INTEGRATED CONTROL OF SWEETPOTATO WEEVIL, *CYLAS FORMICARIUS* FABRICIUS, WITH SEX PHEROMONE AND INSECTICIDE

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ABSTRACT

The sweetpotato weevil (SPW), Cylas formicarius Fabricius, is one of the most destructive pests of the sweetpotato. In Taiwan, it damages on average about 18% of tubers. In severely infested fields, as many of 88% of tubers can be damaged. Recently the sex pheromone of SPW has been isolated, identified, and synthesized. It has great potential for the control of SPW as part of an integrated pest management system. A successful formulation for sex pheromone lure has been developed, and traps designed for practical application in the field.

Experiments have also been conducted to evaluate the integrated effect of sex pheromone and insecticide in the control of SPW. Results indicated that the use of pheromone-baited traps placed at a density of 4 traps/0.1 ha reduced damage to tubers caused by SPW by 57-65%. Use of such traps in combination with the pre-planting application of Chlorpyrifos (Dursban) granules at 2.25 kg a.i./ha reduced damage to tubers by 62-75%. The effect was comparable to that from two applications of Chlorpyrifos (80-85%), one applied just before planting and the other at the time of earthing-up.

The pheromone trap may also be used as a tool for locating and monitoring the occurrence of SPW. Insecticide efficacy tests on SPW revealed that Chlorpyrifos was more effective and persistent than other tested insecticides. The application of insecticide before planting was more effective than application at the time of earthing-up. The use of pheromone-baited traps in the integrated management of SPW is estimated to save 1 to 3 applications of insecticide. This involves a saving of several hundred US dollars worth of insecticide per hectare. Therefore, the SPW sex pheromone appears to be a valuable component in the integrated management of SPW.

INTRODUCTION

Sweetpotato (*Ipomoea batatas* (L.)) is the seventh most important crop in the world (Jansson and Raman 1991). In Taiwan, the area planted in sweetpotato once ranked second only to paddy rice, as did the total yield. Sweetpotato is used as a food, as a feed and as an industrial crop, and more recently has come to be appreciated as a high-fiber food and green vegetable. It has good storage qualities, and both the tuber and the leaf meet the demand in modern society for natural and healthy foods. The total area of sweetpotato cultivated in Taiwan has remained steady at about 10,000 ha in recent years (Anonymous 1999).

The sweetpotato weevil (SPW), *Cylas formicarius* Fabricius, is the most destructive pest of sweetpotato, both in the field and in storage (Chalfant 1990; Hwang 1994; Sutherland 1986). SPW completes seven or eight generations each year in Taiwan (Yen *et al.* 1982). The adults prefer to live in the canopy of vines and leaves, feeding on all parts of the sweetpotato plant. Females oviposit within cavities excavated either in the stems or the tubers, where the larvae develop. Damage results from adults feeding, from the

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cavities excavated for oviposition, and from the tunneling of larvae through the tubers. Their tunnels are filled with excrement, which resembles sawdust. This gives the characteristic terpene odor and bitter flavor of infested sweetpotato that renders them unsuitable for human or livestock consumption (Jansson and Raman 1991).

Although various control measures have been practiced to reduce the damage caused by SPW, insecticide applications remain the main control method (Muruvanda *et al.* 1986; Sutherland 1986). Since the banning of chlorinated-hydrocarbon insecticides, it has been difficult to find alternative insecticides that are both safe and effective. The underground feeding habits of the larvae and nocturnal activity of the adults make it necessary for farmers to apply insecticide three to five times during the five or six months of the growing season, in order to obtain effective control of SPW. The rate of tuber damage caused by SPW is typically at least 18%, and sometimes reaches 88% in severely infested fields (Yen *et al.* 1982).

A sex pheromone, (Z)-3-dodecen-1-o1(E)-2-butenoate, has been identified as highly attractive to male weevils (Health *et al.* 1986). Traps baited with synthetic sex pheromone proved to be a promising tool for monitoring SPW (Proshold *et al.* 1986). We have also prepared a formulation of synthetic sex pheromone and developed a device for the mass trapping of male weevils which is effective, inexpensive, and easy to handle (Hwang 1988; Hwang *et al.* 1989; Hwang *et al.* 1991). The use of pheromone-baited traps, together with soil insecticides, in the integrated control of SPW on Penghu island and other prefectures of Taiwan, has given promising results (Hwang 1991; Hwang and Hung 1991; Talekar *et al.* 1989). This Bulletin gives an overview of current research in the formulation of pheromone lures, trap design, and the practical techniques of sex pheromone usage for the integrated control of SPW in Taiwan.

