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BUREAU OF SUGAR EXPERIMENT STATIONS
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FINAL REPORT
CONTROL OF SOLDIER FLY WITH CONTROLLED-RELEASE INSECTICIDES

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1.0 SUMMARY

The activity of controlled-release granules against soldier fly larvae was evaluated in laboratory bioassays. Five different active ingredients were tested in a range of granule sizes. The product selected as the most effective varied depending on the time which had elapsed after mixing with the soil. For most compounds, smaller granules were more active in the short term but lost activity more rapidly than the larger granules. Rates of loss of activity during incubation varied between active ingredients. Granules containing carbofuran and carbosulfan showed increased activity during the first year. The most active products in soil after 0, 1 and 2 years were phorate 2 mm granules, carbofuran 1 mm granules, carbofuran 1.5 mm granules and tefluthrin 1 mm granules, respectively.

Nine field trials using 2 mm chlorpyrifos granules (14%, suSCon Blue), 1 mm chlorpyrifos granules (10%, suSCon Green) or 1.5 mm phorate granules (10%, suSCon FuMing) were sampled for soldier fly. Results show that chlorpyrifos granules will not control soldier fly. Any efficacy of granules containing phorate was short-lived and not detected in larval numbers > 1 year after application. No residues were detected in cane juice 5-8 months after phorate granules were applied at 4 kg ai ha^{-1}.

2.0 RECOMMENDATIONS

(1) Carry out no further work on chlorpyrifos-based granules.

(2) Set up bioassays of any new commercial products developed in the canegrub program.

(3) Set up field trials with additional products that have greater activity in bioassays than chlorpyrifos-based granules and a longer residual life than phorate-based granules. Of products bioassayed so far, only carbofuran seems worth pursuing further.

3.0 INTRODUCTION

The use of controlled-release insecticides is one strategy being considered for control of soldier fly in sugarcane. Work has proceeded in two phases.

Candidate materials varying in active ingredient and granule size were evaluated in laboratory bioassays. Choice of candidates was guided by discussion with Crop Care. In particular, we concentrated on products already being produced commercially and sold locally or overseas.

Likely products for soldier fly control were then tested in field trials. Trials used suSCon Blue, smaller (1 mm) granules of suSCon Green, and 1.5 mm granules of phorate (suSCon FuMing).

All laboratory bioassays and field trials are complete. This final report summarises the results and makes recommendations for further work.

4.0 MATERIALS AND METHODS

4.1 Laboratory bioassays

Laboratory bioassays were set up in two series, one in 1991 and the other 1992. Insecticides tested in 1991 were suSCon Blue; chlorpyrifos (10%, Product code G01014) in 1, 1.5 and 2 mm granules; carbofuran (15%, Product code G03009) in 1 and 1.5 mm granules; and tefluthrin (3%, Product code G28001) in 1 and 1.5 mm granules. Insecticides tested in 1992 were chlorpyrifos (10%, Product code G01014) in 2 mm granules; carbosulfan (10%, Product code G04005) in 1, 1.5 and 2 mm granules; and phorate (10%, Product code G11002) in 1, 1.5 and 2 mm granules.

Granules were mixed with 400 g of sieved red volcanic (krasnozem) soil (24% moisture content 1991, 23% moisture content 1992, dry-weight basis) on an aluminium tray and transferred to a plastic cup. Cups were incubated at 25°C. Water was added every three months to restore the weight to the original level.

Soil was treated at four insecticide concentrations from 20-160 mg ai kg^{-1} in 1991 and at five concentrations from 10-160 mg ai kg^{-1} in 1992. Each cup served as a replicate. Sufficient cups were set up to allow bioassays of each concentration on three occasions, with three replicates. Cups containing untreated soil were set up as controls.

Soil was bioassayed by adding 20 soldier fly larvae to each cup without disturbing the treated soil. Larvae used to bioassay the 1991 series weighed 22 mg on average at the first bioassay ("0 years", ie 4 weeks after granules were added to soil), 20 mg at the second (1 year) and 22 mg at the third (2 years). Larvae used to bioassay the 1992 series weighed 26 mg on average at "0 years" (ie 6 weeks after granules were added), 21 mg at 1 year and 24 mg at 2 years.

Larvae were removed from the soil after 4-5 weeks and assessed as live or dead. Misshapen or discoloured larvae were classified as dead. The number dead in treated soil was corrected for control mortality by Abbott's formula. Log dose-response regressions were calculated by the probit method using MLP 3.06(NAG).

