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RATIONALISING INSECTICIDE USE IN THE CONTROL OF WIREWORMS

by
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SD97010

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1.0 SUMMARY

This project aimed to develop a method to detect wireworms in pre-plant fallows, thus allowing rational decisions to be made on whether or not to use insecticide for wireworm control at planting. Insecticide would be used only when wireworm populations exceeded the level required to cause economic loss.

The project commenced in January 1994 under the supervision of Dr Les Robertson, BSES Tully, with work being carried out in the Herbert and Central districts. Dr Peter Samson of BSES Bundaberg subsequently replaced Dr Robertson as supervisor, and the work formerly planned for northern Queensland was carried out near Bundaberg. Work in the Central district remained unchanged.

The relationship between wireworm density and damage to cane was examined by leaving untreated plots in fields that were otherwise treated with liquid chlorpyrifos. Trials were carried out in each of the years 1994-1996.

In 1994 in the Central district, fewer shoots were found in the untreated plots at four of 17 fields examined. In the Herbert, there were fewer shoots in untreated plots at three of five trial sites. Fewer wireworms were found in treated rows than in the untreated plots, showing the effectiveness of chlorpyrifos. Earthworms were the only other fauna found regularly. Similar numbers of earthworms were present in untreated and treated rows.

Seven of the 22 fields examined in 1994 had received suSCon Blue for canegrub control. There was no response to chlorpyrifos EC in these fields. It is possible that suSCon Blue may have given some control of wireworms, although it is only registered for control of wireworms in the genus *Heteroderes*. Fields to be treated for canegrubs were excluded from trials in subsequent years.

In 1995, baits of rolled oats were used as a sampling technique before planting at Bundaberg and Mackay. A decision on the need for insecticide against wireworms must be made before planting, and baits are used in some other crops to sample insects in pre-plant fallows. Baits of rolled oats were chosen as the most suitable type, having attracted as many wireworms as germinating seeds in preliminary tests in 1994, and being easy to obtain and handle.

Wireworms were found in all of 18 baited fields at Bundaberg and in all but one of 13 baited fields at Mackay in 1995. Untreated strips were left in 11 of these fields at Bundaberg and 12 at Mackay. At Bundaberg, the reduction in crop establishment when insecticide was withheld was positively correlated with the catch of wireworms at baits, suggesting that baiting could have been used as a decision-support system for insecticide use (Samson and Robertson, 1996). However, no similar relationship was seen at Mackay.

Harvest yields were recorded for nine of the Bundaberg trials. There was no significant difference in cane yield between plots treated or not treated with insecticide in any trial, although initial numbers of shoots were greater in treated plots in three trials. Sugar yield was greater in treated plots in only one trial. These measurements confirm that an initial

increase in shoot numbers is not necessarily reflected in harvest yield, presumably because sugarcane plants produce more shoots than they can carry through to harvest.

In 1996, 17 fields were baited and 10 trials established in these fields at Bundaberg, and 12 fields were baited and received trials at Mackay. Great effort was made to place baits at Mackay close to the time of planting. However, there was no relationship between bait counts and the effect of insecticide on shoot numbers at either Bundaberg or Mackay. Numbers of wireworms were low at Bundaberg but should still have been sufficient to cause an effect on the crop, based on the results from 1995. An effect of insecticide was recorded on two farms where few wireworms had been detected, but the effect was slight and unlikely to influence crop yield. Of more concern was a large response to insecticide recorded at one farm at Mackay where no wireworms had been detected before planting. Eyes damaged by wireworms were found in gaps at this farm. The soil was heavy black clay, and this may have influenced either the attractiveness of the baits or the ease of finding wireworms when baits were retrieved.

Throughout this study, numbers of dead shoots and numbers of gaps apparently caused by wireworms were poor indicators of the effect of insecticide treatment. Fields that produced more shoots in response to treatment often showed little evidence of wireworm damage by these other criteria. Inspection of fields sooner after planting may have provided more evidence of damage that was obscured later, eg by shedding of dead shoots or rotting of damaged eyes. Alternatively, the insecticide may sometimes have controlled unrecognised pest species.

Wireworms collected during the project and in previous studies were reared to adult where possible, and sent to the CSIRO Division of Entomology for identification. A total of 91 specimens were examined; at least 26 species were represented in five genera. Most of the species are unnamed. Many fields contained more than one species, making it impossible to ascribe damage to any one. No one species was typically associated with damage to cane, although species of *Agrypnus, Conoderus, and Heteroderes* were implicated. Wireworms are omnivorous, and some species may be useful predators of other pests such as soldier flies (Robertson and Zalucki, 1985).

Overall, improved crop establishment after insecticide treatment during 1994-1996 was measured in only nine of 41 fields at Mackay (22%) and six of 21 fields at Bundaberg (29%). In addition, minor increases in initial shoot counts did not lead to an increase in crop yield. The use of insecticide against wireworms could be reduced substantially, if a suitable method could be developed for deciding the need for treatment.

The main problem with the baiting method was consistency; the method did not always work. Soil conditions are likely to influence the attractiveness of baits and the ease with which wireworms can be found and counted, with the wet heavy soils at Mackay being particularly difficult. Other barriers to adoption of the method include; technical difficulties, especially timing of baiting and misidentification of insects; economics, insecticide treatment against wireworms is inexpensive (about $30/ha) and monitoring is time-consuming; extension difficulties, including the ease of insecticide application once equipment is installed and the ‘peace of mind’ provided by treatment; risk, the consequences of a wrong decision to withhold insecticide could be severe in the plant crop and in future ratoons. The baiting method is unsuitable as a decision-support tool in the form adopted here. A large research effort would be needed to develop a more suitable technique, and this would be unjustified at present. The situation may change if the use of insecticides becomes more limited in the future.

2.0 BACKGROUND

Over the past 40 years, wireworm control has been based on the application of insecticides to soil before or at planting. The amount of insecticide used against wireworms in Australian sugarcane is second only to that applied against canegrubs. Chlorpyrifos is the only insecticide registered for use against wireworms in cane. In 1996, chlorpyrifos was applied as a prophylactic treatment to more than 37,000 ha at planting for wireworm control, at a product cost to growers of $1m. Prophylactic application of chlorpyrifos at planting is a standard recommendation in some districts, in the absence of adequate information on pest distribution, population dynamics and sampling methods.

Prophylactic treatments are expensive and wasteful of chemical because damaging pest populations are often absent from planting blocks. Such treatment imposes an unnecessary pesticide burden on the environment, with mortality to beneficial organisms, development of secondary pests, resurgence of primary pests, and increased selection pressure for resistance in pests. Chlorpyrifos is also the predominant insecticide applied to soil for canegrub control, being the active ingredient of suSCon® Blue, and it is vital to the industry that its efficacy and continued availability be protected.

