SESSION 2B

NEW COMPOUNDS, FORMULATIONS AND USES (INSECTICIDES & ACARICIDES)

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RESEARCH REPORTS	2B-1 to 2B-7

FLUFENOXURON - AN ACYLUREA ACARICIDE/INSECTICIDE WITH NOVEL PROPERTIES

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ABSTRACT

Flufenoxuron is a new acylurea which is highly effective against mite and insect pests. By virtue of the acaricidal activity flufenoxuron offers a wider spectrum of pest control than other compounds of this type which are already on the market. Field trials demonstrate that, at very low doses, this compound provides excellent protection against many important pests of a range of economically significant crops. These include top fruit, vines, citrus, cotton, maize, soya and vegetables. Early season and prophylactic treatments are particularly effective and observations indicate that this compound presents little hazard to beneficial arthropods under practical conditions.

INTRODUCTION

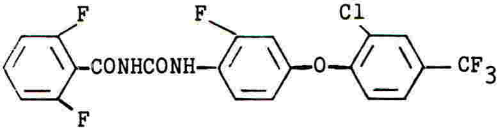
The acylureas (also referred to as benzoylphenylureas) are a developing class of insecticides of growing importance. In contrast with established classes of insecticide which are predominantly neurotoxins, the acylureas kill insects by interfering with the formation of chitin, an essential component of insect cuticle. The attraction of compounds with this mode of action is that they are inherently much less toxic towards mammals, birds and fish and they control pests which have become resistant to earlier types of insecticide.

Research in this area over the past decade has produced a succession of products with improved potency, speed of action and spectrum of activity. This paper introduces flufenoxuron, an acylurea discovered by Shell scientists at Sittingbourne Research Centre. In addition to being an extremely effective insecticide, flufenoxuron is also an outstanding acaricide.

TECHNICAL DETAILS

Chemical name	1-[4-(2-chloro-α,α,α-trifluoro-p-tolyloxy)-2-fluorophenyl]-3-(2,6-difluorobenzoyl)urea
Common name:	Flufenoxuron
Code number:	WL115110

Structural formula:



Molecular formula: $C_{21}H_{11}ClF_6N_2O_3$

Molecular weight: 488.8

Appearance: Colourless, odourless, crystalline solid.

Melting point: 169-172°C, (decomposition)

Vapour pressure: 4.6×10^{-12} N/m^2 at 20°C

Solubilities (g/l) at 25°C: Water: 4×10^{-6} Xylene: 6
Acetone: 82 Dichloromethane: 24

Stability: Flufenoxuron has good hydrolytic and photolytic stability under practical conditions and is thermally stable.

Formulations: In the trials described in this paper, flufenoxuron was formulated as a 5% water dispersible concentrate (referred to as a WDC).

TOXICOLOGY

Acute toxicity (technical material):

Mammals:	Acute oral LD_{50}, rat:	>3000 mg/kg
	Acute percutaneous LD_{50}, rat:	>2000 mg/kg
	Eye irritation, rabbit Skin irritation, rabbit	Non-irritating
Fish:	96 h LD_{50}, *Salmo gairdneri*	>100 mg/l.

PERFORMANCE

Laboratory evaluation

Results from laboratory screens against a range of important insect pests with flufenoxuron gave very encouraging results. The activity obtained was typical for an acylurea in that treated larvae died at the next moult or during the ensuing instar while adult insects remained apparently unaffected except for the deposition of non-viable eggs.

In a comparative experiment, flufenoxuron and diflubenzuron were administered to adult females of *Spodoptera littoralis* by topical application and by allowing newly emerged moths access to a solution containing the test compound. The results obtained (Table 1) indicate quite clearly that flufenoxuron is active by contact and by ingestion.

TABLE 1

Activity of acylureas in the *Spodoptera littoralis* indirect ovicide test

Compound (95% technical material)	Route	Mean dose per female (µg/moth) required to induce 50% egg mortality
Flufenoxuron	topical	1.2
	ingestion	0.002
Diflubenzuron	topical	1.4
	ingestion	0.15

Contact activity against larvae was investigated by topical application using 4th instar larvae and by exposing 2nd instar larvae to dry residues on glass for 1.5 h before the larvae were transferred to unsprayed foliage. Results are given in Table 2.

An initial laboratory evaluation against red spider mites (Tetranychus urticae) showed no activity against either eggs or adults. However, when the compound was applied to infested bean plants, population development was rapidly suppressed by extremely low concentrations (LC_{50} = 0.00013% a.i.). Closer investigation showed that the compound acted against larvae and nymphs at ecdysis and that exposed adults subsequently laid non-viable eggs.

TABLE 2

Contact and topical activity of flufenoxuron against larvae of Spodoptera littoralis

Compound (95% technical)	Topical activity LD_{50}(µg/larva) 2 days	Topical activity LD_{50}(µg/larva) 7 days	Contact activity LD_{50}(% a.i.) 5 days	Contact activity LD_{50}(% a.i.) 7 days
Flufenoxuron	0.0031	0.0018	0.0012	0.001
Diflubenzuron	0.017	0.014	-	-
Parathion	1.12	-	0.0038	0.002
Cypermethrin	0.0057	-	-	-

Field Evaluation

The performance of flufenoxuron has been evaluated in the field on a wide range of crops, concentrating on major outlets such as top fruit, vines, citrus, cotton and vegetables.

Top Fruit

A series of trials was carried out at Gorsem Research Station, Sint Truiden, Belgium to investigate performance against Lepidoptera and Hemiptera in top fruit. Excellent control of the winter moth (Operophtera brumata) and the apple psyllid (Psylla mali) was obtained at similar doses (Table 3).

TABLE 3

Control of Operophtera brumata and Psylla mali on apple

Compound	Formulation	Dose g a.i. /hl	O.brumata Numbers of larvae on 200 trusses	O.brumata % Control	P.mali Numbers of larvae on 200 trusses	P.mali % Control
Flufenoxuron	5% WDC	30	1	99.2	1	97.7
Flufenoxuron	5% WDC	15	2	98.4	9	80.0
Flufenoxuron	5% WDC	7.5	6	95.2	31	31.1
Fenpropathrin	10% EC	5	3	97.6	3	93.3
Methidathion	40% WP	40	3	97.6	0	100.0
Untreated control	-	-	126	-	45	-

A treatment applied at egg hatch gave excellent control of the summer fruit tortrix (Adoxophyes orana) (Table 4). This was impressive in view of the habit of this species of spinning a refuge in the leaf, and despite heavy rain immediately after treatment.

Activity against established infestations of the woolly aphid (Eriosoma lanigerum) and the green apple aphid (Aphis pomi) on apple was low. However, the control of apple psyllid (Psylla mali) (Table 3) encouraged trials against pear sucker (Psylla pyri), a far more significant pest with a history of resistance development which now extends to pyrethroids in certain areas.

TABLE 4

Control of Adoxophyes orana on apple

Compound	Formulation	Dose g a.i./hl	Numbers of larvae on 50 shoots	% control
Flufenoxuron	5% WDC	20	6	92.7
Flufenoxuron	5% WDC	10	4	95.1
Flufenoxuron	5% WDC	5	9	89.1
Fenpropathrin	10% EC	5	1	98.7
Methidathion	40% EC	40	18	78.3
Untreated control	-	-	83	-

Treatments were applied against larvae of the second generation and assessed 28 days later (Table 5). Flufenoxuron gave excellent control and showed a characteristic shallow dose response, so that 15 g a.i./hl or less would have provided commercially acceptable control. Other trials gave similar results but also showed that doses below 30 g a.i./hl needed a minimum of 8 days to become fully effective against established infestations where adults were present.

TABLE 5

Control of Psylla pyri on pear

Compound	Formulation	Dose g a.i./hl	Numbers of larvae on 50 shoots	% control
Flufenoxuron	5% WDC	30	2	99.7
Flufenoxuron	5% WDC	15	11	98.5
Flufenoxuron	5% WDC	7.5	27	96.3
Endosulphan	35% EC	70	129	82.7
Amitraz	19% EC	38	181	75.7
Diflubenzuron	25% WP	30	10	98.6
Untreated control	-	-	747	-

The apple leaf miner (Phyllonorycta blancardella) is a sporadic pest in N. Europe but heavy infestations can seriously affect the size and colour of fruit. When treatments were applied against the second generation at egg hatch, flufenoxuron exhibited a very high degree of efficiency (Table 6).

TABLE 6

Control of <u>Phyllonorycta blancardella</u> on apple

Compound	Formulation	Dose g a.i./hl	Nos. of larvae on 100 leaves	% control
Flufenoxuron	5% WDC	20	1	99.8
Flufenoxuron	5% WDC	10	2	99.7
Flufenoxuron	5% WDC	5	2	99.7
Alphacypermethrin	5% EC	1	21	97.0
Fenpropathrin	10% EC	5	0	100.0
Diflubenzuron	25% WP	25	13	98.3
Untreated Control	-	-	766	-

On mites, an extensive programme against the fruit tree red spider mite (<u>Panonychus ulmi</u>) on apples and pears gave excellent results. In France, a series of four trials were sprayed at 50-80% hatch of winter eggs and then monitored throughout the season. Treatments were re-sprayed as necessary when the mean number of motiles/leaf exceeded 5. The results obtained are summarised in Table 7.

TABLE 7

Control of <u>Panonychus ulmi</u> on apple; summary of four trials

Compound	Formulation	Dose g a.i./hl	Mean Nos. applications /season	Mean interval between treatments (days)
Flufenoxuron	5% WDC	40	1.75	100.5
Flufenoxuron	5% WDC	20	2.25	54.8
Flufenoxuron	5% WDC	10	3.00	51.9
Cyhexatin	60% SC	48	3.00	51.1
Cyhexatin	60% SC	24	3.75	38.9
Cyhexatin	60% SC	12	4.75	25.1
LSR.-two treatments (P=0.05)		-	1.10	1.5

The results reflect the excellent persistence of the compound and the very high levels of activity against non-adult motile stages. Further trials against established populations later in the season showed that efficacy depended upon the proportion of adults and non-adults in the population and the rate of mite development.

The overall conclusion that can be drawn from performance trials in top fruit is that flufenoxuron provides commercially acceptable control of mites and insects at 20 g a.i./hl or less. Similar confirmation of this dual activity has been found in other crops such as vines.

<u>Vines</u>

Efficacy of flufenoxuron against the mites <u>Panonychus</u>, <u>Eotetranychus</u> and the grape berry moth (<u>Polychrosis</u>) can be exemplified with results from a trial where all three pests occurred together in high numbers. Two sprays were applied. The first was an overall treatment against mites (T1), while the second (T2) was applied 14 days later to the central row in each plot against Polychrosis. Results are given in Tables 8 and 9. Control of both mite species was extremely efficient. Against grape berry moth the acylurea was noticeably better than fenvalerate after only one spray. The marginal difference between one and two sprays for flufenoxuron indicated that a single spray would suffice to control mites and grape berry moth.

TABLE 8

Control of Panonychus ulmi and Eotetranychus carpini on vines

Compound	Formulation	Dose g a.i./ha	Mean numbers of motile mites on ten leaves per plot (27 DAT)* Panonychus	Eotetranychus
Flufenoxuron	5% WDC	400	1.6	1.9
Flufenoxuron	5% WDC	200	2.3	1.7
Flufenoxuron	5% WDC	100	2.8	3.3
Fenvalerate	20% EC	75	176.4	5.7
Untreated control	-	-	167.7	37.1
LSR.-two treatments	-	-	2.4	5.6
treatment vs control (P=0.05)	-	-	2.2	4.5

*Results detransformed from $\log_{10}(x+1)$.

TABLE 9

Control of Polychrosis botrana on vines. (Comparison of single and double applications).

Compound	Formulation	Dose g a.i./ha	Mean numbers of larvae on 50 bunches* T1+35	T2+21
Flufenoxuron	5% WDC	400	2.4	2.1
Flufenoxuron	5% WDC	200	5.2	1.6
Flufenoxuron	5% WDC	100	7.8	3.9
Fenvalerate	20% EC	75	49.2	32.3
Untreated control	-	-	190.0	190.0
LSR.-two treatments	-	-	2.6	2.4
treatment vs control (P=0.05)	-	-	2.3	2.1

*Results detransformed from $\log_{10}(x+1)$.

Citrus

Good control of Panonychus citri has been obtained as exemplified by results from Spain summarised in Table 10. In this trial the control population always exceeded the threshold for treatment. Rapid control was seen together with good persistence of effect against increasing population pressure.