4.2 Field trials

Trials were set up using either commercial suSCon Blue (14% chlorpyrifos), 1 mm granules of suSCon Green (10% chlorpyrifos), or 1.5 mm granules of suSCon FuMing (10% phorate). A list of trials is given in Table 1.

Six complete trials were set up with a range of application rates and placements in randomised complete-block designs. Three additional trials were primarily variety trials, as part of SRDC Project BS61S, with five bands of insecticide treatment across each trial area and 10 plots containing different varieties planted within each treatment. In two of these additional trials (BS61S-1 and BS61S-3), Temik (aldicarb) was also applied annually with coulters to the suSCon-treated plots, at a nominal rate of 2.5 kg ai ha^{-1}, in an attempt to provide additional soldier fly control. Plot size in all trials was a minimum of 4 rows by 10 m, with at least five replications.

For "at-planting" applications in most trials, cane setts were uncovered by hand within a few days of planting. Granules were spread in a band about 20 cm wide and covered with at least 5 cm of soil. In the trial using CR-phorate, however, granules were applied during planting using a cone-seeder. For fill-in applications, granules were spread in the drill to a total band width of about 20 cm and then immediately covered with soil by mechanical cultivation.

Trials were sampled for soldier fly larvae in the middle rows of each plot. Samples comprised four soil cores (6.5 cm diam. x 20 cm deep) or two spade samples (each 1370 cm^3) taken beside cane stools, or the whole root mass of single stools, depending upon crop age and soil conditions. Larvae were wet-sieved from the samples using a 1 mm screen and counted.

Cane samples were taken on 27 May 1993 from trial ES92-12 for analysis of phorate residues. Samples were taken from plots treated with 4 kg ai ha^{-1} and from untreated plots. Four stalks were cut from each plot and combined over replicates. Leaves were cut from the stalks and subsampled after shredding in a cutter-grinder. Stalks were fed through a cutter-grinder and shredded samples (about 1 kg) were pressed at 200 bars pressure for three minutes. Resulting juice and fibre samples were subsampled as necessary. All samples were stored frozen until dispatched in dry ice to the analytical laboratory (Analchem Consultants Pty Ltd) on 1 June 1993.

5.0 RESULTS

5.1 Laboratory bioassays

All bioassay activities discussed refer to the amount of active ingredient, not to the product.

In the 1991 series of bioassays (Fig. 1), 2 mm granules of chlorpyrifos had very similar activity in both suSCon Blue (14%) and suSCon Green (10%) formulations. Activity of these granules was constant over 2 years incubation. The 1.5 mm and 1 mm granules of chlorpyrifos were more active than the 2 mm granules when first mixed with soil. However, these smaller granules lost activity sooner than the 2 mm size, with the 1 mm granules showing appreciable loss of activity within 1 year and the 1.5 mm granules within 2 years. Although the 1 mm granules were the most effective size at 0 years, they were the least effective after 2 years.

Carbofuran granules at 0 years had lower activity than chlorpyrifos granules of the same size. However, the activity of carbofuran granules had increased greatly after 1 year so that they were much more active than chlorpyrifos. Activity of the 1 mm granules then declined markedly in the second year. The 1 mm granules of carbofuran were more active than the 1.5 mm granules at both 0 and 1 years but were much less active after 2 years.

Tefluthrin granules were the most active of any tested at 0 years. After 1 and 2 years, the activity of tefluthrin was similar to the 0 years measurement.

In the 1992 series of bioassays (Fig. 2), the activity of 2 mm chlorpyrifos granules was similar to that measured in the 1991 series (Fig. 1). This indicates that results can be compared between the two series.

The activity of carbosulfan granules at 0 years increased as granule size decreased (Fig. 2). Their activity was relatively low at 0 years but increased after 1 year with the smallest granules still the most active. By 2 years, however, the smallest granules had lost substantial activity and there was little difference between the three sizes. Carbosulfan granules were less active than carbofuran granules of the same size after equal incubation periods (compare with Fig. 1).

Phorate granules showed very high activity in all sizes at 0 years (Fig. 2). The larger granules were more active than the smaller ones, which was the reverse of the effect observed with other products. Phorate granules lost activity rapidly within 1 year of mixing with soil. After 2 years, the LC_{50} for phorate was much greater than the highest applied concentration of 160 mg ai kg^{-1}.