Integrated pest management (IPM) aims to reduce pesticide use, the simplest strategy being to apply insecticide only when an economic benefit is likely. This relies on a system of detecting pests, and determining whether densities are sufficient to cause economic losses in the crop. Sampling methods for soil insects must be simple and easily applied; otherwise growers will not use them. A simple method for detecting wireworms and other crop-establishment pests in pre-plant fallows, relying on the attraction of pests to germinating seed baits, has been developed recently in other field crops in Queensland (Robertson and Simpson, 1989).

Reduction in chlorpyrifos use would reduce the rate at which soil-living pests develop resistance to the chemical, and lower the probability of microbial degradation of the chemical in the soil. This would prolong the effective life in the sugar industry of chlorpyrifos, which is essential to maintain yields in the presence of canegrubs and wireworms. There would be savings in insecticide cost, and the industry would be seen as adopting an environmentally responsible attitude to pesticide use.

3.0 OBJECTIVES

- Develop a rapid sampling technique to detect wireworm infestations in pre-plant fallows.

- Determine economic injury levels for wireworms in plant cane.

- Formulate a decision-support plan for wireworm management to decide whether or not to treat.

- Promote integrated pest management for wireworms, to reduce prophylactic use of chlorpyrifos.

4.0 ANALYSIS OF OBJECTIVES AND RESEARCH OUTCOMES

- The use of baits before planting of sugarcane was investigated as a rapid sampling technique for wireworms (Objective 1). A range of species was collected at baits in canefields. Baits allowed more efficient sampling than random digging.

- An economic injury level could not be determined for wireworms in plant cane (Objective 2). The economic injury level is the population density of the pest that causes sufficient damage to justify applying a control measure. For wireworm control, the economic injury level must be based on the number of wireworms present before planting, as this is when a decision must be reached on the need for treatment. However, there was not a consistent relationship between the number of wireworms found at baits before planting and subsequent damage. Damage was occasionally recorded in fields where no or few wireworms had been detected.

- Consequently, a decision-support plan could not be formulated or promoted for wireworms (Objectives 3 and 4). Barriers to adoption of any such decision-support plan were examined.

- A large number of wireworms were collected as part of this project, and a reference collection of specimens will be established at the Bundaberg Sugar Experiment Station. This will be of great value in future research.

5.0 IMPLICATIONS AND RECOMMENDATIONS

(1) Wireworms in canefields belong to three main genera, A*grypnus, Conoderus* and *Heteroderes.* However, there is a vast suite of species within these genera, and most of them are unnamed. The assumption that species of *Heteroderes* are the main pests in southern districts, and that the sugarcane wireworm *Agrypnus variabilis* is the main pest further north (Allsopp *et al.,* 1993), is a gross simplification of the true situation.

(2) There is potential to substantially reduce the use of insecticide against wireworms at planting. Trials in this project indicate that more than 75% of insecticide is applied to fields that did not require treatment.

(3) Application of insecticide against wireworms is not expensive for farmers, and although the risk of wireworm attack may be low, the cost of a severe attack would be very high, jeopardising the plant crop and future ratoons.

(4) The baiting method tested here did not consistently predict the risk of wireworm attack.

(5) Further work on this topic is not justified at present; a reliable sampling technique that is cost-effective and acceptable to farmers is unlikely to be forthcoming, given the low cost and ready availability of insecticide treatment.

6.0 INTELLECTUAL PROPERTY ARISING FROM THE RESEARCH

No commercial developments, patents, or licences will arise from the research in BS102S.

7.0 REFERENCES

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APPENDIX I

DEVELOPMENT OF A DECISION-SUPPORT PLAN FOR WIREWORM MANAGEMENT

ABSTRACT

Wireworms (Coleoptera: Elateridae) damage the eyes and young shoots of germinating setts in most mill areas. Liquid chlorpyrifos can be applied at planting to avoid damage. However, there are no guidelines for deciding on whether treatment is warranted, and a sampling method to detect wireworms before planting has not been developed. Trials in the Central and Herbert districts in 1994 showed that crop establishment in most fields was not significantly improved by insecticide at planting. Baits were tested as a method for detecting wireworms in pre-plant fallows. Baits of rolled oats were chosen as the most suitable, performing equally as well as germinating seeds in 1994. In 1995 at Bundaberg, the reduction in crop establishment when treatment was withheld was positively correlated with the catch of wireworms at baits before planting, indicating that baiting could have been used to develop a decision-support system for insecticide use. However, no similar relationship was seen in 1996 or at Mackay in either 1995 or 1996. In general, the effect of insecticide was less than might have been expected from the number of wireworms found before planting. However, severe damage was recorded on one farm at Mackay where no wireworms had been found. Possible barriers to the adoption of baiting as a decision-support tool are discussed; the use of baits ultimately seems unsuitable for this purpose without a great deal more development.

INTRODUCTION

Wireworms (Coleoptera: Elateridae) are pests of plant crops of sugarcane in most mill areas. They eat the eyes and young shoots of germinating setts, causing poor establishment and gappy stands. Chlorpyrifos is the only insecticide registered for wireworm control in Queensland sugarcane, as both controlled-release (suSCon Blue) and liquid formulations. The registered rate of the liquid formulation (eg Lorsban, Chlorfos) is 0.75 kg ai/ha. In the 1996 crop in Queensland, $1m was spent on insecticide specifically for wireworm control at planting (data supplied by Cane Protection and Productivity Boards).

Sampling methods and decision-support systems have not been developed for wireworms, so growers decide to treat at planting based on experience or habit. Insecticide is undoubtedly applied to some fields where damage would not have occurred. This imposes an unnecessary cost, albeit small, to individual growers, but unnecessary treatment has wider implications. Chlorpyrifos is the cornerstone of control of not only wireworms, but also canegrubs. Excessive use of the insecticide may jeopardise its future by promoting resistance or by stimulating environmental concerns within the wider community. The industry should adopt an environmentally responsible attitude to pesticide use, if access to pest control products is to be maintained. For each pest, this requires the adoption of a decision-support plan based on an economic injury level (ie the level of pest abundance that economically justifies insecticide treatment) and the development of a suitable sampling method to monitor the pest population.

This paper reports on work to develop a sampling method and decision-support plan for wireworms. Baiting was investigated as a method of assessing wireworm populations in pre-plant fallows. Baits are used in other cropping systems to detect soil insects before planting (eg Robertson and Simpson, 1989). The relationship between wireworm population and benefit from insecticide treatment was evaluated in trials from 1994-1995, to develop economic injury levels for the pest in sugarcane.

MATERIALS AND METHODS

Comparison of sampling methods before planting

The number of wireworms caught was compared between two bait types, either whole wheat seeds or rolled oats. Both baits have been successfully used for wireworms in Canada (Doane, 1981). Baits were first moistened and then a small handful was buried in fallow fields at sufficient depth to encounter moist soil. Baits were compared in March 1994 in the Central district and May 1994 in the Herbert district. Ten baits of each type were buried in each field; they were excavated four days later and wireworms counted. In addition, 20 holes were dug at random in the same fields at Mackay and wireworms counted in these unbaited sites.