TABLE 10

Control of Panonychus citri on oranges

Compound	Formulation	Dose g a.i./hl	Mean numbers of motile mites on twenty leaves per plot*			
			T+5	T+11	T+18	T+26
Flufenoxuron	5% WDC	40	1.0	2.3	1.6	1.8
Flufenoxuron	5% WDC	20	1.9	3.6	8.7	3.6
Flufenoxuron	5% WDC	10	1.8	4.3	3.9	4.4
Dicofol/ tetradifon	16% EC/ 60% EC	32/ 12	2.9	1.0	1.6	6.0
Untreated control	-	-	32.3	27.7	34.2	83.0
LSR.-two treatments (P=0.05)	-	-	2.9	2.3	3.5	7.7

*Results detransformed from $\log_{10}(x+1)$.

Season-Long Performance

In season-long trials, results against a variety of pests have been encouraging. In an example from New Zealand, flufenoxuron was compared with a commercial standard programme on apple. Overall results are given in Table 11. Control of codling moth and, especially, three species of leaf-roller was extremely good while results for mealybug and San Jose scale were encouraging. However, performance against woolly aphid was unsatisfactory. Control of European red mite (P. ulmi) was excellent and in sharp contrast to the standard programme and the untreated control, both of which needed a corrective application of 12.0 g a.i./hl cyhexatin. Considerable evidence of selectivity was noted toward the predatory mite Typhlodromus pyri.

TABLE 11

Season long control of pests on apple

Treatment			% of fruit*	% of fruit infested*		
Compound	Formulation	Dose g a.i. /hl	undamaged by codling moth/ leafrollers	Mealybug	San Jose Scale	European red mite
Flufenoxuron	5% WDC	10	100.0	1.0	0.5	0.1
Flufenoxuron	5% WDC	5	99.5	1.8	1.3	0.0
Flufenoxuron	5% WDC	2.5	99.3	0.9	1.6	0.0
Azinphos methyl	50% WP	375	99.9	0.3	0.4	17.5
Untreated control	-	-	56.9	3.9	7.1	0.4

* 200 fruits per plot

Vegetables

Vegetables offer a severe challenge to an emerging insecticide in terms of spectrum of activity and the production of blemish-free produce. The quality of control which can be obtained with flufenoxuron is demonstrated by results from the Philippines against diamond-back moth (Plutella xylostella) on cabbage (Table 12). The initial application was made 10 days after transplanting and subsequent applications were made at 7 day intervals up to harvest (a total of six treatments in all).

TABLE 12

Control of *Plutella xylostella* on cabbage

Treatment			Mean damage score	Mean Yield (t/ha)	
Compound	Formulation	Dose g a.i./ha	(T3+4 days)	Total	Marketable
Flufenoxuron	5% WDC	50	0.7	47.6	46.6
Flufenoxuron	5% WDC	25	1.2	47.0	47.0
Flufenoxuron	5% WDC	12.5	1.5	46.5	46.5
Fenvalerate/ methamidophos	3% EC/ 60% EC	60/ 600	2.9	40.0	5.5
Untreated control		-	3.0	29.5	0.5
LSD -two treatments		-	0.4	4.6	1.2
treatment vs control (P=0.05)		-	0.4	4.0	1.1

The mid-trial damage score indicates that differences were readily apparent after 3 weeks. The marketable yield shows large differences between flufenoxuron and the standard treatment.

SUMMARY

The results indicate that the activity, spectrum and speed of effect of flufenoxuron, allied with good foliar persistence, offers considerable potential as an acaricide/insecticide in top fruit, vines, citrus and vegetables. Promising results have also been obtained on other crops including cotton, maize, and coffee as well as in certain non-crop outlets. Results from toxicological work to date do not indicate any barriers to progress. Longer term toxicological studies are now in hand.

The Shell trademark for flufenoxuron marketed outside the United Kingdom and the Republic of Ireland will be 'CASCADE'.

ACKNOWLEDGEMENTS

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TEFLUTHRIN - A NOVEL PYRETHROID SOIL INSECTICIDE

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ABSTRACT

Tefluthrin ("Force") is a novel pyrethroid soil insecticide which provides excellent control of a broad range of soil pests, including members of the Coleoptera, Lepidoptera and Diptera, at doses between 12 and 150 g a.i./ha. It may be used as a soil-applied granule, liquid soil spray, or as a seed treatment. As a pyrethroid, tefluthrin will be particularly useful where pest resistance or enhanced microbial degradation has lowered the efficacy of organophosphorus and carbamate insecticides, and where rotation of chemical types is advisable. Tefluthrin is of low hazard to users, earthworms and birds especially when used as a low concentration granular formulation, and there is also a negligible risk of leaching or groundwater contamination. These factors combine to make the discovery and development of tefluthrin a highly significant advance in the field of soil pest control.

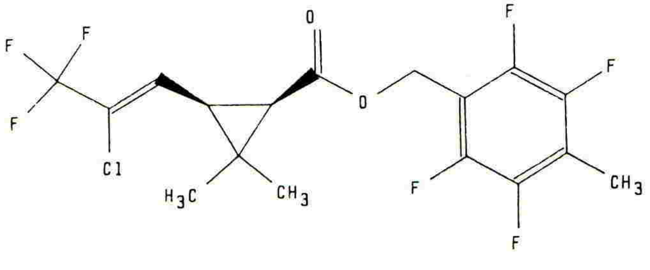
INTRODUCTION

This paper reports the technical properties and biological efficacy of tefluthrin (IUPAC systematic name: 2, 3, 5, 6-tetrafluoro-4-methylbenzyl (Z)-(1RS, 3 RS)-3-(2-chloro-3, 3, 3-trifluoroprop-1-enyl)-2, 2-dimethylcyclopropanecarboxylate).

Tefluthrin is the first pyrethroid soil insecticide to be marketed. Invented at the Jealott's Hill Research Station of ICI Plant Protection Division, tefluthrin was designed rationally for use in the soil environment (McDonald *et al*, 1986) and shows impressive efficacy against a wide range of soil arthropods.

CHEMICAL AND PHYSICAL PROPERTIES

Structural Formula



1:1 Mixture with stereochemical isomer (1S, 3S)

Solubility : 0.002 mg/l (purified and buffered water, pH5 and pH9). Soluble in a range of common organic solvents at 21°C.

Melting Point : 44.6°C (317.8K)

Appearance : White solid (pure tefluthrin)
Off-white (technical grade tefluthrin)

Odour : No characteristic odour

Vapour pressure : 8×10^{-6} KPa at 20°C

Stability : Stable for at least 9 months at 15-25°C

TOXICOLOGICAL PROPERTIES

Toxicological studies show tefluthrin to be less acutely toxic than the standard organophosphorus and carbamate soil insecticides; this benefit is accentuated by the markedly lower doses recommended for this soil pyrethroid.

Acute Oral Toxicity (Rat)

Formulation	Sex	Route of Administration	Median Lethal Dose (mg/kg)
Technical*	Male	Oral	22
Technical*	Female	Oral	35
1.5% granule	Male	Oral	3019
1.5% granule	Female	Oral	1531
Technical*	Male	Dermal	148-1,480
Technical*	Female	Dermal	262
1.5% granule	Male	Dermal	> 2000
1.5% granule	Female	Dermal	> 2000

* Using corn oil carrier

Technical material is a slight skin and eye irritant in the rabbit.

ENVIRONMENTAL ACCEPTABILITY

Residues of tefluthrin have not been detected (limit of determination, 0.01 mg/kg) on major crops treated with tefluthrin at recommended doses (Amos & Leahey, 1986).

Field studies on earthworms have been conducted in maize in the USA and in the UK where tefluthrin granules were applied at seeding in an 18 cm surface band in Spring. Rates of application were 168g and 112g a.i./ha respectively. Effects on earthworms were not observed 1 and 5 months after treatment.

Tefluthrin has been found to present a very low hazard to birds. For instance, the acute oral median lethal dose of technical tefluthrin to the Mallard duck is 4190 mg/kg.

As with other pyrethroids tefluthrin has a high toxicity to fish and some aquatic invertebrates.

Tefluthrin has a half-life of the order of 1-3 months in soil, thus giving scope for sustained pest control without any risk of residue build up in the soil. The parent compound and its degradation products have been shown to have negligible mobility in both sandy loam and loamy sand soils. On the basis of these data, leaching and contamination of groundwater is not expected to be a problem.

BIOLOGICAL EVALUATION

Tefluthrin is highly active against soil pests of the orders Coleoptera, Lepidoptera and Diptera. It possesses a useful vapour pressure which assists mobility of the compound in the soil and also penetration of target organisms (McDonald _et_ _al_, 1986).

Tefluthrin has been evaluated in a number of countries in a variety of granular formulations, mostly with 0.5 to 1.5% a.i. on gypsum-based carriers. According to the pest location, tefluthrin may be applied in the field as a granule, (broadcast, banded, in-furrow, split in-furrow/banded), as a liquid soil spray or as a seed dressing. Tefluthrin may control foliar pests that spend a part of their lifecycle on or in the soil.

Applied at recommended doses, tefluthrin has caused no phytotoxic symptoms in major crops such as maize, sugar beet, potato and cereals.

Coleoptera

Corn Rootworm (Diabrotica spp)

Tefluthrin shows excellent activity against species of corn rootworm, the foremost insect pest in USA maize (Table 1) matching the performance of the leading standards at approximately one tenth of their application doses. Larval damage to maize roots by Diabrotica spp impairs root function and may increase the risk of plant collapse (lodging) especially when mature. Larval damage is kept below the economic threshold by tefluthrin granular applications of 112 g a.i./ha. Lower doses of tefluthrin may be adequate for first year maize.

TABLE 1

Control of Corn rootworm in field corn (USA) with granular formulations banded in furrow at planting.

Treatment	Dose g a.i./ha	Mean Root Rating* (average of trials, 1979-85)
Tefluthrin	84	2.72
Tefluthrin	112	2.68
Tefluthrin	140	2.41
Terbufos	1,120	2.21
Carbofuran	1,120	3.02
Chlorpyrifos	1,120	2.66
Untreated	-	4.56

* Root rating based on the Iowa State University scale: 1 = no damage; 6 = three or more nodes of roots destroyed. "Economic threshold" rating in the region of 2.7 - 3.0, according to several conditions (Turpin *et al*, 1972).

Granular application is by the conventional method of banding in the furrow at planting which creates a 20 cm surface band with some granules incorporated into the seed furrow.

Tefluthrin has shown good efficacy against heavy and light infestations of corn rootworm at a dose of 112 g a.i./ha.

As a pyrethoid, tefluthrin will be especially valuable where growers are encouraged to alternate corn rootworm soil insecticides, rather than using one product or class of chemistry for several consecutive years (Anon, 1986).

The activity of tefluthrin against corn rootworm and other maize pests is further reported by Gouger *et al* (1986).

Wireworm (Agriotes spp, Melanotus spp)

Wireworms are notable pests of potatoes, sugar beet and corn in Europe and the Americas. Tefluthrin granules applied in-furrow gave excellent seedling protection in corn, sugar beet (Table 2), potato and white turnip at doses of 30 - 75 g a.i./ha. In Canada, seed treatment of wheat with 0.4 - 0.6 g tefluthrin/kg seed provided excellent control of wireworm (Table 3). Further trials in Canada showed that granular tefluthrin at 1 g a.i./100m row applied in furrow at planting significantly reduced the numbers of potato tubers rendered unmarketable by wireworm damage.

TABLE 2

Control of wireworm by granular tefluthrin applied in-furrow at planting in sugar beet, France.

Treatment	Dose (g a.i./ha)	% Undamaged Plants (46 DAT)*
Tefluthrin	30	50.3 ab
Tefluthrin	60	57.2 a
Terbufos	300	24.3 cd
Carbofuran	600	31.9 bc
Control	-	11.5 d

* Scores not followed by letters in common are significantly different at the 5% level.

TABLE 3

Control of Wireworm by Seed Treatments on Wheat, Canada.

Treatment*	Dose (g a.i./kg seed)	% Emergence+ 12 DAT
Tefluthrin	0.4	86 a
Tefluthrin	0.6	87 a
Fonophos	1.0	79 a
Fonophos	2.0	85 a
Untreated	-	57 b

* All seeds (including untreated) pretreated with a fungicide (mancozeb, 0.54 g a.i./kg seed)

\+ Scores not followed by a letter in common are significantly different at the 5% level.

Pygmy Mangold Beetle (Atomaria linearis)

Atomaria is a primary sugar beet pest in Europe, the beetles causing feeding damage to the hypocotyl and base of the stem. Tefluthrin has achieved significant reduction of Pygmy mangold beetle damage to sugar beet (Fig. 1) from granular applications at 30 - 60 g a.i./ha, and from a seed pellet formulation (12 - 24 g a.i./100,000 seeds (1 ha equivalent)) in Germany. Tefluthrin applications at one tenth the dose of standard products provided protection of the seedling and healthy plant establishment.