5.2 Field trials with suSCon Blue

In trial ES90-20, the total number of soldier fly (live larvae, pupae and pupal cases) in April 1992 was significantly greater where suSCon Blue had been used at fill-in than in untreated plots (Table 2). However, subsequent counts of the new generation of larvae in July and December 1992 and of larvae, pupae and pupal cases in April 1993 showed no effect of suSCon application (Table 2). Granules recovered in April 1992, 1.3 years after application, contained 9% chlorpyrifos based on dry weight.

Numbers of soldier fly remained low in two other trials of suSCon Blue applied at different times (ES91-6 and ES91-12, Table 3). There was no indication that suSCon Blue was controlling soldier fly in these trials. About 4% chlorpyrifos remained in the granules ≥2 years after application (Table 8).

In a fourth trial, no difference was found between numbers of soldier fly larvae in untreated plots or plots treated with suSCon Blue at 6 kg ha^{-1} at fill-in, despite intensive sampling (BS61S-1, Table 7). The amount of chlorpyrifos remaining in the granules was 2.7%, 2 years after application (Table 8).

5.3 Field trials with 1 mm suSCon Green

Substantial numbers of larvae were present in trial ES91-19 in January 1994, a little more than 2 years after planting (Table 4). There was no difference in larval numbers between treatments. A small larval population was present in January 1994 in trial ES92-3, which was planted a year later than ES91-19, and again there was no apparent effect of insecticide application (Table 4). The concentration of chlorpyrifos in granules from ES91-19 had fallen to < 2%, 2 years after application (Table 8). An unusually low residue was measured in granules applied at planting in ES92-3, 1.4 years after application (Table 8); the reason for this is unknown.

Heavy soldier fly infestations developed within 2-3 years of application of 1 mm suSCon Green at 6 kg ha^{-1} at fill-in in two other trials (BS61S-2 and BS61S-3, Table 7). The insecticide had no effect on larval numbers in any year. The residual concentration of chlorpyrifos had declined to 1.3% after 2 years in both trials (Table 8).

5.4 Field trial with suSCon FuMing

Trial ES92-12 was sampled in April 1993, but only six larvae were found in total with a whole stool dug from each of 42 plots (Table 5). Larvae were present in treated plots. A larger larval population was present in March 1994, with no difference in numbers between treatments (Table 5). Phorate had disappeared from the granules by December 1993, ≥ 1 year after application (Table 8).

No residues of phorate were detected in cane 5-8 months after granule application (Table 6). Traces of phorate oxygen analogue were found in some of the leaf and fibre samples and also in the fibre control. No residues were detected in samples of juice.

6.0 DISCUSSION

All active ingredients tested in controlled-release form had high toxicity to soldier fly larvae in previous bioassays of conventional formulations (Samson 1992). Carbofuran was probably the most active. Carbosulfan was slightly less active than carbofuran, which would be expected from its mode of action.

Except for phorate, smaller controlled-release granules were more active than larger granules shortly after mixing with soil in bioassays. This may reflect both a greater probability of contact between larvae and the greater number of smaller granules, and a more rapid release of active ingredient. Smaller granules then lost activity more rapidly during incubation, and after two years were in some cases less active than the larger granules.

Carbofuran and carbosulfan granules, of all sizes, increased in activity after one year incubation, suggesting slow initial release of active ingredient.

Phorate granules had very high initial activity but low activity after one year, suggesting very rapid release and subsequent depletion of the active ingredient. In a field trial of this product, phorate was lost from granules within one year of application to soil.

Tefluthrin granules had high activity in bioassays, expressed as amount of active ingredient. Tefluthrin had the lowest percentage active ingredient of the products tested, and so had the greatest number of granules present for equal concentration in the soil. Expressed as amount of product, the activity of tefluthrin granules after 2 years incubation was similar to that of suSCon Blue and was much lower than that of 1.5 mm carbofuran granules.

The standard canegrub treatment, suSCon Blue, did not control soldier fly in field trials despite application rates up to 6 kg ai ha^{-1}. An apparent increase in the number of soldier fly larvae after application of suSCon Blue in trial ES90-20, when the trial was first sampled in April 1992, was not repeated in subsequent sampling. The poor performance of suSCon Blue in trials could not be explained by the content of active ingredient remaining in the granules, which seemed satisfactory.