SYNTHETIC SEX PHEROMONE

Formulation and Pheromonal Bioactivity

A rubber septum has been used as the carrier to load SPW sex pheromone (Health *et al.* 1986), but its cost is about US$0.50. In order to develop cheaper and more effective sex pheromone lures, studies were conducted in the laboratory and in the field to compare the attractiveness and persistence of synthetic sex pheromones dispensed onto rubber septa and polyethylene (PE) microtubes with different doses, from 1 ug to 4 mg. Synthetic sex pheromone of SPW (purity > 90%) was provided by Professor Yen of the Department of Applied Chemistry, Providence University, Taichung, Taiwan (Yen and Hwang 1990).

Results showed that 1 mg of synthetic sex pheromone dispensed in PE microtubes had a stronger attractiveness than other types of lure (Table 1 and Table 2). The attractiveness of the formulation was more than ten times higher than the equivalent of 20 virgin females (Hwang *et al.* 1989), and the lure remained effective for more than two months (Table 3). Additionally, the cost of each PE microtube lure was only US$0.10, significantly cheaper than the rubber septum.

TRAP DESIGN AND HEIGHT

An aluminium funnel trap was developed for monitoring SPW with sex pheromone (Proshold *et al.* 1986). The trap was constructed from iron and aluminium materials, and cost more than US$12.0. In order to develop practical, effective and inexpensive traps, we used discarded polyethylene terephthalate (PET) soft-drink bottles, such as Coca-Cola bottles, to make a double funnel trap. The effectiveness of the bottle trap was compared to that of funnel traps made from wire mesh (similar to aluminum mesh) in sweetpotato fields (Fig. 1).

Results indicated that a double funnel PET bottle trap baited with 1 mg of synthetic sex pheromone formulated into a PE microtube could trap several thousand male weevils in a single day. It was as effective at collecting male weevils as the aluminum funnel trap (Table 4). The hand-made double funnel PET bottle trap costs only about US$0.10, and is now widely used by farmers in Taiwan. Recently, the design of the double funnel trap was patented in Taiwan and Mainland China. A commercially produced, double funnel plastic trap costs only US$1.50.

Table 1. Response of *C. formicarius* males to various formulations of synthetic sex pheromone in the turntable test in the laboratory[1]

Test	Lure	% of total males attracted[2]
1	1 ug in microtube	12.6 ± 4.7 d[3]
	10 ug in microtube	17.9 ± 3.2 c
	100 ug in microtube	23.0 ± 2.5 b
	1000 ug in microtube	39.6 ± 3.1 a
	20 virgin females	4.2 ± 1.0 e
	None (sweetpotato only)	2.5 ± 1.3 e
	Total males attracted	288.2 ± 224.5
2	1 mg in microtube	29.7 ± 4.4 a[3]
	2 mg in microtube	31.0 ± 1.7 a
	1 mg in rubber septum	14.2 ± 1.7 b
	2 mg in rubber septum	16.6 ± 1.7 c
	20 virgin females	4.6 ± 2.9 c
	None (sweetpotato only)	3.8 ± 1.1 c
	Total males attracted	319.0 ± 60.6

1) Five hundred 1 to 2-week-old male adults were released. Results were observed 24 hrs after release.
2) Mean ± S. D. derived from 6 and 4 trials for 1 and 2 tests, respectively.
3) Data were transformed to arc sine šx prior to analysis. Means followed by the same letters were not significantly different at a 5% level by DMRT.

Table 2. Response of *C. formicarius* males to various formulations of synthetic sex pheromone in the field

Test	Lure	% of total males attracted[1]
1	1 mg in rubber septum	33.5 ± 5.2 ab[2]
	2 mg in rubber septum	27.8 ± 6.5 b
	4 mg in rubber septum	38.6 ± 8.6 a
	20 virgin females	0.02 ± 0.02 c
	None (sweetpotato only)	0
	Total males attracted	29,471.0 ± 17,997.6
2	110 ug in microtube	34.7 ± 3.5
	1000 ug in microtube	65.3 ± 3.5 * [3]
	Total males attracted	21,228.3 ± 1,601.5

1) Mean ± S.D. derived from 4 and 3 trials for 1 and 2 tests, respectively.
2) Data were transformed to arc sine šx prior to analysis, and means followed by the same letters were not significantly different at a 5% level by DMRT.
3) Significant difference between means at a 5 % level by *t*-test.