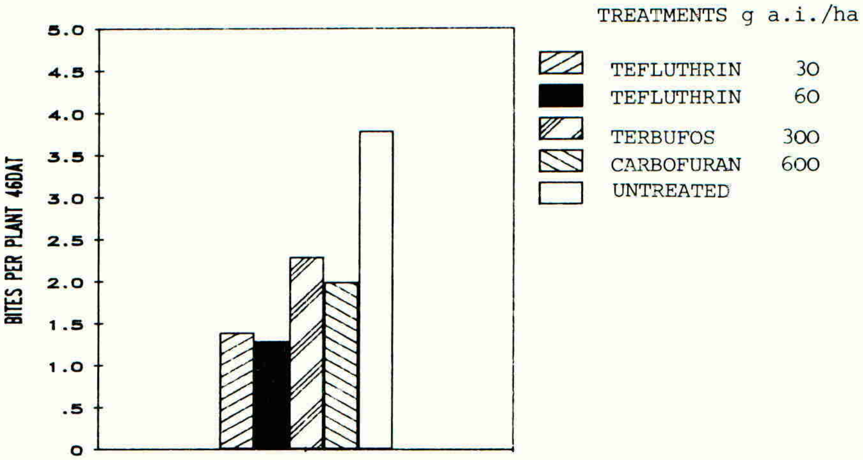


Fig. 1: Control of Pygmy mangold beetle in sugar beet (France) with granular insecticide formulations applied at planting.

Good control of A. linearis in sugar beet in Holland was provided by soil sprays of tefluthrin EC at 75 and 100 g a.i./ha lightly incorporated into the soil just before sowing (Table 4).

TABLE 4

Control of Pygmy mangold beetle by tefluthrin soil spray incorporated into the seed bed, Holland.

Treatment	Dose (g a.i./ha)	% Emergence	A. linearis Damage Index*
Tefluthrin EC	75	94	2.5
Gamma HCH	800	39	4.6
Untreated	-	4	7.6

* Damage Index on a scale 0 - 10 : 0 = no damage, 10 = high level of damage).

Flea Beetle (Chaetocnema spp and Phyllotreta spp)

Flea beetles (Chaetocnema spp.) attacking sugar beet in Italy and Spain were effectively controlled by granular applications of tefluthrin partially incorporated into the furrow at planting. The numbers of lesions caused by flea beetles were significantly reduced in Spanish trials by application of 50 g tefluthrin/ha (Table 5), while the percentage of plants attacked and the foliar area damaged were significantly reduced by applications of 50 - 75 g a.i./ha in Italian trials. Further reports of the activity of tefluthrin against sugar beet pests are given by Gruenholz *et al* (1986).

TABLE 5

Control of flea beetle in sugar beet with granules applied at planting (Spain).

Treatment	Dose (g a.i./ha)	Plants/4m* 32 DAT	Flea Beetle Lesions* 30 DAT
Tefluthrin (in furrow)	50	21 a	36 bc
Tefluthrin (surface band)	50	16 bc	25 c
Terbufos (in furrow)	200	16 bc	46 b
Carbofuran (in furrow)	600	19 ab	27 c
Untreated	-	13 c	91 a

* In each column numbers that do not have a letter in common differ significantly at the 5% level.

In Japanese trials, Striped flea beetle (Phyllotreta spp) on Japanese radish was controlled by application of a 0.3% granular formulation of tefluthrin at 150 g a.i./ha.

Other Coleoptera

Trials in Japan against first and second instar larvae of the chafer, Anomala schoenfeldti in lawn grass have shown good activity of 0.3% tefluthrin granules applied at 150 g a.i./ha, broadcast on the turf surface. Larval populations of the Black chafer (Lachnosterna riotoensis) attacking peanuts in Korea were significantly reduced by tefluthrin granule applications of 50 - 100 g a.i./ha.

Rice water weevil (Lissorhoptrus oryzophilus) was controlled by granular application of tefluthrin incorporated into the soil before planting rice. Pre-flood application of tefluthrin at 112-140 g ai/ha achieved a significant reduction in numbers of weevil larvae, similar to that achieved by carbofuran at 700g a.i./ha.

Other Coleoptera controlled by granular applications of tefluthrin at 75 - 100 g a.i./ha include white grubs (Melolontha melolontha) and grass grubs (Costelytra spp) in turf; and Black maize beetle (Heteronychus spp) in maize and potato.

Lepidoptera

Cutworm (Agrotis spp)

Activity against cutworms is a major advantage of tefluthrin. Excellent activity was shown against Black cutworm (A. ipsilon) in trials on field maize in the USA (Fig. 2). Significant reduction in the percentage of plants damaged by cutworm was achieved by tefluthrin granules at doses as low as 56 - 84 g a.i./ha. Granular application in the trials was by the technique used for corn rootworm control. At application doses used against corn rootworm, tefluthrin provided cutworm control under wet and dry soil conditions (Table 6).

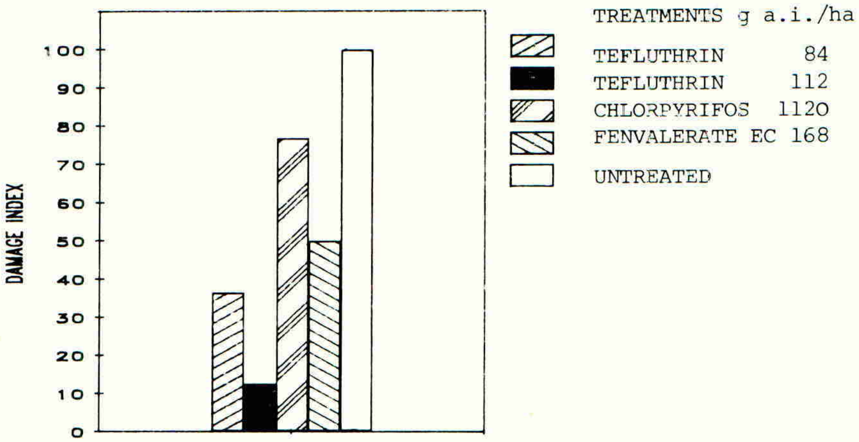


Fig. 2: Control of Black cutworm in field corn, USA, with granular insecticide formulations applied banded in furrow at planting.

TABLE 6

Control of Black cutworm in field maize under different soil moisture conditions, USA.

Treatment	Dose (g a.i./ha)	Dry Conditions		Wet Conditions	
		% plants attacked	% severely attacked	% plants attacked	% severely attacked
Tefluthrin	84	24 ab	3 b	15 c	3 c
Tefluthrin	112	13 b	2 b	11 c	0 c
Chlorpyrifos	1120	20 b	5 b	41 b	20 b
Untreated	-	34 a	18 a	56 a	33 a

In each column, scores not followed by a letter in common differ significantly at the 5% level.

Corn Borer (Ostrinia nubilalis, Sesamia nonagrioides)

Whorl application of tefluthrin granules has given good control of corn borers in several countries. In USA sweetcorn, application of 84 - 112 g tefluthrin/ha gave control of O. nubilalis equivalent or superior to that given by carbofuran at 1120g a.i./ha. In Spanish trials O. nubilalis and S. nonagrioides were effectively controlled by tefluthrin granules, whorl-applied on sweetcorn. Applications were made at the start of tassel emergence, when first instar corn borer larvae were present, and again if necessary, 15 days later.

Diptera

Seedcorn Maggot, Frit Fly and Wheat Bulb Fly

Tefluthrin seed treatments on winter wheat in France significantly reduced attack by Wheat bulb fly (D. coarctata) (Table 7) and in Switzerland by frit fly (Oscinella frit) at a dose of 0.2 g a.i./kg seed. Tefluthrin seed treatments significantly increased corn emergence and reduced Seedcorn maggot (Delia platura) damage in Canada at rates of 0.4 - 0.6 g a.i./kg seed. Similarly, damage caused to beans by D. platura was reduced and plant emergence increased by tefluthrin seed treatments at 0.6 - 0.8 g a.i./kg seed.

TABLE 7

Control of Wheat bulb fly by microencapsulated tefluthrin seed treatment (tefluthrin CS), France.

Treatment	Dose (g a.i./ha)	% Plants Attacked	
		TRIAL 1	TRIAL 2
Tefluthrin CS	10	44.7	22.1
Tefluthrin CS	20	40.9	14.2
Tefluthrin CS	40	33.6	11.7
Gamma HCH + endosulfan	40+100	43.1	19.7
Untreated	-	97.7	42.2

Other Arthropods

Symphylid (Scutigerella spp) larvae damage seedlings of a variety of major crops including corn and sugar beet. Tefluthrin granules applied in furrow at planting have shown good reductions of corn damage by Scutigerella; significant increases in the number of plants emerged; and a significant increase in final yield from application at 50 g a.i./ha. The control achieved was superior to that from carbofuran at 600 g a.i./ha.

CONCLUSIONS

Tefluthrin is a novel pyrethroid soil insecticide which offers the farmer many important benefits and shows a number of significant advantages over existing soil insecticides:

- Control of a broad spectrum of soil arthropods including corn rootworm, wireworm, flea beetle, chafer, Pygmy mangold beetle, cutworm, corn borer, frit fly, Wheat bulb fly and others (eg symphylids) at rates of 12 - 150 g a.i./ha.

- Flexibility in mode of application as granules, soil sprays or seed treatments using conventional equipment.

- Low user hazard (as expressed by acute toxicity values) in comparison with leading soil insecticide products. This feature is enhanced by low doses of application and low concentration of the formulation.

- Novel chemistry and mode of toxic action which are essential in "aggressive" soils that show enhanced degradation of carbofuran (Bewick et al, 1986).

In addition, tefluthrin poses:

- Low hazard to birds and earthworms.
- Low risk of leaching and groundwater contamination by tefluthrin and its breakdown products.

ACKNOWLEDGEMENTS

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SD 208304 - A NEW BROAD SPECTRUM SOIL INSECTICIDE

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ABSTRACT

In the USA, the most economically important pests on corn (maize) are larvae of the corn rootworms (Diabrotica spp.) and cutworm larvae of the dark sword-grass moth (Agrotis ipsilon). SD 208304 (FORTRESS™ Insecticide) is a new broad spectrum soil insecticide from DuPont that in 1984-1986 gave outstanding control of the above-mentioned species, as well as wireworms, with single planting-time applications at low doses. Studies on vegetable crops showed SD 208304 to be highly active against various rootfly maggots.

The low water solubility of SD 208304 limits soil movement, an advantage for increased performance and decreased environmental impact. Accelerated microbial breakdown of SD 208304 has not been detected in any soil type, even those known to have this effect on other products.

INTRODUCTION

The soil insecticide market in the USA is concerned primarily with the control of the larvae of two coleopterous pests of corn (maize), the western corn rootworm (Diabrotica virgifera virgifera) and the northern corn rootworm (D. longicornis barberi). In 1985, almost 12 million hectares of corn were treated with soil insecticides in the United States (representing 35% of the total corn acreage) and of these more than 10.5 million hectares had treatments applied at planting time.

Another soil pest of significant agronomic importance is the cutworm larva of the dark sword-grass moth (Agrotis ipsilon) which is a problem mainly on seedling corn and some other crops throughout North America and in many other countries. Because of the migratory habits of this latter pest, and its consequent unpredictability, prophylactic applications of pesticides are most often used to control it. In the USA in 1985, one third of the corn acres treated with soil insecticides were treated with the control of the cutworm as one of the principal objectives.

The biology of the cutworm and the rootworm are quite different, as are the types of damage they cause to corn. With the cutworm, the damage is confined mostly to the corn seedling in the first two or three weeks after the emergence of the coleoptile. Typically the larvae eat through (or cut) the small seedlings at, or slightly below, the soil surface leading to loss of plant stand and subsequent yield reduction. A 3% cutting level is accepted as an economic threshold. The damage to corn from larvae of the corn rootworms is confined to the root systems of the plants through the main growing season. In heavily infested areas, larval feeding can lead to total pruning of the roots, severe lodging of the plants and considerable yield reductions.

Thus the most economically important pests of corn in the USA occur at different times of the season and in different parts of the soil profile. From the farmers' point of view, it would be beneficial to apply one product on a single occasion to control all the above-mentioned pests. However none of the currently available soil products gives consistently good control of the larvae of both the *Diabrotica* complex and of the moth.

Data are presented in this paper to demonstrate that, in three years of extensive field testing, the new DuPont soil product SD 208304 consistently outperformed all standard products used for the control of rootworms and cutworms. SD 208304 has also given outstanding results against a range of wireworm species on a number of crops and has provided excellent control of the European corn borer (*Ostrinia nubilalis*), and a number of soil pests of vegetable crops.

