 fields (12%). Fenamiphos (9.6 kg a.i. ha⁻¹) had been applied to 47 fields for control of nematodes in vegetable crops grown in rotation with cane. Fields frequently received a combination of chemicals.

Pesticide treatments were grouped as no pesticide, chlorpyrifos E.C. alone, suSCon Blue (alone or with additional treatments), and other insecticide and nematicide combinations. The frequency of soldier fly damage and these treatments were not independent (Table 3; $\chi^2=14.6$; $P=0.002$).

However, there was a change in pesticide treatment in different ages of ratoons (Table 3). The proportion of fields that had received no pesticide was highest in crops that were older than third ratoon at the time of the survey. These

older crops were particularly prone to soldier fly damage (see above). Use of suSCon Blue was most frequent in crops that were only first or second ratoon. Controlling for crop age, the frequency of damage was independent of the pesticide treatments ($\chi^2=12.2$, $G^2=16.0$, $df=12$; $P>0.05$).

Effect of rotary hoe

The soil in 302 fields (94%) had been cultivated with a rotary hoe since the previous cane crop. Of these, 14.9% were damaged by soldier fly, and 10.0% of the remainder were damaged. Soldier fly damage and rotary hoe use were independent ($\chi^2=0.08$; $P=0.784$).

Effect of cultural practices

More cane had been planted in autumn (69% of fields) than in spring (Table 4). Cane is harvested and old crops ploughed out in late winter-early summer. Thus the autumn-planted fields had an interval (or "spell") of up to 6 months when no cane was present in the ground. Of the spring-planted fields, most were "ploughout-replants" (i.e. replanted 1-10 weeks after ploughout of the previous crop) but 28 fields had been planted after a long spell of about 1 year. A rotation with vegetable crops, mostly cucurbits (47 fields) and tomatoes (25 fields), was carried out in conjunction with either autumn or spring planting.

Soldier fly damage and cultural practices were not independent when no other variables were considered ($\chi^2=13.6$; $P=0.018$). However, there was an interaction between cultural practices and ratoon age (Table 4). Both ploughout-replants and rotations with vegetable crops were more frequent in younger ratoons.

Analysis of the data by log-linear models while controlling for ratoon age showed independence of damage and cultural practices, when the latter were considered separately (Table 5 i). However, grouping of the "cultural practices" categories into composite classes revealed some significant effects. Frequency of damage differed between ploughout-replants, weedy fallows, and other practices grouped either as autumn and spring plantings (Table 5 ii) or as fields with and without a vegetable crop rotation (Table 5 iii). Excluding the ploughout-replant and weedy fallow fields, there was no difference between the frequency of damage after autumn and spring planting (Table 5 iv) or bare fallow and rotation with vegetable crops (Table 5 v). When the latter categories were grouped, then the frequency of damage differed significantly between fields that had a weed-free spell from cane-growing (with or without a vegetable crop rotation) and ploughout-replant fields (Table 5 vi). The frequency of damage may also have differed between weed-free spelled fields and weedy fallows, depending on which test statistic is accepted (Table 5 vii). A weed-free spell reduced the frequency of damage in comparison with ploughout-replant or weedy fallow fields

(Table 4).

Discussion

More frequent damage in older ratoons in our survey probably reflects a build-up of soldier fly numbers with time after planting. Density of larvae is presumably low when most fields are planted, being reduced by cultural practices associated with ploughout of the previous crop and ground preparation for replanting. Soldier flies take 1 or more years to complete a generation (Hitchcock 1976; Gerard and Burton 1983). Females lay most of their eggs near where they emerge, provided there is a cover of vegetation (Moller 1965; Dixon and Gerard 1979). The flies may then disperse (Osborn and Halbert 1972). Increasing damage with increasing ratoon age is consistent with a slow build-up of numbers, with breeding from larvae carried over from the previous cropping cycle and immigration from neighbouring canefields and grassland. Damage may also be more visible in older ratoons because of an accumulation of injured cane plants each year.

Past observations suggest that varieties may respond differently to soldier fly (Moller 1965). We did not detect such differences. However, only 3 varieties occurred frequently enough in pure stands to allow statistical analysis, and only 2 of these varieties, CP44-101 and Q110, were represented as pure plantings in crops older than third ratoon.