Table 3. Persistence of synthetic sex pheromone of *C. formicarius*(1)

Lure age (months)	% of total males attracted(2)
0	29.4 ± 5.3 c
1	27.5 ± 5.4 c
2	12.1 ± 5.9 b
3	7.1 ± 3.4 ab
4	8.5 ± 3.4 ab
5	6.1 ± 2.3 a
20 virgin females	4.7 ± 1.5 a
None (sweetpotato only)	4.6 ± 2.8 a
Total males attracted	309.2 ± 31.4

1) Five hundred 1- to 2-week-old male adults were released. Results were observed 24 hrs after release.
2) Mean ± S. D. derived from 5 trials. Data were transformed to arc sine šx prior to analysis, and means followed by the same letters were not significantly different at a 5% level by DMRT.

In order to improve the trapping efficiency of the pheromone trap, a number of factors were studied in the field. These included trap color and size, lure and trap heights, slip helper (Polytetrafluoroetylene, PTFE) and insecticides that affect the capture of male weevils (Hwang and Hung 1992). Results showed that clear (transparent) PET bottle traps were more effective at capturing weevils than green-colored PET bottle traps. There was no significant difference in trapping efficiency between traps with funnel diameters of 8.8 cm to 12 cm.

However, lure and trap heights are very important factors in catching weevils. Traps with a pheromone lure 4 cm above the funnel caught significantly more male weevils than those traps with pheromone lures 0 cm or 8 cm above the funnels. No significant difference was found in trap catch when traps with the top of the funnel 4, 8 or 16 cm above the plant canopy were used.

We found that using the double funnel PET bottle traps with a DDVP-impregnated cotton strip placed at the bottom of the collecting bottle, and with a slip helper coated inside the collecting bottle, did not affect weevil capture and could prevent captured weevils from escaping. Proshold *et al.* (1986) have reported that no difference was found in the number of males captured with a funnel diameter varying from 5.5 to 25.5 cm. Traps with a metal funnel at the height of the sweetpotato canopy caught significantly more males than any other traps, but traps in which the top of the funnel was > 30 cm above the canopy had very poor capture rates.

EFFECTIVENESS OF THE PHEROMONE TRAP

The release-recapture method has been used to estimate the active distance and effectiveness of the pheromone trap (Hwang *et al.* 1989). Results indicated that the percentages of males recaptured in pheromone-baited traps at 5, 10, 20, and 40 meters away from the release point were 69.1, 10.7, 1.5 and 0.4%, respectively (Table 5). Therefore, the maximum active distance of SPW pheromone traps was estimated to be around 10-15 meters.

Total recapture rates varied according to ambient temperatures in different trials. They were lower (54.4%) when temperatures were less than 18°C, and higher (97.1%) when temperatures were 29°C or more (Table 5). In other words, total recapture rates increased with an increase in temperature. The linear regression between total recapture rate (Y) and temperature (X) was $Y = -12.366 + 3.463X$, $r= 0.941^{**}$ (Hwang *et al.* 1989).

INTEGRATED CONTROL OF SPW WITH SEX PHEROMONE AND INSECTICIDE

A field experiment was conducted in 1989 to evaluate the integrated effect of sex pheromone and insecticide in the control of SPW (Hwang and Hung 1991). We selected

A

C

B

D

Fig. 1. Three types of trap designs used to attract males of *C. formicarius.* A is the single funnel bottle trap, B is the double funnel bottle trap, and C is the netting funnel trap. D shows the mass of male adults trapped.

Table 4. Efficiency in trapping males of various trap designs baited with 1 mg synthetic sex pheromone of *C. formicarius*

Trap type [1]	% of total males captured[2]
Single funnel PET bottle trap	33.0 ± 5.1
Double funnel PET bottle trap	33.6 ± 7.5
Netting funnel PET bottle trap	33.4 ± 9.9 n.s.[3]
Total males captured	18,725.2 ±17,281.5

1) The various trap designs are the same as in Fig. 1.
2) Mean ± S. D. derived from 5 trials.
3) Data were transformed to arc sine šx prior to analysis, with no significant difference at a 5% level by DMRT.