CHEMICAL AND PHYSICAL PROPERTIES

Chemical name:	*O*, *O*-diethyl *O*-1,2,2,2-tetrachloroethyl phosphorothioate.
Code number:	SD 208304
Tradename/Mark:	FORTRESS™ Insecticide
Molecular Weight:	336
Appearance:	White crystalline powder
Solubility:	Water: <1 mg/l. Soluble in hexane, ethanol, xylene, acetonitrile, chloroform.
Vapour pressure:	Approx. 8×10^{-4}mm Hg at 20°
Formulations:	Various concentration granules (7.5 - 20%)
Stability:	Technical and formulated material stable at ambient temperatures.

TOXICOLOGY

Rat:	Oral LD_{50} = 1-10 mg/kg
Mouse:	Oral LD_{50} = 20-50 mg/kg
Rabbit:	Dermal LD_{50} = 20-200 mg/kg
Rabbit:	Skin/eye irritation - minimal

RESULTS

SD 208304 is primarily an insecticide for application to corn at planting time for the early- to mid-season control of a variety of soil insect pests. In this outlet, a granular formulation is preferred, and SD 208304 is thus formulated on a clay base at 15% a.i. concentration (15G). Laboratory stability tests over the last few years have shown this 15G formulation to be stable and to have good handling properties. No dust problems have been observed and the formulation flows well through all types of application equipment without problems. The 15G formulation of SD 208304 has been utilised in over 150 trials in the last three years with the main emphasis of this work being in corn (maize) through the mid-western states of the USA. Alternative formulations have been tested on other crops. The performance of SD 208304 against rootworms, cutworms, wireworms, European corn borer and a number of other pests is discussed below.

Corn rootworm (Diabrotica spp.)

The results given in Fig. 1 are a summary of all trials carried out on this pest with a 15% granule in the seasons 1984-1986 inclusive. It can be seen that the activity of SD 208304 was at least twice that of terbufos, and more than twice that of any of the other soil products at their commercially recommended doses. The root ratings given in Fig. 1 are based on the Iowa State University 1 to 6 scale, with a rating of 1 indicating a plant showing no rootworm feeding damage, and a rating of 6 indicating a plant with at least three complete nodes of roots pruned by larval feeding. On this scale, it should be born in mind that the recommended economic threshold for rootworm control is a root rating of 3.00 and that, at the 0.56 kg ai/ha dose shown for SD 208304 in Fig. 1, no ratings as high as a 3.00 have been observed in any of the 1985 or 1986 trials. In contrast,

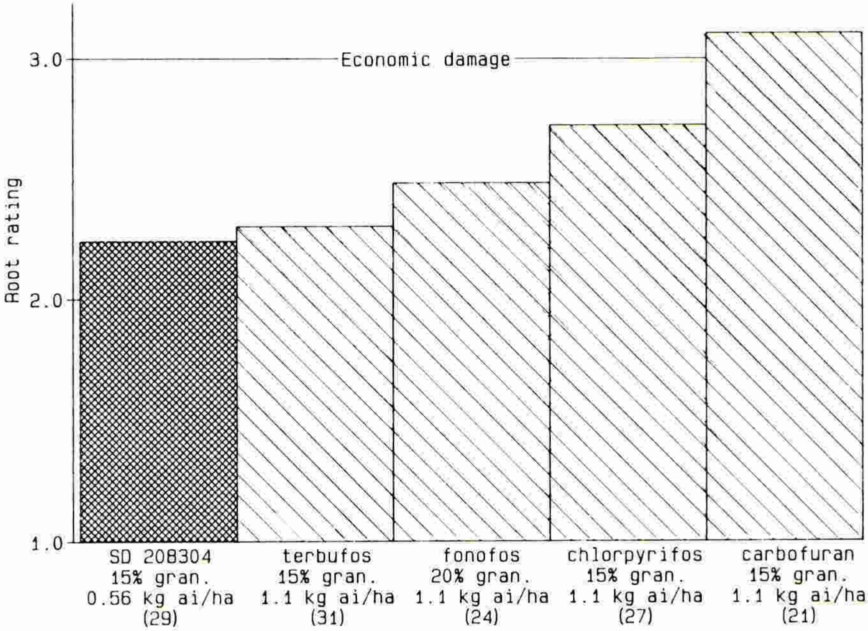

Fig. 1. Summary of all U.S. corn rootworm trials 1984-1986 (numbers of trials in parentheses)

many ratings of 3.00 or above were recorded for all the products used as standards, even at their full recommended doses, thus highlighting the consistency of SD 208304. The results contributing to Fig. 1 were comprised of about 60% from university trials, 30% from trials with private contractors, with the remainder being in-house trials.

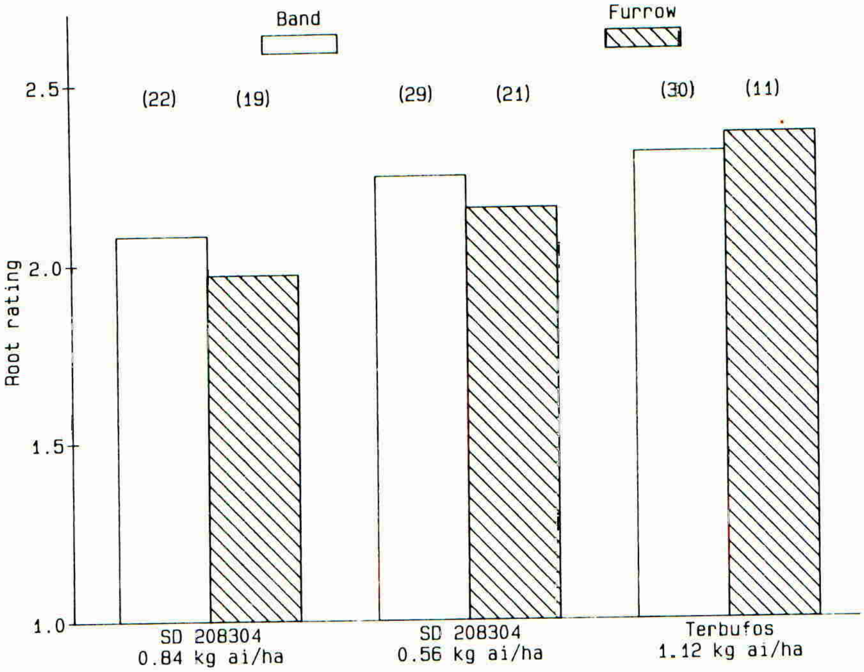

Fig. 2. Band vs. furrow comparisons in U.S. corn rootworm trials,1984-1986 (numbers of trials in parentheses)

All the results given in Fig. 1 are with treatments applied at planting as 18-cm bands, usually with a small amount of incorporation from spring tines or short drag chains. Fig. 2 summarises comparisons between banded and furrow applications of SD 208304. As very few in-furrow applications are currently recommended, not many of the trials included such treatments and sufficient data were available to include only terbufos in Fig. 2. The improved performance of SD 208304 when applied in this way is readily apparent. The only other product known to be improved by in-furrow application is the carbamate carbofuran.

Cutworms (Agrotis ipsilon)

The results of tests with SD 208304 against natural populations of cutworms on corn in the mid-west in 1985 and 1986 are given in Fig. 3.

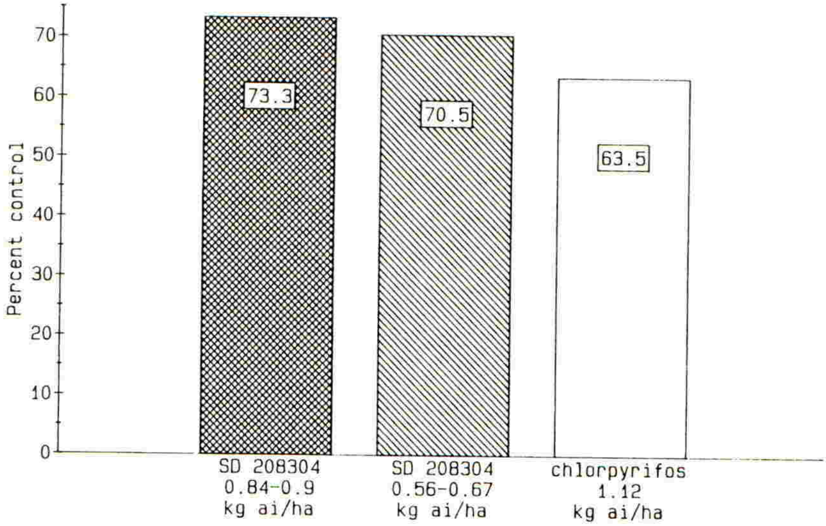

Fig. 3. Summary of all U.S. trials (natural infestations): 1985-1986

In these trials SD 208304 was evaluated at doses of 0.84-0.90 and 0.56-0.67 kg ai/ha, with chlorpyrifos being included at the recommended dose of 1.12 kg ai/ha. In the two seasons, a total of nine trial sites developed populations of larvae and, in these, the level of cutting in the untreated plots averaged some 10.4%, considerably above the economic treatment threshold of 3%. The excellent performance of SD 208304, even at the 0.56-0.67 kg ai/ha rate was evident in all these trials.

Wireworms

Throughout many parts of the USA wireworms have become increasingly important as pests over the last few years, possibly due to a combination of increasing acreage of no-till and lay-by land and the gradual loss of organochlorine residues from those areas where in earlier years other products were in regular use. Table 1 shows some of the results obtained in corn trials with SD 208304 in 1985 and 1986. From the viewpoint of prevention of seed damage or protection of plant stand, SD 208304 was equal to, or better than, any of the standards currently recommended for wireworm control.

On potatoes in Washington State, wireworms can be a problem and, in this outlet too, the performance of SD 208304 was excellent, as can be seen from Table 2. Interestingly, many treatments in these trials, including SD 208304, were applied as broadcast treatments with the products used as standards being applied at much higher doses. In Table 2, damaged tubers are defined as any showing injury as severe as that described in Sec. 51.1560 and 51.1564 of the U.S. Standards for Grades of Potatoes.

TABLE 1

Control of wireworm damage to corn seed in 4 Iowa fields, 1985-1986

Treatment		Rate	Mean % Damaged Seed	
Insecticide	Formulation	kg ai/ha	Band	Furrow
SD 208304	15G	0.84	13.6	8.2
SD 208304	15G	1.12	15.7	8.6
Fonofos	20G	1.12	39.7	-
Terbufos	15G	1.12	-	21.3
Chlorpyrifos	15G	1.12	42.3	31.8
Ethoprop	15G	1.12	38.1	-
Phorate	20G	1.12	34.6	-
Untreated control	-	-	71.8	71.8

TABLE 2

Control of wireworm damage to potato in Washington, 1985

Treatment		Place-ment*	Rate	% Control of Tuber Damage	
Insecticide	Formulation		kg ai/ha	Field 1	Field 2
SD 208304	15G	PPB	1.12	99.0	98.8
Fonofos	15G	PPB	4.48	96.6	95.7
Fonofos	10G	PPB	4.48	98.5	100.0
Fonofos	10G	APF	2.24	97.3	69.2
Ethoprop	10G	PETI	6.72	98.2	98.9
Ethoprop	10G	PETI	4.48	93.0	96.8
Ethoprop	10G	PETI	2.24	86.2	91.5
% tubers damaged in untreated control				12.9	4.6

*PPB=preplant broadcast; APF=at plant seed-piece furrow; PETI=post emergence topical incorporated.

Other pests

Good activity against several root maggot (root fly) species affecting carrots and cruciferous crops has been recorded with SD 208304 (Thompson *et al.*, 1986a, 1986b). In addition, excellent control has been observed in the field against southern corn rootworm (*Diabrotica undecimpunctata howardi*) on corn, with substantial yield increases being recorded.

Residue degradation

A problem currently facing the users of some soil insecticide products is that of enhanced microbial degradation by soil micro-organisms in certain locations. In some cases, the breakdown can be so rapid that almost total failure of the product can be observed. Soils collected from a number of fields identified as being of interest for their degradative capacity were used to test SD 208304 alongside other commercial compounds. No problems were found with SD 208304 in these or other soil types.

Insecticide mobility

The water solubility of SD 208304 is lower than that of all the other granular soil insecticides. SD 208304 does not appear to move far in the soil, improving its environmental acceptability and also allowing the compound to remain in the part of the soil profile where it is needed for pest control.

CONCLUSIONS

From the data presented in this paper, it is clear that SD 208304 is a soil insecticide with a truly wide spectrum of activity against all the main pests of corn in the USA. Evaluations on other pests/crops and in other countries are continuing; preliminary results suggest that SD 208304 also has promise in many other agronomic outlets. Numerous trials have confirmed that SD 208304 is remarkably consistent in its performance and that it is active at low doses, suggesting considerable environmental acceptability. Environmental studies are continuing.