The frequency of soldier fly damage was independent of past dieldrin use. We thought dieldrin use might have affected soldier fly incidence in several ways. Firstly, past applications of dieldrin may still have been conferring some protection to cane at the time of the survey. Alternatively, fields that had been treated in the past may be prone to infestations e.g. because of a particularly suitable soil environment. Lastly, old applications may have decayed to concentrations ineffective against soldier fly but active against natural enemies. This would allow a resurgence of soldier fly (Moller and Mungomery 1963). These effects were apparently not important in the survey area or they cancelled each other out.

We found an apparent effect of pesticides other than dieldrin on soldier fly damage when ratoon age was not considered. This was probably an artifact caused by some pesticide treatments being disproportionately represented in younger ratoons. The apparent effect of pesticides was particularly marked with suSCon Blue and no fields treated with this product showed soldier fly damage. Marketing of suSCon Blue only commenced in 1984. Another survey in several years time may indicate whether suSCon Blue confers any protection against soldier fly.

Vigorous cultivation of ground with a rotary hoe at ploughout is recommended for soldier fly control (Allsopp and Bull 1987). We found no effect of rotary hoeing on soldier

fly damage but there were too few non-hoed fields to support reliable conclusions.

Replanting of cane soon after removal of the previous cane crop increased the likelihood of soldier fly damage. This practice is considered inappropriate in soldier fly areas (Moller 1965; Allsopp and Bull 1987). Presumably there is a greater carry-over of larvae from the previous crop when the ground is not spelled from cane and subjected to periodic cultivation for weed control. Carry-over numbers in ploughout-replant fields may be high enough to inhibit germination of the newly-planted cane setts (Moller 1964).

Weedy fallows seem to have encouraged soldier fly damage in the subsequent cane crop. Larvae can survive on the roots of many host plants including common pasture grasses, legumes, and broad-leaved weeds (Saunders 1963; Hewitt 1969; Gerard and Parr 1977). Some farmers may have replied incorrectly to the question of fallow cleanliness, and it is very likely that some of the fields claimed to have been weed-free were not so. The real effect of weeds in fallows is still uncertain but may be greater than measured in this survey.

More soldier fly damage was expected after autumn planting than after spring planting following a long spell from cane. A long spell should disinfest ground of larvae more effectively than a shorter one. This expected difference was not shown in the results but the sample size was small.

Few farmers are prepared to leave their ground out of cane production for 1 year.

Since 1985 there has been an increase in the number of farms in the district rotating cane with vegetable crops, mostly tomatoes and cucurbits. In New Zealand, soldier fly feeding has been recorded mainly on cereal crops and pastures, but also on both cucurbits and tomatoes (Hewitt 1969). We found no evidence that a vegetable crop grown in rotation with cane affected the likelihood of subsequent soldier fly damage, compared with a bare fallow. However, rotations with vegetable crops were poorly represented in crops older than third ratoon, and there may be a different finding in a future survey.

Our findings reinforce 2 current recommendations for soldier fly control in sugarcane: farmers should avoid replanting fields immediately after ploughout of the previous crop, and should keep fallows weed-free. Older ratoons are more likely to suffer damage than younger ones and may serve as reservoirs of infestation for newly planted fields. There is a trend in the Millaquin-Qunaba area for sugarcane to be grown in rotation with vegetable crops, but our survey was unable to reliably assess the effect of this on soldier fly damage to cane.

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References

- ALLSOPP, P.G. and BULL, R.M. (1987)--Cultural methods for soldier fly control. BSES Bull. 20: 20-21.
- BELL, A.F. (1934)--Report on the Division of Entomology and Pathology. Ann. Rep. Bur. sugar exp. Stns Qd 34: 50-72.
- DIXON, G.M. and GERARD, P.J. (1979)--Effect of stocking rate on emergence, dispersal, and behaviour of soldier fly adults in pasture. N.Z. Jl agric. Res. 22: 507-510.
- FIENBERG, S.E. (1980)--The analysis of cross-classified categorical data. Massachusetts Institute of Technology Press: Cambridge.
- 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.
- GERARD, P.J. and PARR, A.M. (1977)--The effect of pasture species on the growth of soldier fly larvae. Proc. N.Z. weed pest control Conf. 30: 198-201.
- HEWITT, S.R. (1969)--The effect of Australian soldier fly on pasture, crops and production. Proc. N.Z. weed pest control Conf. 22: 280-286.
- HITCHCOCK, B.E. (1970)--The soldier fly pest. Proc. Qd Soc. sugar cane Technol. 37: 207-216.