Table 5. Trapping efficiency and active distance of funnel PET bottle trap baited with 1 mg of synthetic sex pheromone of *C. formicarius*

Trial no.	Temp. (°C)	% of males recaptured at various distances					No. of males released
		5m	10m	20m	40m	Total	
1	23.6	46.0	24.2	1.3	0.4	71.9	5,994
2	22.8	65.9	11.4	2.4	0.2	79.8	2,574
3	17.0	52.2	9.2	0.2	0.2	61.8	2,853
4	18.0	40.5	10.4	2.9	0.6	54.4	3,908
5	27.1	80.4	3.8	0.4	0.3	84.9	4,114
6	26.4	87.5	6.5	1.0	0.1	95.1	3,119
7	26.4	83.8	10.0	0.9	0.03	94.8	3,228
8	29.0	91.6	4.3	0.1	0.1	97.1	883
9	28.6	74.3	16.7	4.5	1.5	97.0	798
Average		69.1	10.7	1.5	0.4	81.9	3,052

four sweetpotato fields, each around one hectare in area, with a distance of 300 meters between each field. Four corner plots of 0.1 ha in each field received one of four treatments. (A) used pheromone-baited traps only; (B) used pheromone-baited traps and pre-planting application of Chlorpyrifos (Dursban) granules in the furrows; (C) received applications of Chlorpyrifos before planting and at the time of earthing-up; and (D) was the untreated control. The middle section of each field received three applications of Terbufos granules, an insecticide commonly used by farmers (as E treatment).

In pheromone-treated plots, four double funnel PET bottle traps baited with 1 mg of synthetic sex pheromone dispensed into PE microtubes were set in each 0.1 ha field for trapping male weevils throughout the period from planting to harvest. Traps were fixed with their tops about 10 cm above the sweetpotato canopy. Once a month, trapped male weevils were counted, pheromone lures were renewed, and each trap was rotated. In the plots where soil insecticide was used, Chlorpyrifos 5% granules were applied at a rate of 2.25 kg a.i./ha.

In order to detect the relative densities of weevils in plots which had received different treatments, pheromone-baited traps were set out two weeks before harvest at a rate of 4 traps/plot. The trapped male weevils were counted five days later. At the time of harvest, six sampling sites were randomly selected in each plot. Ten adjacent plants from each sampling site were examined for SPW injury to vines and tubers. The main vines were inspected 10 cm above the ground, and the level of plant damage was recorded. The tubers were then dug up, and numbers and weights of damaged and undamaged tubers were recorded. Tubers weighing less than 30 g were considered unmarketable and discarded. Percentages were subjected to arc sine šx transformation prior to an analysis of the variance.

Table 6 summarizes the results of integrated application of synthetic sex pheromone and insecticide in the control of SPW. Percentages of plants with vine damage ranged from 19.6% in plots treated with two applications of Chlorpyrifos (treatment C) to 32.1% in untreated plots

Table 6. The effect of integrated application of sex pheromone and insecticide on the control of *C. formicarius* in four fields in Taichung, Taiwan

Treat-ment[1]	% of plants damaged	% of tubers damaged Measured by number	Measured by weight	No. of tubers per 10 plants	Tuber weight per 10 plants	No. of weevils per trap
A	25.4 a[2]	5.4 a[2]	5.7 a[2]	28.6 a[2]	7.1 a[2]	22.5 a[2]
B	25.0 a	4.8 a	4.6 a	37.2 a	9.0 ab	13.8 a
C	19.6 a	2.5 a	3.0 a	38.9 a	8.3 ab	26.8 a
D	32.1 a	14.2 b	20.0 b	29.4 a	6.9 a	59.5 b
E	25.0 a	4.4 a	5.3 a	40.8 a	9.5 b	17.2 a

1) A: Use of pheromone-baited traps; B: Use of pheromone-baited traps and Chlorpyrifos (Dursban) before planting; C: Application of Chlorpyrifos before planting and at the time of earthing-up; D: Untreated control; and E: Conventional insecticide as applied by farmers.
2) Data were transformed to arc sine šx prior to analysis, and means within each column followed by the same letters were not significantly different at a 5 % level by DMRT.