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WL108477 - A NOVEL NEUROTOXIC INSECTICIDE

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ABSTRACT

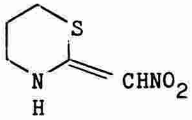
Early nitromethylene heterocycle (NMH) insecticides exhibited interesting levels of biological activity and an extremely rapid action. However this was accompanied by a level of photo-instability which precluded commercial development. WL108477, the N-formyl derivative of 2-nitromethylene-1,3-thiazinane, is a compound which retains the desirable levels of biological activity coupled with greater photostability. The rapid action of the parent has been maintained. Results indicate the effectiveness of the compound against a range of insect species including strains resistant to organophosphorus, carbamate and pyrethroid insecticides. Where such insects are also virus vectors, for example plant-hoppers on rice, this combination of effects is of great utility especially as it is allied to low toxicity in mammals and fish.

INTRODUCTION

In 1978, Soloway described the evolution of a new group of insecticides known collectively as the nitromethylene heterocycles (NMHs) and discussed the structure activity relationships for these compounds. (Soloway et al., 1978).

The most active of the NMH compounds was 2-nitromethylene-1,3-thiazinane (I).

(I)



This compound had high insecticidal activity, rapid action, low acute mammalian and fish toxicity and low environmental persistence. The last mentioned property of the compound is a result principally of its short photochemical half-life. Although short persistence may be desirable, the persistence of (I) under field conditions was found to be too short for agricultural use. Considerably higher doses than indicated by laboratory experiments were required to achieve control in the field.

A programme of research was begun at Sittingbourne in 1981 directed at overcoming the major problem of the photoinstability of (I) whilst maintaining its high activity. In the course of this work, a large number of derivatives was synthesised. The compound which was chosen from these for further development was the N-formyl derivative, WL108477. This paper describes the activity of WL108477.

WL108477

TECHNICAL DATA

Chemical name: 2-nitromethylene-1,3-thiazinan-3-yl-carbamaldehyde

Molecular formula: $C_6H_8N_2O_3S$

Molecular weight: 188

Appearance: Pale yellow crystals

Melting point: 138-140°C (decomposition)

Solubility at 20°C: Water 0.5 g/l. ; xylene 2.5 g/l.

Log P-Octanol/: water 20°C 0.23

Toxicity:		
	Acute Oral Mouse LD_{50}	1000-2500 mg/kg
	Acute Percutaneous Mouse LD_{50}	>600 mg/kg
	Rainbow trout 96h LC_{50}	>100 mg/l.

PHOTOSTABILITY

Table 1 demonstrates the increased photostability of WL108477 compared with that of compound (I).

TABLE 1

Comparison of the photostability of WL108477 and Compound (I) in a thin film exposed to simulated sunlight

	Hours exposure			
	0	5	20	50
% Recovery of (I)	100	26	0	0
% Recovery of WL108477	100	100	95	81

As can be seen from Table 2, the high insecticidal activity observed with Compound (I) is maintained with WL108477.

TABLE 2

Toxicity Index of NMHs $\left(\frac{LC_{50}\text{ parathion}}{LC_{50}\text{ NMH}} \times \frac{100}{1}\right)$ in laboratory tests

Stage / NMH	*Heliothis zea* larvae	*Spodoptera littoralis* larvae	*Spodoptera littoralis* eggs	*Musca domestica* adults	*Nephotettix cincticeps* adults	*Nilaparvata lugens* adults
(I)	1700	120	47	29	140	420
WL108477	1500	100	53	17	230	560

MODE OF ACTION

Electrophysiological studies clearly indicate a novel insecticidal mode of action for the nitromethylene heterocycles. Using *in-vitro* abdominal ganglion nerve preparations from the American cockroach (*Periplaneta americana*), we have established that the NMHs act as cholinomimetics, the toxic effects resulting from the activation of receptors in the central nervous system for the neurotransmitter acetylcholine.

Using the sucrose gap system (Callec and Satelle, 1973), we have demonstrated that the application of µM concentrations of Compound (I) or WL108477 to the sixth abdominal ganglion of the cockroach causes rapid and total depolarisation of the post synaptic membranes, accompanied by a period of intense neural excitation, the depolarisation and block of neural transmission being complete within 2-3 min. At equivalent molar concentrations of freshly made solutions of compound (I) and WL108477, no differences have been observed in either the rate or extent of the observed effects. Analytical experiments have demonstrated that conversion of WL108477 to compound (I) in the testing medium occurs to the extent of less than 2% during the timescale of the experiments. These results suggest that either both compounds have equal intrinsic activity or that enzymic conversion of WL108477 to Compound (I) occurs within the nervous tissue.

The effects of Compound (I) and acetylcholine have been compared, under voltage clamp conditions, on receptors on the cell body of an identified central neurone. Compound (I) bound to the same site and caused the same electrical effects as acetylcholine, demonstrating beyond reasonable doubt that the NMHs act as agonists at insect acetylcholine receptors.

The specificity of the NMHs has been demonstrated by examining the effect of Compound (I) at high concentration (100 µM) on a number of other *in-vitro* preparations. Apart from the acetylcholine receptor, no effect has been observed in any of the preparations tested including sensory neurones, axonal conduction, neuromuscular junction, skeletal muscle, acetylcholinesterase and potassium transport across the gut.

BIOLOGICAL PERFORMANCE

The improvement in biological performance of WL108477, compared with compound (I), as a result of its increased photostability is clearly illustrated by the results of an experiment conducted out of doors in Japan on potted rice plants bioassayed at various intervals after treatment (Table 3).

TABLE 3

% mortality after 24 h exposure caused by NMHs on potted rice plants, maintained out of doors in Japan, using a bioassay with adult female Nephotettix cincticeps

Compound 95% Technical Material	Dose (g a.i./ha)	Days after treatment before artificial infestation		
		0*	1	2
(I)	500	100	6	7
WL108477	500	100	83	64
Untreated control	-	0	3	0

* Separate laboratory experiment.

Bioassays of field-weathered deposits on cabbage using the Egyptian cotton leafworm (Spodoptera littoralis) indicated a half life for WL108477 of about one day (Table 4).

TABLE 4

The field persistence of WL108477 deposits on cabbage.

Compound	Formulation	Half life in days obtained from bioassays of weathered deposits using Spodoptera littoralis
WL108477	25% WP	1.06
Methomyl	20% SL	0.84
Alphacypermethrin	10% EC	3.12

The combination of high activity against leaf- and plant-hoppers (Table 5) and caterpillars, together with low mammalian and fish toxicity indicate that WL108477 is well suited for use on rice. The fast action of the compound, which gives rapid knock down and control of Nephotettix virescens, the main vector of Tungro virus, results in significantly reduced virus infection in the crop (Table 6). WL108477 also shows appreciable activity on adult insects including the rice whorl maggot (Hydrellia philippina) and leaf folder (Cnaphalocrosis medinalis) (Table 6) and the black stink bug (Scotinophara coarctata) (Table 7).

TABLE 5

The activity of WL108477 against adult female leafhoppers (Nephotettix cincticeps) and plant-hoppers (Nilaparvata lugens) in residual bioassays on rice.

Compound 95% Technical Material	Mean LC_{50} (% a.i.)	
	Nephotettix cincticeps	Nilaparvata lugens
WL108477	0.0011	0.0014
BPMC	0.0054	0.0310
Cypermethrin	0.00045	0.0043
Ethyl parathion	0.0048	0.0150

TABLE 6

Activity of WL108477 against the rice whorl maggot (RWM) and the leaf folder (LF) in the Philippines

Compound	Formulation	Dose g ai/ha	RWM≠	LF≠	% hills infected with RTV*	Yield t/ha
WL108477	25% WP	300	2.25	1.75	4.00 (0.49)	5.15
WL108477	25% WP	100	2.25	2.63	6.51 (1.29)	5.08
BPMC	50% EC	750	4.50	5.00	5.64 (0.97)	4.78
Cypermethrin	20% EC	30	2.75	1.13	5.65 (0.97)	3.74
Untreated control		-	6.75	5.13	33.50 (30.47)	2.86
LSD-two treatments (P=0.05)		-	2.40	0.83	16.09 -	1.26
LSD-treatment vs control (P=0.05)		-	2.08	0.73	13.90 -	1.09

≠ RWM and LF scored on a 1-9 damage scale.
* % virus infestation was transformed by ARCSIN; detransformed means are given in brackets.

TABLE 7

Activity of WL108477 against the black stink bug (*Scotinophara coarctata*) on rice in Malaysia.

Compound	Formulation	Dose g a.i./ha	Mean numbers of adult bugs in two $1m^2$ quadrats* 1 DAT	3 DAT
WL108477	25% WP	100	1.67	1.59
WL108477	25% WP	50	2.00	2.08
Endosulphan	35% EC	750	3.24	1.59
Cartap	50% WP	750	18.02	15.07
Untreated control		-	82.40	29.30
LSR-two treatments (P=0.05)		-	2.58	1.92
LSR-treatment vs control (P=0.05)		-	2.07	1.60

*Results detransformed from $\log_{10}(x+1)$.

The activity of WL108477 against lepidopterous pests, where the rapid knock down leads to good control of defoliating species is illustrated by the results of a trial against the velvet bean caterpillar (*Anticarsia gemmatalis*) on soya beans (Table 8).

TABLE 8

The activity of WL108477 against the velvet bean caterpillar (*Anticarsia gemmatalis*) on soya beans.

Compound	Formulation	Dose g ai/ha	Mean numbers of larvae per 2m row* 1 DBT	 3 DAT	 5 DAT
WL108477	25% WP	300	92.08	4.76	6.98
WL108477	25% WP	100	110.77	14.25	27.40
Monocrotophos	40% WMC	150	103.49	2.97	8.51
Monocrotophos	40% WMC	75	120.96	12.31	18.14
Untreated control		-	121.43	197.61	198.43
LSR-two treatments		-	1.66	2.73	2.71
LSR-treatment vs control		-	1.56	2.40	2.38

*Results detransformed from $\log_{10}(x+1)$.

As discussed above, the NMHs differ in mode of action from synthetic pyrethroid, organophosphorus and carbamate insecticides. It was therefore of great interest to examine WL108477 against pests resistant to the above-mentioned insecticide classes. The results in Table 9 confirm the effectiveness of WL108477 against the multiresistant Nakagawara strain of *Nephotettix cincticeps* as well as against a susceptible strain.

TABLE 9

Activity of WL108477 against adult female susceptible and resistant strains of *Nephotettix cincticeps*

Compound 95% Technical Material	Dose g ai/ha	Mean % mortality at 1-24 h. 1	 2	 4	 24
a) susceptible strain					
WL108477	500	94	97	97	100
Untreated control	-	0	0	0	0
b) Nakagawara resistant strain					
WL108477	500	74	86	86	100
Propaphos	500	0	4	38	96
Propaphos	250	0	0	11	87
Untreated control	-	0	0	0	0

WL108477 has also shown excellent activity against a strain of the glasshouse whitefly (*Trialeurodes vaporariorum*) which is highly resistant to pyrethroids (Table 10), demonstrating a lack of cross resistance to the NMH.

TABLE 10

The activity of WL108477 against adults of a resistant strain of *Trialeurodes vaporariorum* in a leaf residue test.

Compound 95% Technical material	LC_{50} (% a.i.) Susceptible strain	LC_{50} (% a.i.) Resistant strain	Resistance Factor*
WL108477	0.0159	0.0193	1.2
Alphacypermethrin	0.00014	0.0889	635.6

* Resistance factor = $\frac{LC_{50}\text{ resistant strain}}{LC_{50}\text{ susceptible strain}}$

Although innately only moderately active against larvae of the diamond back moth (*Plutella xylostella*), WL108477 has been shown to be unaffected by resistance to a variety of other insecticide types in a strain originating in the Cameron Highlands of Malaysia (Table 11).

TABLE 11

The activity of WL108477 against susceptible and resistant strains of *Plutella xylostella*

Compound 95% Technical material	LC_{50} % a.i. Susceptible strain	LC_{50} % a.i. Resistant strain	Resistance factor*
Mevinphos	0.018	0.110	6
Methomyl	0.029	0.110	4
Cypermethrin	0.00042	0.0040	10
WL108477	0.041	0.039	0.95

* Resistance factor = $\frac{LC_{50}\text{ resistant strain}}{LC_{50}\text{ susceptible strain}}$

DISCUSSION

The discovery of a new insecticide belonging to a novel chemical class and with a distinctive mode of action is a comparatively rare event. This combination of characteristics has been found by Shell Research in the WL108477 molecule. WL108477 has emerged as a fast acting insecticide which exhibits high activity against a range of insect species including strains which have developed resistance to organophosphorus, carbamate and pyrethroid insecticides. Where such insects are also virus vectors, for example with plant-hoppers in rice, this combination is of great practical value especially when allied with low toxicity to mammals and fish. The short persistence of WL108477, coupled with its low mammalian and fish toxicity should ensure that the environmental impact of the material is minimal.