- HITCHCOCK, B.E. (1976)--Studies on the life-cycles of two species of soldier flies (Diptera, Stratiomyidae) which affect sugar-cane in Queensland. Bull. ent. Res. 65: 573-578.
- MOLLER, R.B. (1964)--Some practical aspects of soldier fly control in the Bundaberg district. Cane Grow. quart. Bull. 27: 108.
- MOLLER, R.B. (1965)--The soldier fly pest of sugar cane. Bureau of Sugar Experiment Stations: Brisbane.
- MOLLER, R.B. and MUNGOMERY, R.W. (1963)--Some insect pests adversely influencing ratooning in south Queensland. Proc. int. Soc. sugar cane Technol. 11: 672-677.
- OSBORN, A.W., and HALBERT, E.J. (1972)--Mating behaviour and dispersion of the pasture soldier fly, Inopus rubriceps. Proc. int. Soc. sugar cane Technol. 14: 481-490.
- SAUNDERS, G.W. (1963)--Soldier fly attacks Atherton Tableland pastures. Qd agric. J. 89: 217-219.
- STEEL, R.G.D. and TORRIE, J.H. (1980)--Principles and procedures of statistics, a biometrical approach. 2nd ed. McGraw-Hill: New York.

Table 1. The incidence of soldier fly damage in successive ratoon crops of sugarcane

	Ratoon					
	1	2	3	4	5	>5
% fields damaged	1.4	8.8	15.9	36.8	20.7	33.3
Total No. of fields	72	80	88	38	29	15

Table 2. The incidence of soldier fly damage in different sugarcane varieties, and the proportion of each variety in different ratoon crops

Variety	Total No. of fields	% fields damaged	% fields in following ratoons containing each variety			
			1	2	3	>3
CP44-101	132	14.4	24	25	44	68
H56-752	54	13.0	4	15	3	0
Q110	18	16.7	7	20	18	21
others and mix	118	15.3	65	40	35	11

Table 3. The incidence of soldier fly damage to sugarcane after different pesticide treatments (other than dieldrin) since ploughout of previous crop, and the history of pesticide usage in different ratoon crops

Pesticide	Total No. of fields	% fields damaged	% fields in following ratoons treated with each pesticide			
			1	2	3	>3
none	89	24.7	18	11	29	50
chlorpyrifos (E.C.) alone	157	13.4	49	58	51	38
suSCon Blue	39	0.0	18	21	7	4
other	37	10.8	15	10	13	8

Table 4. The incidence of soldier fly damage to sugarcane with different cultural practices before planting, and the history of cultural practices employed in different ratoon crops

Cultural practice	Total No. of fields	% fields damaged	% fields in following ratoons planted with each practice			
			1	2	3	>3
ploughout-replant	72	16.7	36	19	24	12
autumn plant, bare fallow	151	15.2	29	50	41	66
autumn plant, rotation	58	8.6	25	16	25	6
spring plant, bare fallow	8	0.0	3	2	0	5
spring plant, rotation	19	5.3	6	9	4	5
weedy fallow	14	42.9	1	4	6	6

Table 5. Probabilities associated with the test statistics calculated by log-linear models for different comparisons between cultural variables (see Table 4). Independence between soldier fly damage and each variable was tested while controlling for ratoon age (R = 1, 2, 3, >3). 0 = spring plant, ploughout-replant; 1 = autumn plant, bare fallow; 2 = autumn plant, vegetable crop; 3 = spring plant, bare fallow; 4 = spring plant, vegetable crop; 5 = weedy fallow

Comparison	χ^2	G ²	df
(i) 0vs.1vs.2vs.3vs.4vs.5	26.2	26.4	19a
(ii) 0vs.(1,2)vs.(3,4)vs.5	25.1*	24.5*	12
(iii) 0vs.(1,3)vs.(2,4)vs.5	23.8*	21.6*	12
(iv) (1,2)vs.(3,4)	2.3	3.7	3a
(v) (1,3)vs.(2,4)	0.8	0.8	3a
(vi) 0vs.(1,2,3,4)	13.0*	13.6*	4
(vii) (1,2,3,4)vs.5	11.0*	7.8	3a

* $P < 0.05$

a Analysis included 2 cells with zero expectation and degrees of freedom were reduced accordingly