Crop establishment, 1994 trials

Untreated strips were left in fields that were otherwise treated with chlorpyrifos EC (emulsifiable concentrate) at planting in the Central and Herbert districts during 1994. The design of the untreated strips varied from one to several groups of single or multiple rows, usually running the whole length of the field.

Trials were assessed in October 1994. Numbers of live shoots, dead shoots and gaps were counted in 10 x 1.0 m (Herbert) or 1.5 m (Central) lengths of row in adjacent segments of the untreated and treated sections of each field. The presence of a circular entry hole in dead shoots was diagnostic of wireworm damage. The assessment was carried out over a row length of about 20-30 m; in the Central district we chose that part of the field showing any evidence of poor establishment. Numbers of wireworms were then counted in the root zone of 10 plants in each treatment. Setts in gaps (>0.5 m) were dug up and examined for wireworm damage, and the number of gaps with evidence of damage was recorded.

Crop establishment and yield, 1995 trials

Potential trial sites were baited with rolled oats before planting in 1995. Baits were set in groups of four in a square, each corner of the square being about 3 m apart. Eight squares were set in each field, ie 32 baits in total, with two squares across and four squares along each field. The baited area covered the length of most fields to the width of a section between irrigation winch tracks. At Bundaberg, baits were placed during February and left in place for 5-11 days. At Mackay, baits were placed from April-June for 7-9 days. Eighteen fields were baited at Bundaberg and 13 at Mackay.

Trials to measure the benefit of chlorpyrifos EC application at planting were subsequently set up in 11 of the baited fields at Bundaberg and 12 at Mackay. At Bundaberg, all trials but one were planted in March, 2-4 weeks after baits were placed; the remaining trial was planted in April, seven weeks after bait placement. At Mackay, one trial was planted in April, two weeks after bait placement, while remaining trials were planted from June-early August, 4-13 weeks after baiting (average eight weeks).

Trials comprised a single strip of four rows within otherwise-treated fields. The strip was placed on the side of the field with more wireworms, if bait counts varied across the field. Four replicates of plots with and without chlorpyrifos EC were planted along the strip, with each plot 19-25 m long depending on the length of the field (total trial length = 200 m maximum). A treated buffer was left between the trial strip and headlands.

Trials were assessed in May-June 1995 at Bundaberg, 8-13 weeks after planting, and June-October at Mackay, 8-12 weeks after planting. The number of live shoots, dead shoots, and gaps >0.5 m were recorded for the middle two rows of each plot. Dead shoots and gaps were dug up for diagnosis. Wireworms were counted under 8-10 plants dug from the middle two rows in each plot.

The yields of nine Bundaberg trials were measured at the 1996 harvest, by one of two methods. Either the weight of cane in the middle two rows of each plot was measured by a weighing machine filled by a commercial harvester, or millable stalks in the middle two rows were counted and then 40 stalks were hand-cut and weighed. A six-stalk sample was collected from each plot for measurement of commercial cane sugar (ccs) using a small mill.

Crop establishment, 1996 trials

Methods of baiting and trial implementation in 1996 were the same as in 1995. At Bundaberg, baits were placed during February-March and left in place for 5-8 days. At Mackay, baits were placed from April-July for 5-7 days. Seventeen fields were baited at Bundaberg and 12 at Mackay. Trials to measure the benefit of chlorpyrifos EC application at planting were set up in 10 of the baited fields at Bundaberg and all fields at Mackay. At Bundaberg, all trials were planted in March, 1-3 weeks after baits were placed. At Mackay, trials were planted from May-August, 1-6 weeks after baiting (average 2.6 weeks). Plots were 15-25 m long. Trials were assessed in May 1996 at Bundaberg, 9-12 weeks after planting, and from August-November at Mackay, 11-15 weeks after planting. Assessment was the same as in 1995 except wireworms were not counted in the crop after planting.

Statistical analyses

In 1994 trials, the number of shoots and number of gaps were compared between treated and untreated strips by *t*-test. However, the individual shoot counts in this year did not correspond to true replicates, and caution is needed when inferring the effect of treatment. The number of wireworms in 1994 was compared between insecticide treatments by paired *t*-test, with the total number of individuals in untreated and treated strips on each farm constituting a pair. In 1995 and 1996, numbers of shoots and gaps and yields were compared between treated and untreated plots on each farm by analysis of variance. The significance level of the test was taken as 10% because of the few error degrees of freedom available in each analysis. Numbers of wireworms in 1995 were compared between treatments across farms by analysis of variance. In all years, the relationship between wireworm abundance and the apparent reduction in shoot establishment in untreated plots was examined by linear regression or correlation. All analyses used STATISTIX 4.0 (Analytical Software, 1992).

RESULTS

Comparison of sampling methods

Similar numbers of wireworms were found on baits of wheat seed and rolled oats (Table 1). Rolled oats are easy to obtain and handle and were chosen for all future baiting. A rigorous comparison was not made with random digging, but it seemed that more wireworms could be found in conjunction with baits.

Crop establishment, 1994 trials

The number of undamaged shoots in untreated strips in the Central district in 1994 was significantly lower than in treated strips at only four of the 17 fields (Table 2). The number of gaps caused by wireworms was generally low; most gaps were due to other causes such as pineapple disease or the absence of viable setts. Significantly more gaps were caused by wireworms in untreated strips at one farm (Kane) where there was also a large reduction in undamaged shoots. Very few damaged shoots were observed, to a maximum of 0.09 x 10^4/ha in untreated rows at Davies and Kane; no detailed counts are given. In the Herbert district, there were fewer live shoots in untreated plots at two of the four sites (Table 3).

Wireworms were found at three of the farms where there was a significant response to chlorpyrifos EC in the Central district (Table 2). However, none was found at Azzapardi. Wireworms were also found at several farms where chlorpyrifos EC had no significant effect on shoot numbers (eg Finn, Moranino no. 2). There was no apparent relationship between the number of wireworms found in the crop and response to insecticide (Fig. 1, $R^2 = 0.19$, $P = 0.094$). No wireworms were found in the Herbert, despite an apparent response to insecticide (Table 3).

Fewer wireworms were found in treated than in untreated rows in the Central district, with respective means of 0.095 and 1.00/10 spade samples over all trials ($P = 0.007$).

Bin weights were obtained for the Bowman and Kane trials at Mackay, which showed a significant reduction in crop establishment without insecticide. Average yields in treated and untreated strips were 171 and 165 t/ha at Bowman and 95 and 84 t/ha at Kane, respectively.