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CYROMAZINE, A NEW INSECT GROWTH REGULATOR FOR LEAFMINER CONTROL

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ABSTRACT

Cyromazine (TRIGARD ®) is an insect growth regulator which is highly active on dipterous larvae, including species which have developed resistance to conventional insecticides. A special strength of cyromazine is its excellent effect on leafminers of the genus *Liriomyza*. The active ingredient and its formulations are practically non-toxic to mammals, birds, fish, and bees.

Its main use is for edible crops and ornamental flowers where *Liriomyza trifolii* and related species are no longer controllable with the available product range. Outdoor and indoor uses are recommended. Cyromazine is systemic; it can be applied to the leaves or to the soil.

Acceptance of cyromazine at grower level is high, especially where strict phytosanitary regulations exist.

INTRODUCTION

At the 15th International Congress of Entomology in Washington in 1976, Ciba-Geigy Basle presented a new insect growth regulator, reference CGA 19255 (2-azido-4-cyclopropylamino-6-ethylamino-*s*-triazine) with a strong inhibitory effect on the larval and pupal development of *Diptera* (Flück & Herzog, 1976). Further studies within the Plant Protection and Animal Health departments revealed that the major metabolite, cyromazine, was as effective as its precursor and was not phytotoxic.

Around that time the agromyzid fly *Liriomyza trifolii* started to alarm entomologists in Florida. Within a few years this insect developed into a major pest devastating crops such as celery and lettuce. A major reason for this was the development of resistance to conventional insecticides following indiscriminate use of these compounds. To overcome resistance problems in Florida cyromazine received an emergency use permit in 1983 and final EPA approval in 1985. Since this period sales permits have been obtained for various crops in a number of countries.

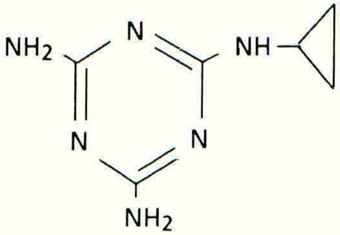
Within eight years of being identified as an economic pest *L. trifolii* spread over the world mainly through exports of infested plant material. At present, this species is found in most regions throughout Europe, in South Africa, the Near East, and the Balkan countries. A related species, *L. huidobrensis,* plays a similar role in some Latin American countries.

With *Liriomyza trifolii* adult females puncture the upper leaf surface for feeding and egg laying. The larvae mine in the leaves and pass through three instars. Pupation is in the soil. Other species pupate in the leaves. There are 8 to 12 generations per year. This tremendous reproductive potential provides large biological variability which explains the rapid development of defence mechanisms. *L. trifolii* is extremely polyphagous. More than 120 host plants are known including crops and weeds. Crop damage by larval feeding includes reduction of photosynthetic capacity, desiccation and premature fall of leaves. *L. trifolii* is a quarantine pest.

2B—5

TECHNICAL SPECIFICATION

Active ingredient:	Code number	CGA 72662
	Common name	Cyromazine
	Chemical name	*N*-cyclopropyl-1,3,5-triazine-2,4,6-triamine
	Structural formula	



Empirical formula	$C_6H_{10}N_6$ (mol. weight 166.19)
Melting point	220-222°C
Solubility	In water 11000 mg/l at pH 7.5 and 20°C,
Hydrolysis	Not significant at pH 5 - 9
Appearance	Pure a.i. forms colourless crystals

Formulations: For plant protection uses the following formulations are available:

75% wettable powder	(WP)	A-6808
15% wettable powder	(WP)	A-7161
10% soluble concentrate	(SL)	A-6963

TOXICOLOGY

Acute toxicity to mammals

	LD_{50} (mg/kg), rat		LC_{50} (mg/m^3), rat	Irritation, rabbit	
	Oral	Dermal	Inhalation (4h)	Skin	Eye
Techn. a.i.	3387	>3100	>2720	slight	none
75% WP	> 5000	>2000	>2120	moderate	slight
15% WP	ca 5000	>5000	>5000	slight	slight
10% SL	> 5000			none	irritant

Cyromazine and its formulations are slightly hazardous to mammals (WHO class III).

Wildlife (technical a.i.)

Bees:	Practically non-toxic: no contact action up to 5 µg a.i./bee.
Fish:	Practically non-toxic: LC_{50} is >100 mg/l for rainbow trout and carp, >90 mg/l for bluegill and catfish.
Birds:	Practically non-toxic: LD_{50} values are 1785 mg a.i./kg for bob white quail and >2510 mg a.i./kg for mallard duck.

MODE OF ACTION

Cyromazine induces morphological aberrations during larval and pupal development of *Diptera* ; emergence of adults is suppressed or incomplete (Awad&Mulla, 1984 a,b). This suggests an interference with moulting and pupation. Neither oral nor topical applications have a lethal effect on adults but reduced egg hatch has been observed after oral uptake (Pochon & Casida, 1983).The biochemical processes involved are under investigation.

On plants cyromazine has a systemic action: applied to the leaves, it exerts a strong translaminar effect; applied to the soil it is taken up by the roots and translocated acropetally.

Crop tolerance: At field rates cyromazine has produced no phytotoxicity in any of the crops and varieties for which its use is recommended.

RESULTS

When applied in five biweekly sprays, all standard products failed to control insecticide-resistant *L.trifolii* on gerbera (Table 1), as shown also by Pandolfo (1985) and Pasini *et al.* (1986). However, cyromazine was very effective at 10 and 20 g a.i./100 l.

TABLE 1

Activity of various commercial products applied as foliar sprays (2000 l/ha) against *L. trifolii* in gerbera. Mean of 3 trials. Italy, 1985

Insecticide	Formulation	Dose (g a.i./100 l)	Undamaged leaf surface in %
Cyromazine	75 WP	20	100
Cyromazine	75 WP	10	98
Methamidophos	180 EC	45	46
Dimethoate	400 EC	60	11
Cypermethrin	200 EC	20	0

Cyromazine at 15 g a.i./100 l protected green beans under heavy *L. trifolii* infestation pressure; even 45 g a.i./100 l were not phytotoxic (Table 2).

TABLE 2

Activity of cyromazine and triazophos against *L. trifolii* on green beans with 3 biweekly foliar applications (1500-2000 l/ha); Spain, 1984

Insecticide	Formulation	Dose (g a.i./100 l)	Leaf surface damaged in %
Cyromazine	75 WP	45	0.3
Cyromazine	75 WP	15	3
Triazophos	400 EC	40	20
Untreated		-	88

The activity and persistence of cyromazine were dose-dependent; 15 g a.i./100 l controlled *L. trifolii* over a period of more than seven days (Table 3).

TABLE 3

Activity and persistence of cyromazine against *L. trifolii* with a foliar spray (1500-2000 l/ha) applied to chrysanthemum; USA, 1983

Cyromazine (g a.i./100 l)	Formulation	No. of pupae / 80 leaves Pre-treatment	Post-treatment 7d	14d	21d
30	75 WP	59	0	3	33
15		75	0	16	97
7.5		64	2	206	203
Untreated		66	101	553	330

At 75 g a.i./ha cyromazine gave good control of *L. trifolii* on greenhouse crops (Table 4).

TABLE 4

Activity of cyromazine against *L. trifolii* with 4 foliar sprays (1000-2000 l/ha) applied at 7-day intervals to cucumber and tomato; Netherlands, 1985

Cyromazine (g a.i./ha)	Formulation	Reduction of mines in % Cucumber	Tomato
150	75 WP	94	99
75		90	98
37.5		71	69
Untreated (total mines per plant)		(171)	(158)

Cyromazine can also be applied to the soil. A single soil treatment with granules (650 g a.i./ha) achieved control of leafminers, over a period of 80 days, equivalent to that of biweekly foliar sprays totalling 1300 g a.i./ha (Table 5). In another experiment three soil treatments at 300 g a.i./ha effectively controlled *L. trifolii* for at least 31 days (Table 6).

TABLE 5

Efficacy of 6 foliar sprays (WP; 2000 l/ha) and single soil application (granules) of cyromazine against *L. trifolii* in gypsophila; Israel, 1984

Cyromazine formulation	Total g a.i./ha	No. live larvae / 100 leaves - DAT 17	28	44	61	80
75% WP	1300	37	11	1	8	0
3% Granules	650	6	2	4	12	6
3% Granules	1300	1	1	1	6	0
Untreated	-	236	155	106	300	65

TABLE 6

Efficacy of 3 applications of cyromazine applied as a soil treatment through drip irrigation against *L. trifolii* in tomato;Spain, 1985

Cyromazine (g a.i./ha)	Formulation	Undamaged leaf surface in % 31 and 48 days after 3rd application 31	 48
400	75 WP	100	99
300		100	84
200		94	54
Untreated (% leaves damaged)		(48)	(35)

Parrella *et al.* (1983) showed that cyromazine at low doses is harmless to beneficials (Table 7). Higher doses than 3 g a.i./100 l were not included in this experiment since 6 g a.i./100 l already gave 100 % mortality of *Liriomyza* larvae.

TABLE 7

Effect of a foliar spray (to run-off) of cyromazine 75 % WP on *L. trifolii* and its endoparasite *Chrysocharis parksi* in chrysanthemum (Parrella *et al.*, 1983)

Treatment	Insects/10 plants Pre-treatment *L. trifolii* (larvae)	 Post-treatment *L. trifolii* (adults)	 *C. parksi* (adults)
Control (leafminer)	201	170	-
Control (parasite)	197	38	34
Cyromazine, 3 g a.i./100 l	178	35	-
Cyromazine + parasite	159	19	31

Leibee (1985) developed a method of bioassaying insecticides against *L.trifolii* larvae. This method was used to select for cyromazine resistance in a field-collected strain of this insect. Nine generations out of 14 were exposed to LD_{50} (6 mg a.i./l) pressure. The results indicated that resistance had not developed.

CONCLUSIONS

Trial work and commercial use confirm the high activity of cyromazine against *L. trifolii* and related leafminer species irrespective of resistance to other insecticides. Its high selectivity makes it suitable for IPM programmes, especially in greenhouses.

Experimental work carried out from 1983 to 1985 led to the following general recommendations for leafminer control [1]:

Beans, carrots, celery, cucurbits, lettuce, onions, peas, pepper, potatoes, tomatoes: 12-30 g a.i./100 l <u>or</u> 75-225 g a.i./ha depending on crop size.

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[1] Cyromazine is also recommended for the control of sciarid fly larvae in mushrooms (US trade mark: ARMOR ®). In animal health areas the product has been developed as a feed additive for poultry diet (LARVADEX®), for topical applications on fly breeding sites (NEPOREX®), for the control of blowfly larvae, and for other uses.

Flowers: carnation, chrysanthemum, gerbera, gypsophila, etc.:
10-22.5 g a.i./100 l as a full cover spray or 100-250 g a.i./ha (US trade mark for flowers: CITATION ®).

The effect of cyromazine is dose-dependent. Higher doses markedly prolong the lasting effect compared with low doses. The product can be applied to the leaves using ground or aerial equipment. For soil treatments 200-1000 g a.i./ha are recommended. At the higher dose an effect lasting 8 weeks can be expected.

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PROTECTION OF BLACKCURRANT AGAINST BLACKCURRANT GALL MITE WITH THE SYNTHETIC PYRETHROID FENPROPATHRIN

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ABSTRACT

In trials over three years at several locations within the UK, the synethetic pyrethroid insecticide fenpropathrin (Meothrin; 10.9% a.i. wt/wt; Shell Chemicals) gave excellent control of blackcurrant gall mite *(Cecidophyopsis ribis)* on blackcurrants. Efficacy data, together with residue and taint test data will be submitted to the Pesticides Registration Department of MAFF (Ministry of Agriculture, Fisheries and Food) to obtain registration for this use of the product in 1987.

INTRODUCTION

Blackcurrant gall mite *(Cecidophyopsis ribis)* is one of the most serious pests of blackcurrants, not only in the UK, but also in the rest of Europe (Massee 1952). Severe infestations of the mite reduce the vigour of blackcurrant bushes and, more importantly, they spread reversion virus which leads to progressive loss in cropping (Anon 1981). Protection of crops against the mite is therefore vital.

In the early 1970's the pest was maintained at acceptable levels (Anon 1981), but levels of *C. ribis* then increased until by 1981 it was estimated that about 15% of the national fruiting acreage of 3,500 ha was seriously affected (Whewell, pers comm).