(treatment D). However, levels of SPW infestation did not vary significantly among different treatment methods. On the other hand, the percentage of tubers damaged, whether based on number or weight, showed a significant difference between the pheromone and/or insecticide treatments and the untreated control. The untreated control showed the highest level of tuber damage, 14.2% by number and 20.0% by weight (Table 6).

The number of harvested tubers per 10 plants in different treatments ranged from 28.6 to 40.8. Total weight of tubers per 10 plants ranged from 7.1 to 9.5 kg (Table 6). There was no significant difference in the number or weight of tubers in plots with no treatment, compared to plots where pheromone traps and other treatments were used. Under the conditions of this study, weevil infestation did not appear to have much impact on the potential yield of sweetpotato. However, the weight of tubers was reduced significantly (27%) in the untreated plots, compared to the plots that received the conventional, relatively intensive application of Terbufos. It is also likely that even though weevil infestation did not reduce the yield (number and weight) of tubers, it did reduce their quality for human and livestock consumption.

During the entire growing season (April to October), we collected 1,547 to 21,722 male weevils from plots with pheromone-baited traps. We also collected 1,877 to 18,290 male weevils from plots treated with pheromone-baited traps and a pre-planting application of Chlorpyrifos. As shown in Table 6, the number of male weevils trapped from the untreated plots two weeks prior to harvest reached 59.5 weevils per trap. This was significantly higher than the number trapped in plots given treatments (13.8 - 26.8 weevils per trap).

In order to compare the efficacy of different treatments for the control of SPW, the percentage of damaged tubers (measured by number and weight) was converted to control rates as shown in Table 7. Control rates with pheromone-baited traps for the number and weight of tubers were 62.6 and 67.4%, respectively, with a mean of 65.0%. Control rates for B and E treatments averaged 75.4 and 71.0%, respectively. The control rate of SPW with 2 applications of Chlorpyrifos averaged 84.5%, the highest among the treatments but not significantly greater than the others.

The correlation between the parameters used to evaluate the efficacy of integrated control of SPW was also examined. Correlation coefficients between the parameters shown in Table 8 indicated a low positive correlation between the number of weevils trapped in pheromone traps, and SPW damage to various parts of the plant. Therefore, the pheromone trap may be used as a tool for locating and monitoring the occurrence of

Table 7. Percent control of *C. formicarius* obtained with different treatments in four fields in Taichung, Taiwan

Treatment[1]	Control (%)[2]		
	% tubers damaged (by number)	% tubers damaged (by weight)	Mean
A	62.6 a[3]	67.4 a[3]	65.0
B	70.5 a	80.3 a	75.4
C	83.3 a	85.7 a	84.5
D	0	0	0
E	69.7 a	72.3 a	71.0

1) A: Use of pheromone-baited traps; B: Use of pheromone-baited traps and Chlorpyrifos before planting; C: Application of Chlorpyrifos before planting and at the time of earthing-up; D: Untreated control; and E: Conventional insecticide as applied by farmers.
2) Percent control = (% damage in check - % damage in treatment) ÷ % damage in check x 100%.
3) Data were transformed to arc sine šx prior to analysis, and means within each column followed by the same letters were not significantly different at a 5% level by DMRT.

Table 8. Correlation coefficients for parameters used in evaluation of the control of *C. formicarius* in four fields in Taichung, Taiwan

Evaluated measure (X)	Evaluated measure (Y)[1]				
	% of plants damaged	% of tubers damaged (by number)	% of tubers damaged (by weight)	No. of tubers per 10 plants	Tuber weight per 10 plants
No. of weevils trapped	-0.03	0.17	0.28	-0.18	-0.28
% of plants damaged	-	0.72*	0.62**	-0.64**	-0.32
% of tubers damaged (by no.)	-	-	0.96**	-0.56*	-0.31
% of tubers damaged (by wt.)	-	-	-	-0.48*	-0.27
No. of tubers per 10 plants	-	-	-	-	0.69**

1) The marks "*" and "**" indicate significant correlations at the 5 and 1% levels, respectively.

SPW, but the trap catch alone is not a good predictor of SPW infestation.