Seven fields in both districts received suSCon Blue for canegrub control. This insecticide is also registered for control of wireworms in the genus *Heteroderes.* There was no positive response to chlorpyrifos EC in the suSCon-treated fields (Tables 2 and 3). This may have been a coincidence, but fields to be treated with suSCon Blue were not considered for subsequent trials in 1995.

Crop establishment and yield, 1995 trials

Wireworms were found in all 18 fields baited before planting at Bundaberg in 1995, with 1-13 wireworms/32 baits. In subsequent trials on 11 farms, a significant ($P = 0.10$) reduction in shoot establishment was recorded on only four farms when no insecticide was applied at planting (Table 4). Three of these had the highest number of wireworms recorded in the pre-plant fallow. There was a positive and highly significant relationship between the number of wireworms found at baits before planting and subsequent reduction in establishment in untreated plots (Fig. 2).

Wireworms were found at 12 of the 13 fields baited before planting at Mackay in 1995. The highest count was 56 wireworms/32 baits; no trial was placed on this farm but all other fields subsequently received trials (Table 4). A significant ($P = 0.10$) reduction in shoot establishment in untreated plots was recorded at only one farm, Deguara, and that farm had a low count of wireworms before planting. Two farms with very high wireworm counts, Micallef and Russell, subsequently showed no reduction in establishment in untreated plots. There was no relationship between pre-plant wireworm counts and subsequent reduction in establishment in untreated plots at Mackay (Fig. 2, $R^2 = 0.001$, $P = 0.92$).

Numbers of gaps identified as being caused by wireworms were low in all trials (Table 4). A significant increase in such gaps in untreated plots was recorded in only one farm at Bundaberg (Zunker) and none at Mackay. Very few shoots were found killed by wireworms (numbers are not given). The highest density in any treatment was 0.008 x 10^4/ha, which was much too low to account for observed differences in crop establishment (see Table 4).

Few wireworms were found in fields after planting, especially at Mackay (Table 4). The mean number of wireworms/10 samples was 0.30 and 0.13 in untreated and treated plots at Bundaberg, respectively, and 0.03 in both untreated and treated plots at Mackay. Numbers did not differ significantly between treatments ($P = 0.16$). At Bundaberg, there was no significant correlation ($P > 0.05$) between the number of wireworms found in the crop and either the number of wireworms found at baits before planting ($r = 0.076$) or the reduction in shoots in untreated plots ($r = 0.077$). Too few wireworms were found in crops at Mackay to analyse those data.

Crop yields at harvest in 1996 were measured for most of the Bundaberg trials (Table 5). Sugar yield was significantly greater ($P = 0.10$) in treated plots compared with untreated plots in only one trial (Killer); there was no significant increase in sugar yield in two other trials where there had been an initial improvement in crop establishment in treated plots (Tables 4 and 5, Davey and Rehbein). Cane yield was not significantly increased by treatment in any trial.

Crop establishment, 1996 trials

Wireworms were found in 11 of 17 fields baited before planting at Bundaberg in 1996, with 1-19 wireworms/32 baits. In subsequent trials on 10 farms, a significant ($P = 0.10$) reduction in shoot establishment without insecticide was recorded on only two farms, Hansen and Baretta, and the difference in shoot numbers was small (Table 6). Few wireworms were recorded on these two farms in the pre-plant fallow. No effect of chlorpyrifos on establishment was recorded on the three farms with the highest number of wireworms, ie 10 per 32 baits. There was no relationship between the number of wireworms found at baits before planting and subsequent reduction in establishment in untreated plots (Fig. 3, $R^2 = 0.12$, $P = 0.32$).

Wireworms were found at eight of the 12 fields baited before planting at Mackay in 1996. The highest count was only 6 wireworms/32 baits. All of the baited fields subsequently received trials (Table 6). A significant ($P = 0.10$) reduction in shoot establishment in untreated plots was recorded at four farms. There was no relationship between pre-plant wireworm counts and subsequent reduction in establishment in untreated plots (Fig. 3, $R^2 = 0.002$, $P = 0.88$). No wireworms had been found at the farm with the greatest reduction in establishment (D Russell, Table 6).

Numbers of gaps identified as being caused by wireworms were low in most trials (Table 6). A significant increase in such gaps in untreated plots was recorded at D Russell at Mackay, where there was also a large reduction in the number of living shoots in untreated plots. Significant increases in wireworm-related gaps were also recorded at Strathdee at Bundaberg and Atkinson at Mackay, where numbers of shoots did not differ significantly between treatments. Few shoots were found killed by wireworms, and numbers are not given. None were found at Bundaberg; the highest density in any treatment at Mackay was 0.04×10^4/ha, and none were found at D Russell.

Wireworm identification

A total of 91 wireworms were examined by Dr A Calder, CSIRO Division of Entomology, after having been reared to adult on a diet of maize seeds and larvae of sugarcane soldier fly *Inopus rubriceps* (Diptera: Stratiomyidae). The specimens included wireworms collected within this project, plus some others collected from canefields during previous studies. Specimens included a large brown cylindrical wireworm in the genus *Dicteniophorus*, and a pinkish coloured wireworm with a simple pair of spines at the anal end, *Hapatesus bubanus*. Remaining specimens, which were all a similar creamy colour with a brown, hardened anal plate with marginal spines, belonged to the genera *Agrypnus, Conoderus,* and *Heteroderes.* Only four named species were found in these three genera, with another 20 species unnamed (Table 7).

Agrypnus variabilis, the species designated with the common name of 'sugarcane wireworm', was found in only three canefields (Table 7). *Agrypnus* spp. tended to be more abundant in the Central region and *Conoderus* spp. in the Southern region, with *Heteroderes* spp. similarly represented in both. However, this was not a structured survey of wireworm occurrence, and it is not possible to draw conclusions on distribution.

Table 8 lists the identity of wireworms from canefields showing actual wireworm damage, or showing a positive response to chlorpyrifos application as significantly increased shoots or reduced gaps caused by wireworms (from Tables 2, 4, and 6). The table only includes wireworms successfully reared to adult, so the identity of wireworms in many fields was not determined. Many species from the three genera *Agrypnus, Conoderus* and *Heteroderes,* were found in affected fields. More than one species were found in some canefields. At

Kane, 1994, for example, three separate species of *Agrypnus* were associated with greatly reduced crop establishment in untreated plots (compare with Table 2).

DISCUSSION

Many species of wireworms were found in canefields, most of them unnamed. Presumably many more would be found with further collecting. Identification to species level would require revisionary work on the family.

No one species of wireworm was typically associated with damage to cane. *Heteroderes* sp.#5 occurred frequently in Central and Southern regions and was found in five damaged fields. The same unnamed species was reported by Allsopp and Hitchcock (1987) as damaging sugarcane at Bundaberg in the 1980s (A Calder, pers. comm.). *Heteroderes* nr *cairnsensis* was found in four damaged fields, *Conoderus subflavus* in three, and *Conoderus* sp.#8 and *Agrypnus variabilis* in two damaged fields each. However, many canefields contained more than one species, and it is not possible to decide which wireworms were responsible for damage. Not all species may be damaging; wireworms are omnivorous, and some species may be useful predators of other pests such as soldier flies (Robertson and Zalucki, 1985).