The reasons for this increase in mite infestation are not clear but are thought to be associated mainly with a reduction in the efficiency with which plantations have been rogued, leading to an increase in the reservoir of the pest and its migration to other bushes.

Control of C. ribis relies on a combination of planting only certified stock, regular spraying and thorough rogueing. However, as the migration period of the mite may extend from April into June or even July (Smith 1965), complete chemical control is very difficult. The standard material for control of the mite is endosulfan, applied as a 20% a.i. EC formulation three times during each crop: first open flower, last flower and again two weeks later. In 1980, 86% of the blackcurrant acreage in the UK was treated with endosulfan (Sly 1982).

Even with these spray timings, the full migration period of the mite may not be covered. Because the Harvest Interval for endosulfan is six weeks, the acaricide cannot be used to control the late infestations on each crop and, moreover, the ambient temperature must be above 13°C for the acaricide to perform best.

To devise an alternative protection strategy, ADAS in collaboration with Shell Chemicals Ltd, carried out trials with fenpropathrin, a pyrethroid insecticide which has a broad spectrum of activity against insects and mites, typically low residues on produce, a short harvest interval in field usage, and activity even at low temperatures. Results obtained in these trials are summarised in this paper.

MATERIALS AND METHODS

The sites of the trials described were deliberately chosen as having a high level of gall mite present, to present a severe test for the products. All sites were in commercial plantations of blackcurrants. Trials were carried out from 1983 to 1986 by ADAS at sites in Staffordshire and Herefordshire and by Shell Chemicals Ltd at sites in Essex and Norfolk.

All trials used fully replicated plots in randomised block design; plot size varied from three to fifteen bushes. Treatments were applied as high volume sprays to run-off, the water volume increasing from 1,000 to 1,500 litres per hectare as crop canopy developed. Plastic screens were used between plots when spraying to reduce cross-contamination. Except where stated, sprays were applied with a knapsack sprayer at standard timings, ie first open flower, last flower and again two weeks later.

Assessments were made on the centre bush of each plot, either on whole bushes or on tagged branches within a bush. Galled buds were counted in February-March (before treatment) and again in the following dormant season, post treatment. It has been shown (Thresh 1965) that counts of galled buds give an accurate indication of the level of mite infestation; normal buds rarely if ever, contain mites.

Comparison of the pre and post-treatment counts enabled the ratio of increase of the pest to be determined; this is termed the Multiplication Factor.

RESULTS

Initial results (Table 1) showed that fenpropathrin was active against C. ribis when applied in a three spray programme and there appeared to be little response to increasing the dose from 50 to 100 mg a.i./l. The increase in the numbers of big buds on unsprayed plots showed the rapid multiplication that can occur with C. ribis in a season.

TABLE 1

The performance of acaricides against blackcurrant gall mite in Norfolk in 1983/84

Treatment	Dose mg a.i./l	Mean numbers of infested buds per bush		Multiplication factor
		Pre-treatment	Post treatment	
Fenpropathrin	50	10.0	5.2	0.52
Fenpropathrin	100	6.7	5.7	0.85
Endosulfan	600-900	13.7	47.7	3.48
Endrin	375	8.2	5.5	0.67
Unsprayed	-	9.8	45.8	4.67
LSD	-	-	27.8	

Endosulfan was applied at 600 mg a.i./l for the first spray and 900 mg a.i./l for the last two sprays.

At the Staffordshire site, the level of infestation by C. ribis was lower (Table 2) and both endosulfan and fenpropathrin gave reasonable control of the infestation, which increased three-fold on unsprayed plots.

TABLE 2

The performance of acaricides against blackcurrant gall mite in Staffordshire in 1984/85

Treatment	Dose mg a.i./l	Mean numbers of infested buds per bush		Multiplication factor
		Pre-treatment	Post treatment	
Fenpropathrin	100	5.3	2	0.38
Endosulfan	600-900	4.3	0.8	0.19
Unsprayed		5.8	18.3	3.16

In Herefordshire, big and normal buds were counted on five branches taken from the middle bush of each plot. This enabled the percentage infestation to be determined. The results showed a clear response to the dose of fenpropathrin, the higher dose being most effective (Table 3). Data from this trial were analysed using the modified binomial analysis method described by Williams (1982). There was a significant ($P < 0.05$) reduction in infestation of C. ribis with all treatments, compared with the unsprayed plots. However, the higher dose of fenpropathrin gave significantly ($P < 0.05$) better control than endosulfan.

TABLE 3

The performance of acaricides against blackcurrant gall mite in Herefordshire in 1984/85

Treatment	Dose mg a.i./l	% buds infested by gall mite post-treatment
Fenpropathrin	50	38.1
Fenpropathrin	100	13.1
Endosulfan	600-900	41.0
Unsprayed	-	69.9

At the Essex site, fenpropathrin and endosulfan were compared when applied as a normal three-spray programme. In addition, two-spray programmes were evaluated to try and determine which of the spray timings was most effective against C. ribis. The spray timings were 1) first open flower, 2) end of flowering and 3) 14 days later.

TABLE 4

The performance of acaricides against blackcurrant gall mite in Essex in 1984/85

Treatment	Dose mg a.i./l	Spray timing	Mean numbers of infested buds per bush: Pre-treatment	Post treatment	Multiplication factor
Fenpropathrin	100	1,2 & 3	3.6	4.1	1.2
Fenpropathrin	100	1 and 2	6.1	26.3	4.3
Fenpropathrin	100	2 and 3	7.6	12.5	1.6
Endosulfan	600-900	1,2 & 3	4.2	11.0	2.6
Unsprayed	-	-	4.8	26.5	5.5
SED				3.3	

The results indicate that the last spray timing (14 days after petal fall) was largely responsible for control of the mite in this season: presumably there was a later extended migration, which was not well controlled by the two earlier sprays (Table 4).

In Staffordshire in 1985/86, (Table 5) both treatments had significantly ($P \leq 0.05$) less big buds per bush than the unsprayed control but fenpropathrin as a three spray programme reduced the numbers of infested buds below the original level. A full spray programme of endosulfan did not prevent the numbers of infested buds per bush from increasing over one season.

TABLE 5

The performance of acaricides against blackcurrant gall mite in Staffordshire in 1985/86

Treatment	Dose mg a.i./l	Mean numbers of infested buds per bush: Pre-treatment	Post treatment	Multiplication factor
Fenpropathrin	100	37	17.2	0.47
Endosulfan	600-900	39	52.3	1.34
Unsprayed	-	39	179	4.6
SED			24.9	

This was an extremely heavily infested site, and the majority of commercial plantations would have much lower levels of C. ribis than this. The multiplication factor shown in Tables 1–5 indicates the huge potential for increase by this pest; a 4 to 5-fold increase in infestation levels over the season on unsprayed bushes appears to be normal. In these trials however, fenpropathrin treatments decreased the factor significantly in four trials.

DISCUSSION

Blackcurrant gall mite continues to be a major pest on blackcurrants despite regular spraying. In order to reduce its levels, commercial plantations must be rogued more thoroughly. However, chemical treatments must also be maintained and a routine 3-spray programme is advised by ADAS.

Results from three seasons work reported here show that fenpropathrin applied High Volume will give as good, and usually better, control than endosulfan. As fenpropathrin is not systemic, thorough spray coverage is necessary for best results. As well as control of C. ribis, this material shows good activity against several other pests of blackcurrant, including two-spotted spider mite (Tetranychus urticae) and blackcurrant leaf midge (Dasineura tetensi) (Wardlow 1986).

However, because of its broad spectrum action, fenpropathrin will also kill predatory insects and mites (Kapetanakis et al., 1986) and this feature must be taken into account when planning an effective spray programme.

Migration of blackcurrant gall mite is determined largely by weather conditions (Massee 1952) and, in cold springs, migration may extend into July. When this happens, sprays may need to be applied later than is currently recommended. With fenpropathrin, this should be possible without excessive residues on the fruit being present. Work is in progress at two sites in the 1986/87 season to determine the effects of later applications. The data presented in this paper has been submitted to the Pesticides Registration Department of the Ministry of Agriculture, Fisheries and Food, with the aim of obtaining registration for a three spray programme of fenpropathrin on blackcurrants.

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PP 321: A NEW INSECTICIDE FOR BOLL WEEVIL CONTROL

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ABSTRACT

'Karate' (PP 321), a recently discovered broad spectrum pyrethroid insecticide with pronounced repellent effects, was evaluated for the control of the boll weevil (Anthonomus grandis) and the cotton whitefly (Bemisia tabaci) in cotton in Central America.

In replicated trials in 1983/84 and farmer tests in 1984/5, 10 g PP 321/ha provided equivalent season-long boll weevil control to methyl parathion, applying both insecticides at 3 or 4 day intervals during the main period of attack. Toxaphene used as a ULV spray carrier enhanced the effect of methyl parathion and PP 321. PP 321 eliminated the need for extra sprays for whitefly control whilst the standard spray programme based upon methyl parathion needed up to thirteen extra sprays to control whitefly. Symptoms of whitefly-transmitted leaf crumple virus were absent only from fields sprayed with PP 321. Treatments with PP 321 increased yields of seed cotton by at least 10%. In 1985/86, the first season of commercial use, 12.5 g PP 321/ha provided excellent pest control and increased cotton yields in Nicaragua by 20%.

INTRODUCTION

The biology of the boll weevil (Anthonomus grandis) markedly influences the choice of chemicals and spray application strategy used for its control. The adult weevil is the only stage of the life cycle exposed to spray during application and rapid knockdown of adults is necessary to prevent oviposition. Methyl parathion, a highly active fumigant insecticide with short persistence, has been the standard for many years. However, a persistent insecticidal effect is also desirable because infestations are spread over weeks or sometimes months including the fastest growth phase of the crop. This effect can therefore only be achieved by frequent spraying at short intervals.

The introduction of photostable synthetic pyrethroids has enabled increased protection of crops against many insect pests including the boll weevil (Davis et al. 1977; Moore 1980, Wolfenbarger et al. 1977). PP 321, a pyrethroid recently discovered by ICI (Jutsum et al. 1984), is highly active as a residual contact insecticide but also has pronounced repellent effects, and so warranted extensive trials against boll weevil. Results of trials in Central America are summarised in this paper. PP 321 can prevent the transmission of plant viruses (Perrin & Gibson 1985), and the effects of PP 321 on the cotton whitefly (Bemisia tabaci) and its transmission of leaf crumple virus are also described.

METHODS

Small plot trials: 1983/84

PP 321 was tested in four replicated trials designed to investigate the parameters of weevil control. Most treatments (Table 1) were applied every

3-4 days during the period of infestation. All trials used four replicated randomised blocks. Plot sizes were 15 rows x 20 m (Nicaragua), 14 rows x 20 m (Guatemala), and 8 rows x 15 m (El Salvador). Sprays were applied using manually carried air-blast sprayers giving 100 l/ha (Nicaragua), and 60 l/ha (Guatemala and El Salvador). Samples were selected at random from the central area of each plot. The numbers of live adult weevils and oviposition damage were determined on 25 squares/plot; whitefly adults were counted on 50 leaves/ plot; the numbers of live Heliothis larvae and damaged squares were recorded on 25 squares/plot. Plants were harvested for yield assessments from the centre four or five rows of each plot, discarding two or three metres at each end.

Farmer tests: 1984/85

The objective of the tests was to compare three PP 321 treatments with current farmer practice. Eleven large scale aerially sprayed tests were carried out using five sites in Guatemala, five in El Salvador and one in Nicaragua. The sites were on commercial farms and the treatments (Table 1) were applied under commercial conditions. The standard plots were sprayed with methyl parathion to control boll weevil and specific products were added to control other pests including whitefly and various Lepidoptera. The same principle applied to the use of PP 321 for boll weevil. In Guatemala, all treatments were sprayed at ULV with toxaphene as the carrier for a period in the middle of the season. Plot size was 6 to 8 ha, each plot being at least four aircraft swath-widths wide. Sprays were applied by aircraft fitted with either hydraulic nozzles or rotary atomisers. The spray volume of water-based sprays was 20-25 l/ha and of ULV toxaphene based sprays in Guatemala, 3.0 l/ha. All sprays were applied when boll weevil scouting indicated 8-10% damaged squares, or on the basis of other thresholds used normally by each farmer. Assessments were carried out at twice weekly intervals at ten stations randomly selected from the centre of each plot. The numbers of adult boll weevils and damaged squares were recorded on 400 squares per plot; adult whitefly and scales were counted on 50 leaves in the upper and 50 leaves in the middle canopy; Heliothis eggs and larvae, and damaged squares were assessed on 400 squares per plot. Other pests were counted on 50 plants per plot. Yields were monitored when the plots were commercially harvested.