Smaller (1 mm) chlorpyrifos granules had greater activity than suSCon Blue in the short term in bioassays. However, this product was also ineffective in field trials. Residue analyses indicated that chlorpyrifos was lost from the granules more quickly than from standard suSCon Blue. The 1 mm granules probably have a useful life of less than 2 years. Application of the small granules had no appreciable effect on soldier fly numbers even within this time period.

Phorate granules had very high initial activity in bioassays. In the field trial of this product, only a small number of larvae were found in samples taken less than one year after treatment. However, some larvae were found in the treated plots. No control of larvae was evident in samples taken the following year. The active ingredient had been lost by that time, but these larvae would have been present in the field for many months. Soldier flies have a generation time of at least one year and mostly oviposit in autumn. Larvae collected in the second samples would have hatched from eggs by June 1993, only 6-9 months after phorate treatment. Phorate was apparently unable to control these small larvae.

We compared the concentrations of insecticide in field trials and in our bioassay cups. A field application rate of 4 kg ai ha^{-1} was chosen for comparison, as this or a higher rate was used in all trials. An application rate of 4 kg ai ha^{-1} in field trials equals a concentration of 3 g ai m^{-2} within a treated band of width 20 cm in each row of sugarcane (row spacing = 150 cm). In our bioassay, cups with a surface area of 79 cm^2 correspond to 24 mg ai in total or 59 mg ai kg^{-1} of soil. Values of LC_{50} for every bioassayed insecticide were below this concentration on at least some occasions (Figs 1-2). There is potential for all of the tested products to have had some effect on soldier fly larvae in field trials. Their lack of efficacy in the field suggests that larvae did not contact the granules as frequently as in bioassays. This may indicate inappropriate placement, although field treatments were designed to avoid this (see below). Alternatively, larvae may move less in the field and so have a lower probability of contact with granules, in comparison with bioassays. Larvae travelled extensively in the bioassay cups, as shown by their tunnels in the soil. No roots were available as food in bioassays, and larval movement may be reduced when living roots are present.

Soldier fly larvae are concentrated along rows of sugarcane (Samson and McLennan 1992) so application of granules only within rows is appropriate for control. Application times were varied in field trials to determine the best depth of granules for contact with larvae. Application at planting placed the granules near the level of the planting pieces (setts); it is usual for control of most canegrubs in sugarcane and is convenient for growers. However, soldier fly larvae are mostly found within 15 cm of the soil surface (Samson and McLennan 1992) and are usually above sett level. Application at fill-in placed the granules closer to the surface than application at planting. The split application placed some granules in both positions. However, none of these application methods was successful.

In summary, the results of field trials show that controlled-release granules containing chlorpyrifos will not control soldier fly. Phorate granules have much higher potency than chlorpyrifos granules in the short term (≤ 1 year). In the field trial of this product, we could not draw a conclusion on initial activity; however, any efficacy was lost within 1 year of application. Efficacy beyond one year would be most desirable in any controlled-release product.

7.0 REFERENCES

Samson P.R. (1992) Laboratory bioassays of insecticides against larvae of the sugarcane soldier fly, *Inopus rubriceps* (Macquart) (Diptera: Stratiomyidae). *Plant Protection Quarterly* **7:** 117-120.

Samson P.R. and McLennan P.D. (1992) Distribution of larvae of *Inopus rubriceps* (Diptera: Stratiomyidae) around sugarcane plants. *Journal of Economic Entomology* **85:** 2185-2193.

TABLE 1

Controlled-release trials against soldier fly

Trial	Insecticide	Description of trial
ES90-20	suSCon Blue	2, 3, 4 kg ai ha^{-1} at fill-in (19/12/90)
ES91-6	suSCon Blue	3, 4, 6 kg ai ha^{-1} at planting (11/4/91) and fill-in (4/7/91)
ES91-12	suSCon Blue	3, 4, 6 kg ha^{-1} at planting (3/9/91), fill-in (26/11/91), and split
ES91-19	suSCon Green 1 mm	3, 4, 6 kg ai ha^{-1} at planting (10/10/91), fill-in (17/12/91), and split
ES92-3	suSCon Green 1 mm	3, 4, 6 kg ai ha^{-1} at planting (17/8/92), fill-in (8/12/92), and split
ES92-12	suSCon FuMing	1, 2, 4 kg ai ha^{-1} at planting (29/9/92) and fill-in (7/12/92)
BS61S-1	suSCon Blue	6 kg ai ha^{-1} at fill-in (26/11/91)
BS61S-2	suSCon Green 1 mm	6 kg ai ha^{-1} at fill-in (24/1/92)
BS61S-3	suSCon Green 1 mm	6 kg ai ha^{-1} at fill-in (4/12/91)