Numbers of dead shoots and numbers of gaps apparently caused by wireworms were poor indicators of the effect of insecticide treatment. Fields that responded to treatment often showed little evidence of wireworm damage by these criteria. Inspection of fields sooner after planting may have provided more evidence of damage that was obscured later, eg by shedding of dead shoots or rotting of damaged eyes. Alternatively, the insecticide may sometimes have controlled unrecognised pest species other than wireworms.

Reduced crop establishment in untreated plots during 1994-1996 was measured in only nine of 41 fields in the Central region (22%) and six of 21 fields at Bundaberg (29%). Reductions in crop establishment in untreated plots were relatively severe at a few farms (eg Kane) at Mackay in 1994. Parts of fields showing signs of damage were deliberately targeted for assessment in that year, and overall damage in those fields is undoubtedly overestimated. In other years, the reduction in young shoots in untreated plots was less than 30%, except for one farm at Mackay in 1996.

Minor reductions in initial shoot counts may not lead to a reduction in crop yield. There was little reduction in yield in two of the 1994 trials at Mackay where there had been a large difference in crop establishment. In the 1995 trials at Bundaberg, reductions in initial shoot counts of up to 30% gave little or no loss of yield at harvest.

Therefore, the withholding of insecticide reduced crop establishment infrequently, and even then crop yield was often unaffected. The use of insecticide against wireworms could be reduced substantially.

Results of trials at Bundaberg in 1995 indicated that baiting before planting could be used to decide whether insecticide treatment was warranted. There was a good relationship between the number of wireworms before planting and the increase in crop establishment resulting from insecticide treatment (see also Samson and Robertson, 1996).

No such relationship was seen at Mackay in 1995. However, for most fields the benefit from using insecticide was less than expected, based on the number of wireworms at baits and the Bundaberg results. Only one field that should have been treated (Deguara) may have escaped treatment if baiting had been used as a decision-support tool.

I thought that results may have differed between districts in 1995 because of a difference in time elapsed between baiting and planting. At Bundaberg, autumn planting was carried out over a short time period, and baiting could be closely aligned with expected planting date. At Mackay, however, planting was more dependent on rainfall, and trials were often planted a considerable time after baiting. Ideally, baits should be put out after fields are fully prepared for planting, as any subsequent delay, including changes in soil conditions or additional cultivation, may change the wireworm status in the field.

In the 1996 trials, great effort was made to place baits at Mackay close to the time of planting. However, there was no relationship between bait counts and the effect of insecticide at either Bundaberg or Mackay in that year. Numbers of wireworms were low at Bundaberg but should still have been sufficient to cause an effect on the crop, based on the results from 1995. An effect of insecticide was recorded on two farms where few wireworms had been detected, but the effect was slight and unlikely to influence crop yield. Of more concern was a large response to insecticide recorded on one farm at Mackay where no wireworms had been detected before planting. Eyes damaged by wireworms were found in gaps on this farm, and there is little doubt that wireworm control was responsible for the crop response to insecticide treatment. The soil on this farm was heavy black clay, and this may have influenced either the attractiveness of the baits (see below) or the ease of finding wireworms when baits were retrieved.

It is possible that other baiting techniques may have been superior to the one tested here. Various studies have investigated the effectiveness of different types of baits, exposed for different times and under different circumstances (eg Doane, 1981; Toba and Turner, 1983; Bynum and Archer, 1987; Jansson and Lecrone, 1989; Seal *et al.*, 1992; Kirfman *et al.*, 1986). There may be ways to increase the attractiveness of baits, eg Bynum and Archer (1987) found that sorghum seed covered with a layer of charcoal dust and a piece of clear polyethylene was more effective than uncovered baits. However, Jansson and Lecrone (1989) recommended simple oatmeal-cornflake or rolled oat baits for wireworms in potato fields, as being more effective and quicker to process than seed baits. Any baiting method for use by cane farmers must be simple if it is to be adopted.

Despite an abundance of studies on baiting methods for wireworms, there are fewer examples of the use of baiting to predict the likely damage to crops. One such study in potatoes found no relationship between pre-planting wireworm catches at baits and the subsequent level of wireworm damage (Parker, 1996). Damage occurred even where no wireworms were detected. These results were attributed to both the patchy nature of wireworm distribution within a field, and the sampling errors involved in trying to estimate the population size accurately. A further problem was the likelihood that the attractiveness of baits would vary depending on soil temperature, soil moisture, the availability of alternative food sources, and soil friability. For example, few wireworms were caught at baits in a field with a dense soil structure, although a moderate to high wireworm infestation was known to be present. Similar conclusions can be reached in the present study.

Wireworms were not the only insects found at baits in sugarcane fields. False wireworms (Coleoptera: Tenebrionidae) occurred in low numbers, but they can be readily distinguished from true wireworms by their shape and absence of an anal plate. Misidentification was more likely with larvae of carabid beetles (probably *Clivina* sp.), which outnumbered wireworm larvae at baits in some fields at both Bundaberg and Mackay.

Possible barriers to the commercial adoption of baiting as a decision-support tool include:

(a) **consistency:** the method did not always work. Soil conditions are likely to influence the attractiveness of baits and the ease with which wireworms can be found and counted, with the wet heavy soils at Mackay being particularly difficult.

(b) **technical difficulties:** misidentification of insects, and the presence of different wireworm species that may not be equally damaging. Both these factors are likely to lead to conservative decisions, ie unwarranted treatment of fields, and so their consequences may not be severe. A delay between baiting and planting may sometimes be inevitable in central and northern districts; this may again lead to a conservative decision if further cultivation is carried out before planting. However, if soil conditions, especially soil moisture, change between baiting and planting, there is a possibility of a wrong decision to withhold treatment.

(c) **economics:** assessment of 32 baits as done in 1995 and 1996 occupied several hours at each farm. This cannot be justified economically in relation to the cost of chlorpyrifos treatment (about $30/ha). However, it is unlikely that this number of baits could be reduced, given the low numbers of wireworms found.

(d) **extension difficulties:** growers would need to allocate time to baiting; once insecticide application equipment is installed on the planter, then application is very simple and inexpensive; treatment provides ‘peace of mind’, an attitude that will be difficult to reverse; growers need to be convinced of the reliability of the method and of their own ability to implement it.

(e) **risk:** the consequences of a wrong decision to withhold insecticide could be severe, leading to poor yields not only in the plant crop, but also in subsequent ratoons, and possibly the need to replant the field.