Based on the analysis of correlation coefficients, the number of weevils trapped together with the rates of SPW damage to vines and tubers could be used as an index of SPW infestation. However, after considering the ease and accuracy of sampling, we recommend the rate of tuber damage by number as the preferred index of SPW infestation level in sweetpotato.

Similar experiments were conducted in seven village fields in different parts of Taiwan, to ascertain the efficacy of pheromone-baited traps to suppress SPW infestation (Hwang 1991). The results, shown in Table 9, were much the same as those from the earlier experiment. Control rates with pheromone-baited traps (Treatment A) in seven village fields, based on the level of tuber damage, were 56.9% by number and 56.9% by weight, with a mean of 56.9% (Table 10). Control rates for B (use of pheromone-baited traps and Chlorpyrifos before planting) and C (application of Chlorpyrifos before planting and at the time of earthing-up)

Table 9. The effect of integrated application of sex pheromone and insecticide on the control of *C. formicarius* in 7 village fields in Taiwan

Treatment[1]	% of plants damaged	% of tubers damaged: Measured by number	% of tubers damaged: Measured by weight	No. of tubers per 10 plants	Tuber weight per 10 plants	No. of weevils per trap
A	14.0 b[2]	5.3 ab[2]	5.3 a[2]	51.5 a[2]	9.1 a[2]	1,046
B	8.8 ab	4.7 ab	4.8 a	51.8 a	8.5 a	954 n.s.[3]
C	6.4 a	2.4 a	2.6 a	55.6 a	9.8 a	-
D	23.6 c	12.3 b	12.3 b	50.3 a	7.9 a	-
E	14.5	9.1	7.9	37.7	5.7	-

1) A: Use of pheromone-baited trap; B: Use of pheromone-baited traps and Chlorpyrifos (Dursban) before planting; C: Application of Chlorpyrifos before planting and at the time of earthing-up; D: Untreated control; and E: Conventional insecticide as applied by farmers.
2) Data were transformed to arc sine šx prior to analysis, and means within each column followed by the same letter were not significantly different at a 5 % level by DMRT.
3) No significant difference between means at a 5% level by *t*-test

Table 10. Percent control of *C. formicarius* obtained with different treatments in 7 village fields in Taiwan

Treatment[1]	Percent control (%)[2]: % tubers damaged by number	% tubers damaged by weight	Mean
A	56.9a[3]	56.9a[3]	56.9
B	61.8a	61.0a	61.4
C	80.5ab	78.9a	79.7
D	0	0	0
E	26.0	35.8	30.9

1) A: Use of pheromone-baited trap; B: Use of pheromone-baited traps and Chlorpyrifos before planting; C: Application of Chlorpyrifos before planting and at the time of earthing-up; D: Untreated control; and E: Conventional insecticide as applied by farmers.
2) Percent control = (% damage in check - % damage in treatment) ÷ % damage in check x 100%.
3) Data were transformed to arc sinc šx prior to analysis, and means within each column followed by the same letters were not significantly different at a 5% level by DMRT.

treatments averaged 61.4 and 79.7%, respectively. There was no significant difference in control rate between the three treatments (Table 10).

The correlation between the parameters used to evaluate the efficacy of integrated control of SPW in these 7 village fields was examined, and showed the same results as the earlier experiment. Based on an analysis of correlation coefficients (Table 11), we still recommend the number of damaged tubers as the preferred index of SPW infestation levels in sweetpotato.

The efficacy of using sex pheromone for the mass-trapping of male adults to suppress insect pests on crops is a controversial question. The results presented here indicate that the use of pheromone-baited traps in the field was effective in trapping male weevils. Furthermore, it reduced tuber damage by 57-65% relative to untreated plots, where tuber damage ranged from 12.3 to 20%.

Some male weevils will avoid pheromone-baited traps, while other insect pests will also infest sweetpotato after planting. In this study, the integrated

Table 11. Correlation coefficients for parameters used in evaluation of the control of *C. formicarius* in 7 village fields in Taiwan

Evaluated measure (X)	Evaluated measure (Y)[1]			
	% of tubers damaged by no.	% of tubers damaged by wt.	No. of tubers per 10 plants	Tuber weight per 10 plants
% of plant damage	0.92**	0.96**	-0.33	-0.37
% of tuber damage (by no.)	-	0.92**	-0.61	-0.66
% of tuber damage (by wt.)	-	-	-0.26	-0.31
No. of tubers per 10 plants	-	-	-	0.99**

1) The marks "*" and "**" indicate a significant correlation at the 5 and 1% level, respectively.