TABLE 2

Number of soldier fly per four-core sample ($\bar{x}$ ±se) in trial ES90-20, treated with suSCon Blue at fill-in of the planting drill

Rate kg ai ha^{-1}	8/4/92[1]	16/7/92	18/12/92	20/4/93[1]
0	3.4 ± 1.1 b	7.7 ± 1.6	15.7 ± 4.1	7.3 ± 1.2
2	12.3 ± 3.3 a	12.0 ± 2.8	20.0 ± 2.4	7.4 ± 2.5
3	7.6 ± 1.2 a	10.1 ± 2.8	16.7 ± 4.3	5.3 ± 0.8
4	13.4 ± 1.6 a	14.3 ± 4.1	21.7 ± 4.7	8.3 ± 1.9
P (ANOVA)	<0.001	0.30	0.57	0.64

[1] Includes pupae and pupal cases

Means followed by the same letter were not significantly different at the 5% level of lsd

TABLE 3

Number of living soldier fly larvae ($\bar{x}$ ±se) in two trials treated with suSCon Blue at two different times. Larval samples comprised two spade samples in 1993 and four cores in 1994

Application time	Rate kg ai ha^{-1}	ES91-6 16/2/94	ES91-12	
			3/3/93, 19/4/93	18/3/94
Untreated	0	0.0	0.4 ± 0.2	0.0
Planting	3	0.4 ± 0.4	0.3 ± 0.2	0.0
	4	0.0	0.1 ± 0.1	0.6 ± 0.6
	6	0.4 ± 0.4	0.2 ± 0.2	0.6 ± 0.4
Fill-in	3	0.2 ± 0.2	0.2 ± 0.1	0.2 ± 0.2
	4	0.6 ± 0.4	0.0 ± 0.0	0.4 ± 0.4
	6	0.2 ± 0.2	0.2 ± 0.1	0.2 ± 0.2
Split	3	-	0.3 ± 0.2	0.2 ± 0.2
	4	-	0.3 ± 0.2	0.8 ± 0.6
	6	-	0.3 ± 0.2	0.0
P (ANOVA)		0.75	0.38	0.70

TABLE 4

Number of living soldier fly larvae ($\bar{x}$ ±se) in two trials treated with 1 mm suSCon Green at two different times. Larval samples comprised two spade samples in ES91-19 and four cores in ES92-3

Application time	Rate kg ai ha^{-1}	ES91-19 25/1/94	ES92-3 18/1/94
Untreated	0	2.0 ± 0.8	0.6 ± 0.6
Planting	3	3.2 ± 1.6	0.2 ± 0.2
	4	1.0 ± 0.6	0.0
	6	2.8 ± 1.3	0.2 ± 0.2
Fill-in	3	3.0 ± 1.1	0.2 ± 0.2
	4	3.4 ± 1.8	3.2 ± 3.2
	6	4.8 ± 1.4	0.2 ± 0.2
Split	3	3.6 ± 2.4	0.2 ± 0.2
	4	3.6 ± 1.5	1.2 ± 1.2
	6	5.0 ± 2.8	0.2 ± 0.2
P (ANOVA)		0.88	0.93

TABLE 5

Number of living soldier fly larvae ($\bar{x} \pm se$) in trial ES92-12 treated with suSCon FuMing at two different times. Larval samples comprised one stool in 1993 or four cores in 1994

Application time	Rate kg ai ha^{-1}	1/4/93	11/3/94, 25/3/94
Untreated	0	0.2 ± 0.2	1.0 ± 0.4
Planting	1	0.0	0.8 ± 0.3
	2	0.2 ± 0.2	1.3 ± 0.5
	4	0.2 ± 0.2	1.0 ± 0.4
Fill-in	1	0.2 ± 0.2	1.5 ± 0.7
	2	0.0	1.3 ± 0.5
	4	0.3 ± 0.2	1.9 ± 0.7
P (ANOVA)		0.67	0.93

TABLE 6

Residues of phorate in sugarcane taken from trial ES92-12 on 27/5/93 (from Analchem Bioassay Report 93/2548)