In summary, a large number of wireworm species, mostly unnamed, were found in canefields. The number of wireworms counted at baits before planting of trials at Bundaberg in 1995 could have been used to decide whether insecticide treatment was warranted in that year. However, the same method would not have been successful in 1996, or at Mackay in either year. There is potential to reduce the use of insecticide at planting in Bundaberg and Mackay, as an increase in shoots was measured on only 24% of farms and the proportion of farms showing a yield benefit would be lower than this. However, the baiting method is unsuitable as a decision-support tool in the form adopted here. A large research effort would be needed to develop a more suitable technique, and this would be unjustified at present. The situation may change if the use of insecticides becomes more limited in the future.

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Table 1

Comparison of methods of detecting wireworms in pre-plant fallows

Region	Farm	Wireworms/10 baits		Wireworms/10 holes
		Wheat seed	Rolled oats	
Central	Clarke	0	0	1
	Pleystowe	3	4	1
	Tomarini	1	0	0
	Vickers	5	4	0
	Total	9	8	2
Herbert	Morley	0	1	-
	Smith	0	2	-
	Warren	0	1	-
	Total	0	4	-

Table 2

Assessment of crop establishment and wireworms with and without chlorpyrifos EC at planting, Mackay-Proserpine, 1994

Farm	Shoots/ha (10^4)		Wireworm gaps/ha		Wireworms/ 20 samples in crop
	Untreated	Treated	Untreated	Treated	
Azzapardi	1.2	2.4 *	1333	444	0
Bowman	4.6	8.1 *	0	0	2
Kane	0.7	2.8 *	7556	444 *	4
LumWan	3.7	5.6 *	0	444	4
Barron	10.7	8.9	0	0	1
Benson	2.6 [a]	2.8	0	0	- [b]
Bezzina	4.9 [a]	5.9	0	0	0
Camm (1)	4.1	4.4	0	444	1
Camm (2)	2.2	2.3	1333	0	1
Davies	3.6	3.8	444	0	1
Finn	4.5	5.2	444	0	3
Greenwood	2.9	3.9	667	0	0
Leach	2.5 [a]	2.1	0	0	0
McLennan	2.2 [a]	2.8	444	0	1
Moranino (1)	4.0	3.4	0	0	0
Moranino (2)	3.1	3.3	889	0	5
Pratt	3.6 [a]	3.0	0	0	0

[a] suSCon Blue applied
[b] Not sampled
* Difference statistically significant ($P = 0.05$)

Table 3

Assessment of crop establishment and wireworms with and without chlorpyrifos EC at planting, Ingham, 1994

Farm	Shoots/ha (10^4)		Wireworms/20 samples in crop
	Untreated	Treated	
Casale	6.2	10.8 *	0
Russo	2.5	3.5 *	0
Fighera	13.5 [a]	9.3 *	0
Smith	4.5 [a]	4.5	0

[a] suSCon Blue applied
* Difference statistically significant (*P* = 0.05)

Table 4

Assessment of wireworms (WW) in fallows, and subsequent crop establishment and wireworms with and without chlorpyrifos EC at planting, Bundaberg and Mackay, 1995

Farm	WW/32 baits pre-plant	Shoots/ha (10^4)		Wireworm gaps/ha		WW/20 samples in crop
		Untreated	Treated	Untreated	Treated	
Bundaberg						
Fritz	2	10.8	10.5	0	0	0.0
Golchert	2	13.7	14.0	0	0	0.6
Zunker	3	6.2	6.1	267	33 *	0.6
Simpson	3	5.4	6.2	0	0	0.0
Davey	4	7.6	8.5 *	0	0	0.6
Banks	4	9.5	9.6	0	42	0.0
Hansen	5	15.7	16.3	33	0	1.3
Campbell	9	10.3	11.6	0	33	0.0
Davey 2	9	2.5	2.9 *	0	0	0.3
Killer	10	4.8	6.0 *	33	67	1.0
Rehbein	13	4.8	6.6 *	33	0	0.4
Mackay						
Shepherd	0	2.4	2.3	0	0	0.0
Deguara	1	2.2	2.7 *	0	0	0.0
Barnard	1	2.6	2.6	67	0	0.0
Moschino	1	3.0	3.2	0	0	0.0
Torrisi	1	2.6	2.4	33	0	0.0
Graffunder	2	2.6	2.6	0	0	0.0
Vezzoli	2	2.8	2.8	0	0	0.0
Russell Br	2	2.2	2.4	0	0	0.0
LumWan	2	3.9	3.5	0	0	0.0
Ross	7	3.5	4.0	0	0	0.0
Micallef	36	1.7	1.9	0	0	0.0
Russell	38	3.2	3.1	0	0	0.6

* Difference statistically significant ($P = 0.10$)

Table 5

Plant cane yield with and without chlorpyrifos EC at planting in trials established at Bundaberg in 1995

Farm	Tonnes cane/ha		Tonnes sugar/ha	
	Untreated	Treated	Untreated	Treated
Fritz	112	108	16.3	14.7
Golchert	121	109	18.4	17.9
Zunker	99	99	16.4	16.4
Simpson	101	92 *	16.3	14.3 *
Davey	175	179	25.6	26.2
Banks	86	86	14.2	14.2
Hansen	142	128	21.4	20.5
Killer	130	136	19.7	22.2 *
Rehbein	90	97	15.2	15.9

* Difference statistically significant (*P* = 0.10)

Table 6

Assessment of wireworms (WW) in fallows, and subsequent crop establishment with and without chlorpyrifos EC at planting, Bundaberg and Mackay, 1996

Farm	WW/32 baits pre-plant	Shoots/ha (10^4)		Wireworm gaps/ha	
		Untreated	Treated	Untreated	Treated
Bundaberg					
Strathdee	0	1.4	1.7	139	0 *
Harte	0	2.4	2.4	0	0
Hansen	1	1.5	1.6 *	0	0
Pitt 1	2	4.8	5.1	67	0
Baretta	2	4.5	4.8 *	0	0
Rehbein	4	3.8	3.1 *	0	33
Pitt 2	7	5.1	5.2	0	0
DePaoli	10	3.8	3.7	467	0
T Pitt	10	3.5	3.6	0	0
Chapman	10	2.8	2.7	0	0
Mackay					
D Graffunder	0	2.2	2.3	83	0
K Graffunder	0	3.5	3.8	0	0
D Russell	0	4.4	8.4 *	1000	42 *
Zarb	0	3.0	3.1	0	0
Bernard	1	8.6	8.4	167	42
Siddle	1	3.0	2.9	0	0
Galletly	2	2.4	2.3	0	0
Ross	2	9.7	10.3 *	83	42
J Russell	2	5.8	6.5	125	0
Deguara	3	2.2	2.9 *	500	42
Millard	4	1.3	1.5 *	0	0
Atkinson	6	2.7	2.9	433	200 *

* Difference statistically significant ($P = 0.10$)