Table 12. Difference in cost of sex pheromone traps to control *C. formicarius*, compared to cost of insecticide (US dollars per ha)

No. of applications	Sex pheromone cost (US$) lure + trap = total (hand made)[1]	Insecticide cost (US$)	Difference (US$)
1	0.1 x 40 x 3 + 1.5 x 40 = 72 (0.1)[1] (16)[1]	173	-101 (-157)[1]
2	same as above	346	-274 (-330)
3	same as above	519	-447 (-503)

1) Hand-made traps were used.

application of pheromone-baited traps and Chlorpyrifos granules before planting resulted in 61.4 - 75.4% control of SPW. This method is recommended as giving effective and safe control of SPW in association with other cultural practices. These include

- Crop rotation;
- Planting of SPW-free cuttings (by dipping cuttings in insecticide solution);
- Flooding of fields before planting;
- Removal of crop residues and alternate hosts;
- Earthing-up of vines (filling in soil cracks);
- Irrigation, *and*
- Prompt harvesting four to five months after planting (Chalfant 1990; Hwang 1994; Hwang and Hung 1992; Sutherland 1986; Talekar *et al.* 1989).

The cost of one pheromone lure is about US$0.10. The cost of a commercialized double funnel plastic trap is about US$1.50, but a trap costs less than US$0.10 if it is made from discarded soft-drink bottles. When pheromone-baited traps are used in the integrated management of SPW, it is estimated that a saving of 1 to 3 applications of insecticide is achieved, compared to conventional control measures used by farmers. This will save several hundred US dollars in insecticide expenditure per hectare (Table 12).

EFFECTIVENESS OF INSECTICIDES

In the laboratory, the comparative toxicity and persistence of some commonly used insecticides were tested by mixing them into a sandy loam soil infested with SPW adults (Hwang and Hung 1992, Hwang and Hung 1994). Results showed that

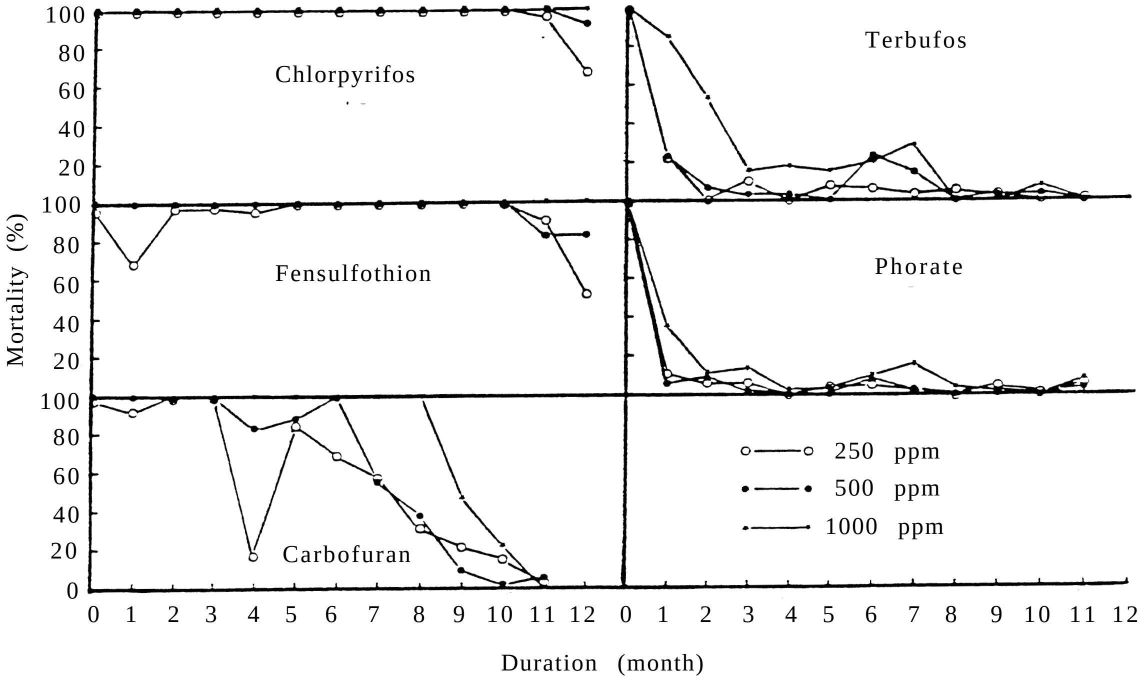

Fig. 2. Comparative toxicity and persistence of some commonly used insecticides mixed with soil against *C. formicarius* adults.