Fraction	Treatment (kg ai ha^{-1})	Phorate (mg kg^{-1})	Phorate oxygen analogue (mg kg^{-1})
Leaves	Untreated	NDR	NDR
	4 at planting	NDR	NDR
	4 at fill-in	NDR	0.03
Juice	Untreated	NDR	NDR
	4 at planting	NDR	NDR
	4 at fill-in	NDR	NDR
Fibre	Untreated	NDR	0.02
	4 at planting	NDR	0.02
	4 at fill-in	NDR	0.03

NDR: no detectable residues
Limit of detection (phorate and POA):juice 0.005 mg kg^{-1}; leaves and fibre 0.02 mg kg^{-1}

TABLE 7

Number of living soldier fly larvae per four-core sample ($\bar{x} \pm se$) collected in autumn-winter from each of 50 plots untreated or treated with suSCon Blue or suSCon Green (1 mm) at 6 kg ai ha^{-1} during fill-in

Year	suSCon Blue BS61S-1		suSCon Green BS61S-2		suSCon Green BS61S-3	
	0 kg	6 kg	0 kg	6 kg	0 kg	6 kg
1992	0.00	0.00	0.40±0.14	0.14±0.05	0.50±0.14	0.24±0.07
1993	0.58±0.15	0.64±0.16	1.94±0.26	2.78±0.40	1.36±0.30	1.02±0.17
1994	0.90±0.20	1.22±0.28	3.69±0.56	4.61±0.65	6.52±1.02	7.52±0.81

Means in each trial in each year were not significantly different between treatments ($P = 0.05$)

TABLE 8

Residual active ingredient in controlled-release granules collected from trials during December 1993-February 1994

Product	Trial	Application timing	Years since application	% ai remaining (dry basis)
suSCon Blue	ES91-6	Planting	2.7	4.3
		Fill-in	2.4	4.0
	ES91-12	Planting	2.3	3.8
		Fill-in	2.0	4.6
	BS61S-1	Fill-in	2.0	2.7
suSCon Green, 1 mm	ES91-19	Planting	2.2	1.3
		Fill-in	2.0	1.7
	ES92-3	Planting	1.4	0.8
		Fill-in	1.1	4.2
	BS61S-2	Fill-in	1.9	1.3
	BS61S-3	Fill-in	2.2	1.3
suSCon FuMing	ES92-12	Planting	1.2	<0.2
		Fill-in	1.0	<0.2