Table 7

Wireworm species identified from canefields in different regions

Species	Number of canefields where species found in each region				
	North	Central[a]	South	NSW	Total
Agrypnus assus (CandΠze)	1	0	0	0	1
A. variabilis (CandΠze)	1	2	0	0	3
A. sp.#1	0	1	0	0	1
A. sp.#2	1	2	0	0	3
A. sp.#3	0	5	0	0	5
A. sp.#4	0	0	2	0	2
A. sp.#5	0	0	1	0	1
A. sp.#6	0	0	0	1	1
All *Agrypnus*	3	10	3	1	17
Conoderus subflavus (Macleay)	0	6	1	0	7
C. sp.#1	2	1	8	0	11
C. sp.#2	0	0	3	0	3
C. sp.#3	0	0	3	0	3
C. sp.#4	0	0	3	0	3
C. sp.#5	1	0	0	0	1
C. sp.#6	0	0	1	0	1
C. sp.#7	0	0	2	0	2
C. sp.#8	0	0	4	0	4
C. spp.[b]	0	0	2	0	2
All *Conoderus*	3	7	27	0	37
Heteroderes cairnsensis Blackburn	0	0	2	0	2
H. nr *cairnsensis*	0	1	6	0	7
H. sp.#1	0	1	0	0	1
H. sp.#2	0	1	0	0	1
H. sp.#3	0	1	0	0	1
H. sp.#4	0	1	0	0	1
H. sp.#5	0	5	7	0	12
All *Heteroderes*	0	10	15	0	25
Dicteniophorus sp.	0	0	1	0	1
Hapatesus bubanus Neboiss	0	0	2	0	2
All species	6	27	48	1	82

[a] Mackay-Proserpine
[b] Specimens too damaged for identification to species level

Table 8

Identity of wireworms from canefields showing wireworm damage or a positive response to chlorpyrifos application at planting

Year	District	Farm	Species
1994 (Table 2)	Central	Bowman	*Conoderus subflavus*
		Kane	*Agrypnus variabilis*, *A.* sp.#1, *A.* sp.#2
		LumWan	*Conoderus subflavus*, *Heteroderes* sp.#1
1995 (Table 4)	Bundaberg	Davey	*Conoderus* sp.[a]
		Davey 2	*Heteroderes* sp.#5
		Killer	*Conoderus* sp.#6, *C.* sp.#8, *Heteroderes* nr *cairnsensis*
		Rehbein	*Heteroderes* nr *cairnsensis*
		Zunker	*Conoderus* sp.[a], *Heteroderes* nr *cairnsensis*
1996 (Table 6)	Bundaberg	Baretta	*Conoderus* sp.#8
	Mackay	Atkinson	*Heteroderes* sp.#4, *H.* sp.#5
		Deguara	*Agrypnus variabilis*
		Ross	*Heteroderes* nr *cairnsensis*, *H.* sp.#5
Damaged ratoons	Mackay	Comelli	*Conoderus subflavus*, *Heteroderes* sp.#5
		BSES	*Heteroderes* sp.#5

[a] Specimen too damaged for identification to species level

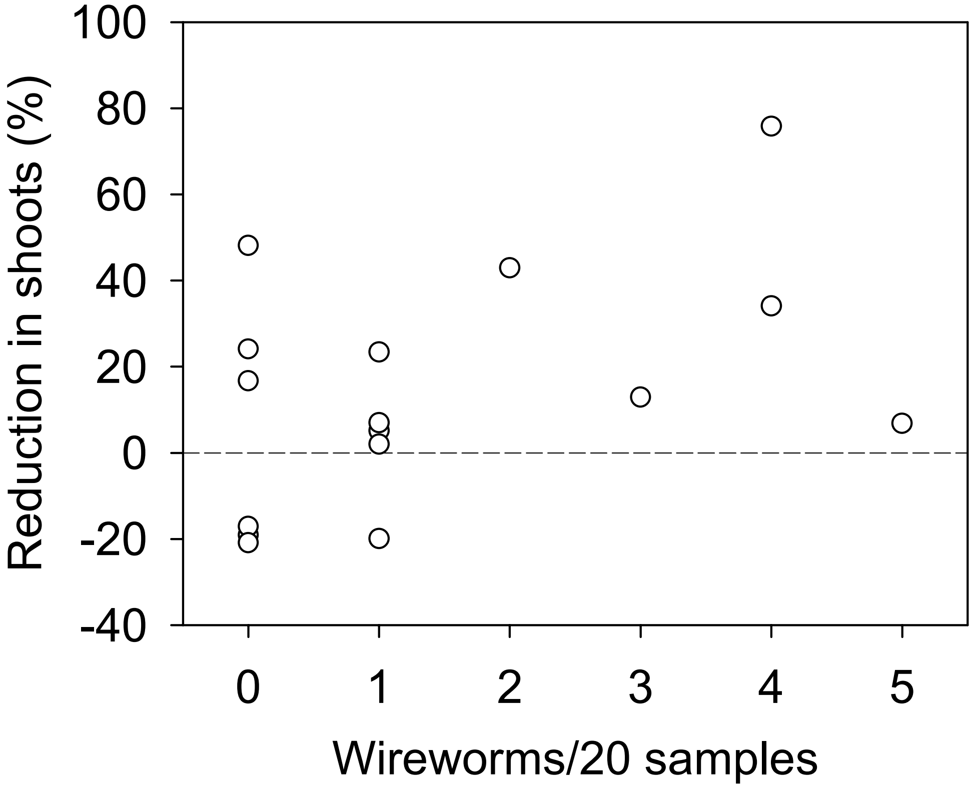

Figure 1 - Wireworms after planting and stand reduction in untreated strips in the Central district, 1994