TABLE 1
Treatments used in small plot (SP) trials and aerial (A) tests in C America

Insecticide (6)	g a.i./ha	Guatemala		El Salvador		Nicaragua	
PP 321	5	SP					
	7.5		A	SP		SP	
	10	SP	A		A,A(5)		A
	15	SP	A	SP	A	SP	A
	22.5	SP		SP		SP	
	30	SP		SP		SP(1)	
	37.5	SP		SP		SP(1)	
	22.5/7.5(2)	SP		SP		SP	
Methyl parathion	(3)	SP	A		A		A
M.parathion/deltamethrin	(4)					SP	
Untreated				SP			

[1] Sprayed once a week. [2] Sprayed alternately.
[3] 720 g a.i./ha in small plot and 600 to 1150 g a.i./ha in aerial tests.
[4] Methyl parathion (847 g a.i./ha) + deltamethrin (12 g a.i./ha).
[5] Spray decisions based on the "toxic carpet" schedule (Morton *et al.* 1981).
[6] Formulation: PP 321 - 'Karate' 8.33% EC; deltamethrin - 'Decis' 2.5% EC; methyl parathion - various.

RESULTS

The timing and numbers of sprays

The small plot trials were sprayed more or less twice a week and, throughout the season the intervals stayed between 3-6 days. As the trials started a few weeks late, the total number of sprays applied (average 17) was low compared with some seasons.

The farmer tests provided a more desirable level of variability in spray timing and exposed the experimental treatments to the full diversity of conditions experienced in commercial practice. Spray intervals varied throughout the season between 1 and 14 days. Spraying started earlier than the previous year and related more satisfactorily to the timing of infestations. An average of 28 sprays were applied in Guatemala, 14 in El Salvador and 16 in Nicaragua.

Control of boll weevil

There was a clear response to increasing PP 321 doses in terms of damage to squares and mortality of adults. Doses greater than 7.5 g PP 321/ha provided superior weevil control to methyl parathion (Tables 2,3). In the farm tests 10 g a.i./ha was a reliable basic dose.

TABLE 2
Mean % weevil-damaged squares in small plot trials.
Note: Results followed by the same letter are not significantly different at the 5% level of probability.

Insecticide	Dose (g a.i./ha)	Guatemala	El Salvador		Nicaragua
			El Rebalse	Indeo	
PP 321	7.5	9.6	12.6B	20 A	8.2
	15 g	7.6	10.8B	16.2B	7.6
	22.5	6.9	8.8CD	14.6B	6.1
Methyl parathion	720	11.1	-	-	7.7
Untreated		-	17.8A	22.9A	-

TABLE 3
Mean numbers of weevils/100 squares in small plot trials.

Insecticide	Dose (g a.i./ha)	Guatemala	El Salvador	
			El Rebalse	Indeo
PP 321	7.5	3.5	1.4A	1.9AB
	15 g	2.7	1.2BD	1.4B
	22.5	2.3	1.1CD	0.8C
Methyl parathion	720	3.9	-	-
Untreated		-	1.4A	2.1A

Excellent results from El Salvador and Guatemala during the peak of the infestation in 1983/4 were confirmed the following season in a Guatemalan farm test. Due to the proximity of a trap crop, very high infestations built up in the PP 321 and methyl parathion (770 g a.i./ha) plots but as the season progressed only PP 321 brought the weevil under control (Figure 1).

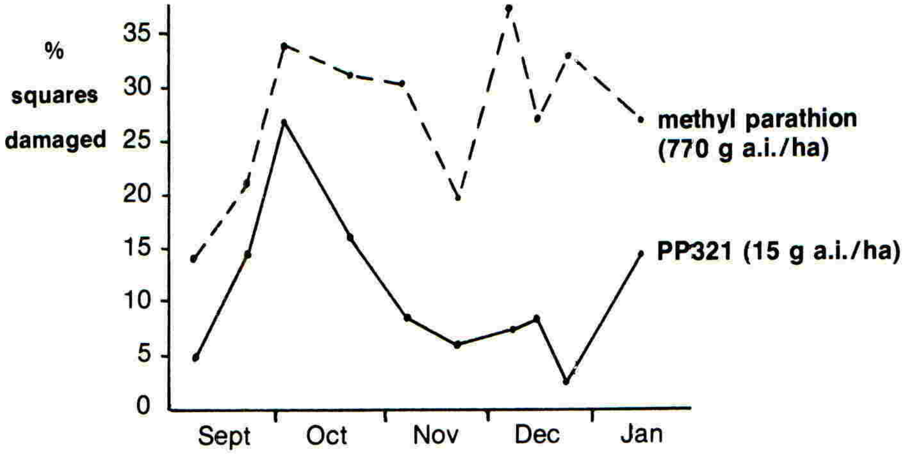

Fig 1. Bollweevil control under heavy pressure. Guatemala 1984/5.

Control of whitefly and spread of virus

PP 321 gave good control of whitefly. Dose responses occurred between 7.5 and 22.5 g a.i./ha in 1983/4, and all rates gave commercially acceptable control. In the aerial tests the following season, the influence on the spray programme was more apparent, particularly in Guatemala. Whilst 2-13 extra sprays of methamidophos, profenofos or monocrotophos were needed in the standard fields, none was required in those sprayed with PP 321. In Guatemala and El Salvador in 1983/4, there were no virus symptoms in PP 321-sprayed plots. These effects were confirmed in the farm tests in Guatemala and Nicaragua in 1984/85. It was noted however, that in fields sprayed with 7.5 g PP 321/ha, symptoms occurred towards the end of the season as spray intervals lengthened.

Control of other pests

During the course of the trials, infestations of Bucculatrix thurberiella, Trichoplusia ni and Heliothis spp were well controlled by all doses of PP 321.

Cotton production

Higher doses of PP 321 produced higher yields, corresponding to the dose responses for weevil and whitefly (virus) control. In two of the four replicated trials doses of PP 321 higher than 10 g a.i./ha provided higher yields than the standard programme. The on-farm tests provided a more realistic assessment, and results from three of these are presented in Table 4. 10 g PP 321/ha provided a yield increase of about 10%.

TABLE 4 :
Yield of seed cotton from three farm tests 1984/85
Percent increase over farmer programme( )

Site	PP 321 dose (g a.i./ha)			Farmer programme
	7.5	10	15	
Guatemala A	2437	2737(11)	2777(13)	2460
B	2969(16)	2834(11)	3255(27)	2552
Nicaragua	-	4479(11)	4621(15)	4028

In the first season of commercial use (1985/86), doses of PP 321 of 12.5 g a.i./ha gave the same level of pest control as in the farm tests the previous season. Yields were severely limited in Guatemala by inclement weather but under more normal conditions in Nicaragua an average yield increase of about 20% was achieved (Table 5).

TABLE 5 :
Profitability in commercial use
Comparison of methyl parathion and PP 321 based spray programmes;
Nicaragua 1985/86

	Chinandega[1]		Leon[2]	
	PP 321[3]	M.parathion	PP 321[3]	M.parathion
Yield kg/ha	2588	2109	2035	1752
Insecticide costs £/ha (4)	322	339	306	288
Cost/benefit (kg/£)	8.04	6.22	6.65	6.08
% improvement in benefit	29.3	-	9.4	-

[1] Split farm comparisons on eleven farms.
[2] Eleven farms sprayed with PP 321, six neighbouring ones with methyl parathion.
[3] PP 321 doses 12.5 to 15.0 g a.i./ha; methyl parathion 600 to 1150 g a.i./ha.
[4] Includes cost of insecticides used for other pests.

DISCUSSION

The effect on boll weevil

Unless adult weevils come into direct contact with wet spray solution, PP 321 does not give the immediate knockdown mortality characteristically exhibited by methyl parathion. However, in keeping with the normal mode of action of pyrethroids, the dry deposit has an immediate effect (Hopkins *et al*. 1984) and in these trials the crop scouts confirmed other work (Bariola & Bergman 1982) in reporting an immediate cessation of weevil activity. Dead weevils were not encountered between rows until 48 h. after spraying, but damage assessments confirmed that feeding and oviposition ceased immediately after spraying. Immobility, feeding deterrence, repellency and reduced fecundity are effects that have been reported (Micinski *et al*. 1982; Moore 1980) and PP 321 was undoubtedly effective through some or all of these.

Persistence and spray interval

The chemical persistence of PP 321 is longer than methyl parathion, but there was no evidence in these trials that the interval between sprays could be lengthened. Crop growth can produce 10 to 20 cm of new terminal in three to four days and, with continuous re-infestation occurring, this requires protecting.

Generally, insecticides are more effective wet than when dry (Hopkins et al. 1984), but the only time weevils are accessible to wet spray is when they are feeding in open flowers or crawling on wet surfaces. Therefore the more frequent the spraying the greater will be the influence of mortality from wet spray. Nevertheless, the time available for direct contact is minimal. The powerful, though short lived, fumigant effect of methyl parathion overcomes this. However, the greater residual or "repellent" effect of PP 321 appeared to provide more than adequate recompense. Thus for different reasons, frequent spraying is essential with both insecticides.

The value of early season weevil control

Several studies have shown that pest attack as early as 60 to 75 days from planting can cause cotton plants to compensate with new fruit to such an extent that the final yield is higher than if pest attack had not occurred, (Gutierrez et al. 1981; Morton 1979). However for this to happen it is essential that the crop is subsequently very well protected. It is worthwhile considering whether control of early boll weevil attack in C America could be relaxed.

The first weevil infestation of the season is usually light, occasionally not even breaking the spray threshold, but it generates a second infestation which may be as much as six times as severe (Gutierrez et al. 1981). Measures to reduce the first infestation, such as the use of trap crops, have a major impact on the level of the second infestation. In our trials and farm tests, the second and major infestation was far more severe when the early weevil attack was poorly controlled or not controlled at all due to a late start to the trial. So, counter to the capacity of the plant to compensate for early damage is the direct relationship between the level of the early infestation and the severity of the later main attack. We therefore propose that the first infestation must be particularly well controlled, possibly by utilising a lower damage threshold of say 5%, so that weevil breeding in the crop for the second infestation is minimised.

Toxaphene

It is generally accepted that toxaphene enhances the performance of insecticides on cotton. This was confirmed in a small plot replicated trial in El Salvador in 1985/86 in which toxaphene mixtures provided significantly better weevil control than methyl parathion or PP 321 alone. A local commercially available mineral oil was also as effective as toxaphene. The precise reason for the enhanced activity is not known. Work on mixtures with toxaphene (Bigley et al. 1981; Buck et al. 1980; Ware et al. 1980, and Brown et al. 1982), molasses (Lincoln et al. 1966; Price et al. 1970), camphene and cedar oil (Bigley et al. 1981) and a vegetable oil ULV carrier (Southwick et al. 1983) suggests they can cause an increase in the initial deposit on leaves, a reduction in the rate of penetration into the leaf and an increase in persistence. Such an increase in the initial availability of active ingredient would be particularly important in boll weevil control and could explain the results reported here.

Phytotoxicity

Methyl parathion can be phytotoxic to cotton and, in the long and intense programme of sprays required for weevil control, it would be surprising if the crop was not affected. However, the phytotoxicity is not simply foliar damage. In tests on two varieties of cotton in Georgia, USA, between 1975 and 1977 (Weaver et al. 1979) methyl parathion sprays resulted in delayed maturity, reduced lint percentage and lower yields. Yields were reduced 12.5% as a result of adding methyl parathion to fenvalerate and 29% after adding methyl parathion to permethrin. Spraying methyl parathion during the early flowering period was especially damaging compared with programmes starting later in the season. It is likely that substituting PP 321 for methyl parathion early in the season thus avoids adverse growth effects and is one of the prime reasons for there being an increase in yields.

CONCLUSIONS

In intensive replicated trials, extensive farm tests and commercial use PP 321 provided an excellent broad spectrum basis for the control of the Central American cotton pest complex.

To control the principal pest, the boll weevil, short interval spraying is necessary throughout its long period of infestation and especially during early squaring and flowering. PP 321 is particularly suited to this because it is safe to the crop and controls many other pests as they spasmodically occur. PP 321 also uniquely has the attribute of whitefly repellency and hence prevention of virus attack. Farm tests and commercial use of PP 321 has provided 10-20% increases in yield.

The trials reported here and confirmed in commercial practice suggest a PP 321 dose of about 10 g a.i./ha as a minimum reliable dose for weevil control with a range to 15 g a.i./ha for high infestation levels. These trials have not demonstrated that the spray interval can be any longer than used with existing products, i.e. 3-5 days depending on infestation intensity. Toxaphene may be beneficially used as the carrier for ULV applications. An early start to spraying, at the commencement of squaring, increased the chance of a yield increase and there was also the suggestion that a lower spray threshold of 5% damage squares during August and September lowered the level at which the main infestation later peaked.

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