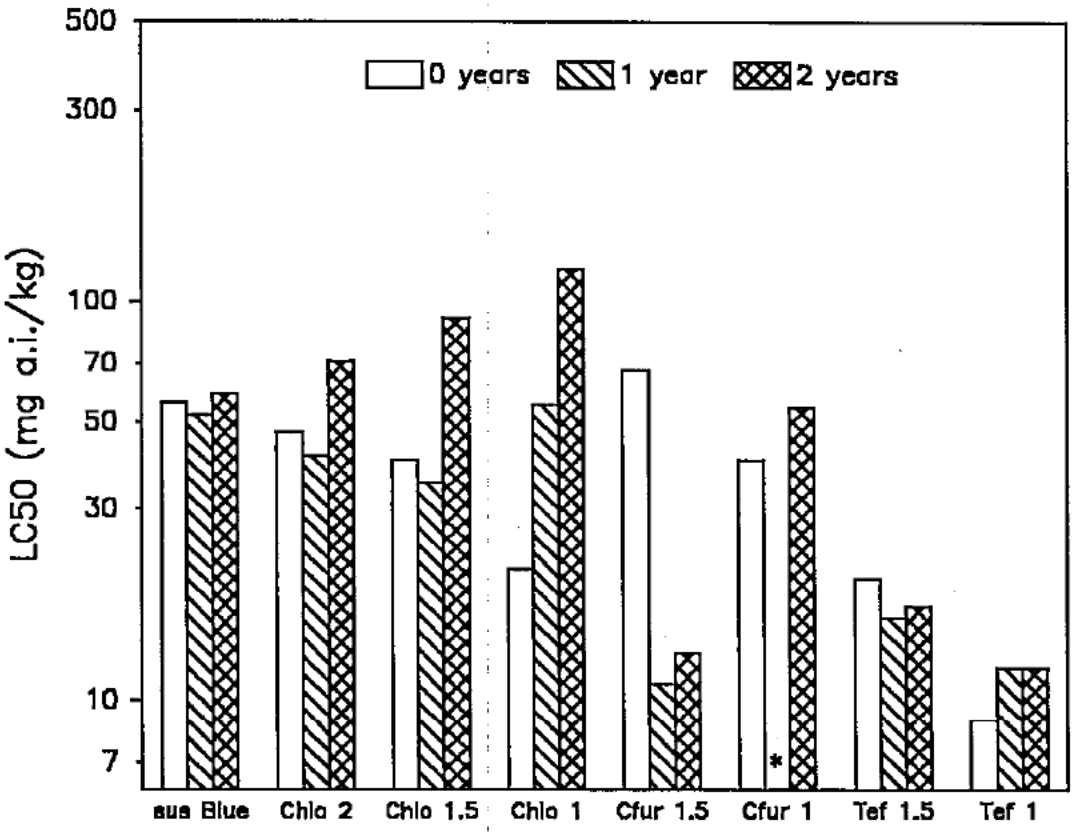

Figure 1 - Activity against soldier fly larvae of controlled-release granules of chlorpyrifos 10% 2 mm (suSCon Blue: sus Blue), and of chlorpyrifos 10% (Chlo), carbofuran 10% (Cfur) and tefluthrin 3% (Tef) in granule sizes from 1 - 2 mm, in successive years after mixing with soil (* LC_{50} << 20 mg ai kg^{-1})

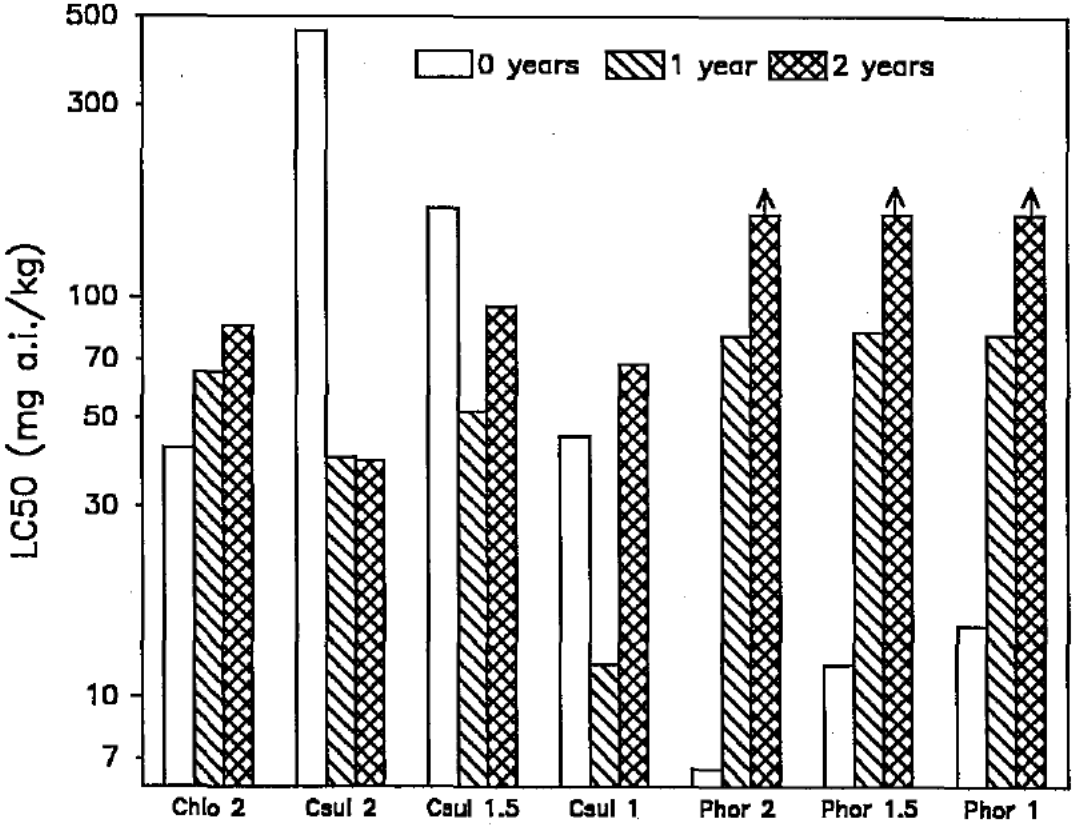

Figure 2 - Activity against soldier fly larvae of controlled-release granules of chlorpyrifos 10% (Chlo), carbosulfan 10% (Csul) and phorate 10% (Phor) in granule sizes from 1 - 2 mm, in successive years after mixing with soil.