Table 13. Efficacy of various soil insecticides in control of *C. formicarius* on sweet potato

Insecticide & rate	(a.i./ha)[1]	% tuber damage[2]	% of control
Chlorpyrifos 5 % G.	2.25 kg	6.1 a	76.8
Fensulfothion 5 % G.	3.0 kg	12.8 ab	51.3
Phorate 10 % G.	4.0 kg	14.5 ab	44.9
Carbofuran 3 % G.	1.2 kg	16.1 abc	38.8
Terbufos 10 % G.	3.0 kg	16.3 bc	38.0
Untreated control		26.3 c	0

1) Insecticides were applied twice, before planting and at the time of earthing-up.
2) Mean derived from 6 replicates. Data were transformed to arc sine šx prior to analysis, and means followed by the same letters were not significantly different at a 5% level by DMRT.

Chlorpyrifos and Fensulfothion granules were more toxic to SPW adults than the other insecticides tested, while their persistence was about ten months in the laboratory (Fig. 2). Carbofuran granules were of medium toxicity to SPW adults and had a persistence of about six months. Terbufos and Phorate granules were less toxic to SPW adults, and their persistence was only one or two months (Fig. 2). We also found that a moisture content of 5-15% and a pH value of between 4 and 8 in sandy loam soil does not influence the toxicity of insecticide to SPW adults, although it was reduced if the soil had a zero moisture content.

Sunshine does not affect the efficacy of Chlorpyrifos, Fensulfothion, or Carbofuran against SPW adults, but may decrease the efficacy of Terbufos and Phorate (Hwang and Hung 1992, Hwang and Hung 1994).

Table 14. Efficacy of different doses and application methods of Chlorpyrifos 5% granules in control of *C. formicarius* on sweetpotato

Treatment	% tuber damage[1]	% of control
A. 4.5 kg a.i./ha applied before planting	8.5 a	81.3
B. 2.3 kg a.i./ha applied before planting	31.4 a b	30.8
C. 2.3 kg a.i./ha applied on earthing-up	33.2 a b	26.9
D. B + C	22.8 a b	49.8
E. Untreated control	45.4 b	0

1) Mean derived from 5 replicates. Data were transformed to arc sinc šx prior to analysis, and means followed by the same letters were not significantly different at a 5% level by DMRT.

In sweetpotato fields, five insecticides were tested for the control of SPW. Each insecticide was applied twice to the soil, once before planting and again at the time of earthing-up (Hwang and Hung 1994). Results showed that Chlorpyrifos 5% granules, applied at a rate of 2.25 kg a.i./ha, resulted in a lower proportion of damaged tubers and a higher control rate (76.8%) than the other insecticides tested (Table 13). The level of control provided by Fensulfothion, Phorate, Carbofuran and Terbufos was 51.3, 44.9, 38.8 and 38.0%, respectively. We also found that the timing and dose of insecticide applications could affect their efficacy. When Chlorpyrifos 5% granules were applied at a rate of 4.5 kg a.i./ha (double the recommended dose), but applied only once (before planting), the control rate was higher (81.3%) than that of other treatments (Table 14). This insecticide application method not only promotes insecticide efficacy, but also saves the labor cost of a second insecticide application.

CONCLUSION

Research into the use of the sex pheromone of *C. formicarius*, including isolation, identification, synthesis, pheromone formulation, trap design, and practical application techniques, is well advanced, and has great potential for improving current SPW management programs. The pheromone can be used for surveying, monitoring and mass trapping. The use of sex pheromone can also be easily combined with insecticides and other control measures into an integrated SPW management program.

In this study, the efficacy of the integrated application of pheromone-baited traps and insecticides to suppress SPW infestation has been successfully demonstrated. Therefore, the sex pheromone of SPW appears to be a valuable component in IPM programs against this pest. Integrating the sex pheromone with other management tactics, especially cultural and biological controls, offers even better control and should be studied further.

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