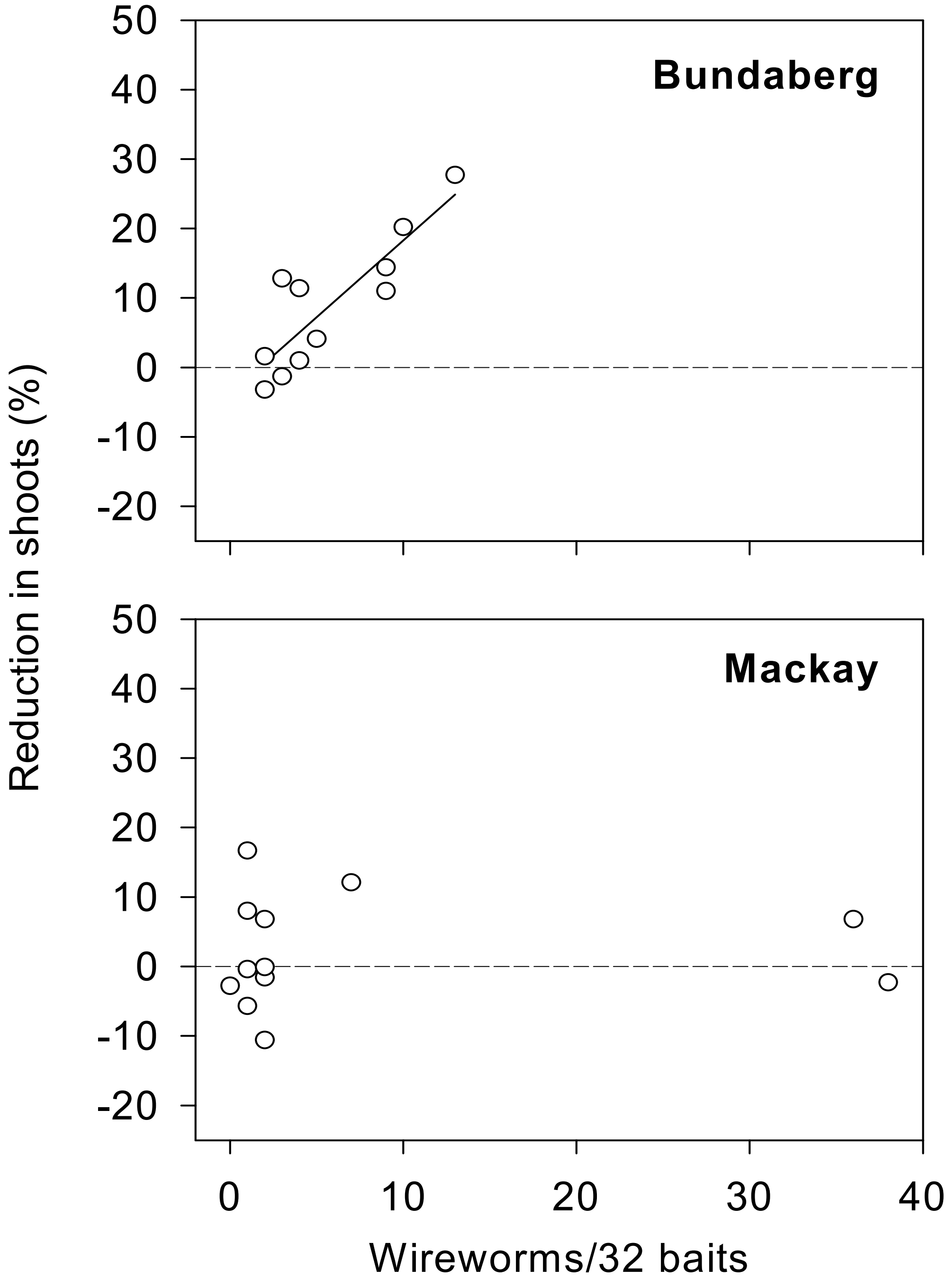

Figure 2 - Wireworms at baits before planting and stand reduction in untreated plots, 1995. The regression at Bundaberg is: shoot reduction(%) = -3.7 + 2.20 wireworms(/32 baits), R^2 = 0.74, P = 0.0007

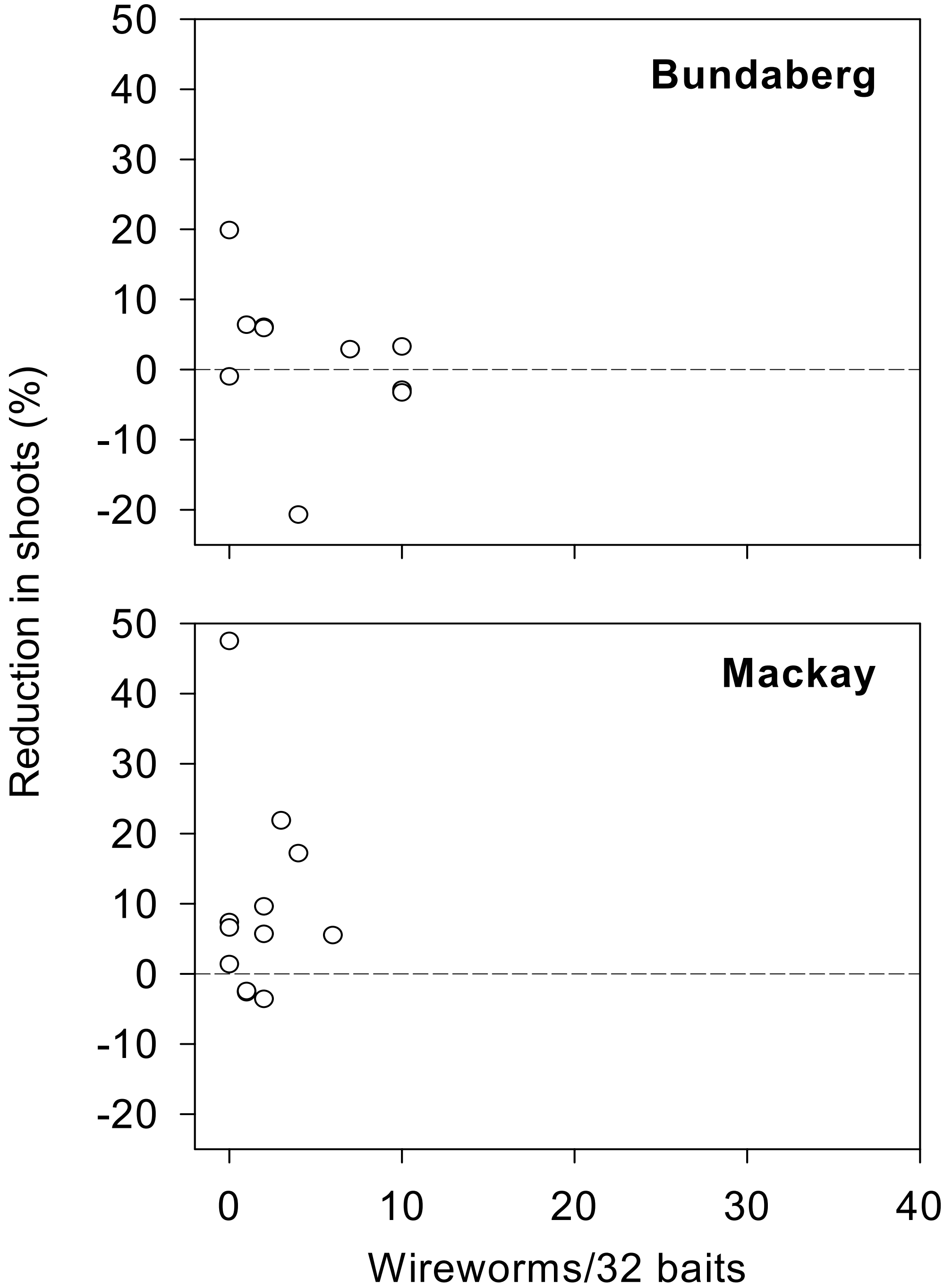

Figure 3 - Wireworms at baits before planting and stand reduction in untreated plots, 1996