USE OF PEGASUS® (DIAFENTHIURON) AGAINST DIAMONDBACK MOTH (*PLUTELLA XYLOSTELLA*) AND OTHER LEPIDOPTEROUS PESTS IN CRUCIFEROUS CROPS

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ABSTRACT

Diafenthiuron is a new type of thiourea derivative for the control of mites, whiteflies and aphids in cotton and vegetables as well as economically important lepidopterous pests in cruciferous crops.

Diafenthiuron controls susceptible and resistant strains of the diamondback moth (*Plutella xylostella)*, the lesser armyworm (*Spodoptera exigua)*, the large white butterfly (*Pieris brassicae)* and the small white butterfly (*Pieris rapae)*.

No cross resistance to other insecticides has been observed so far. With its favourable selectivity, diafenthiuron fits well into IPM programmes. The hymenopterous wasp *Diadegma semiclausum*, an important parasite of *Plutella xylostella*, is not affected by the product. Due to the product's excellent, long lasting activity, treatment with diafenthiuron requires fewer applications than treatment with conventional products in a spray programme.

INTRODUCTION

The diamondback moth (*Plutella xylostella)* and the lesser armyworm *(Spodoptera exigua)* are widespread pests of cruciferous crops, especially in southeast Asia and in the Far East. Four main factors have influenced the diamondback moth and the lesser armyworm to become the most destructive and difficult pests to control, namely continuous cropping, extremely short life cycles (12 - 25 days), low impact of natural enemies and resistance to conventional insecticides.

There is an urgent need for products with a new mode of action in order to keep these pests under control. Diafenthiuron is a new type of compound with a novel mode of action different to organophosphorus compounds, carbamates, pyrethroids and acylurea compounds (Ruder & Kayser, 1993). Diafenthiuron has a broad spectrum of activity covering the most economically important sucking pests, e.g. mites, aphids, whiteflies and important lepidopterous pests in cruciferous crops (Streibert *et. al.* 1988). This paper describes the performance of the product against susceptible and resistant strains of *Plutella xylostella* and *Spodoptera exigua* under field conditions.

MATERIALS AND METHODS

Treatments

Two suspension concentrate formulations of diafenthiuron, a 250 SC (250 g AI / kg) and a 500 SC (500 g AI / kg), and a wettable powder WP 500 (500 g AI / kg) were tested in the field. The tests were carried out using a randomized complete block design with four replicates.

Foliar applications of diafenthiuron at dosage rates ranging from 25 to 60 g AI / 100 l (spray volume 600 - 1000 l / ha) were compared with standard treatments applied at the indicated rates and with untreated checks. The applications were timed on young larvae (L_1 - L_2). For the diamondback moth and the lesser armyworm, sprays are usually warranted, when one out of every three plants is infested.

The assessments were done by counting the number of living larvae on 10 - 20 plants per replicate, and / or a final damage rating was done at harvest. The yield at harvest was grouped into grade A (high quality) and grade B (marketable) produce and is shown in Table 8.

Efficacy against resistant populations

The resistance monitoring data in Thailand showed (Table 1), that the LC_{50} of diafenthiuron for the susceptible diamondback moth strain Tak Fah was in the same order as that for the multiple resistant strains (Bang Bua Thong and Kanchanaburi).

Table 1 Resistance monitoring of *Plutella xylostella* on cruciferous crops, testing method: leaf dipping (Thailand, 1993)

Product	hours	LC_{50} ppm Values of each Location		
		TK	KB	BBT
Diafenthiuron	72	16.2	12.9	15.6
Abamectin	72	0.01	0.02	0.03
Cypermethrin	48	166.3	1430.9	838.5
Cyfluthrin	48	68.01	294.0	456.7
Methamidophos	72	2589.3	3524.9	6381.1
Teflubenzuron	120	0.2	475.8	33.0

TK=Tak Fah (acylurea susceptible strain)
KB=Kanchanaburi (acylurea, organophosphate, pyrethroid. multiple resistant strain)
BBT=Bang Bua Thong (acylurea, organophosphate, pyrethroid. multiple resistant strain)

FIELD TRIAL RESULTS

Diamondback moth (*Plutella xylostella*)

Diafenthiuron was highly effective against the diamondback moth in field trials throughout southeast Asia and the Far East.
Two sprays with diafenthiuron at rates of 33 and 50 g AI / 100 l at intervals of 7 days provided control. The efficacy of diafenthiuron was significantly better than that of standard treatments as demonstrated in the results from Japan (Table 2).

Table 2 Control of *Plutella xylostella* on cabbage (Kagoshima Agr. Exp. Station, Japan, 1989)

Product	Formulation	Dose [1] (gAI/100l)	Mean % efficacy 2 DAT	7 DAT	12 DAT	14 DAT
Diafenthiuron	50 % WP	50	93	85	90	97
Diafenthiuron	50 % WP	33	66	85	89	96
Cartap	50 % SP	57	57	25	50	60
Fenvalerate + Malathion	34 % WP	34	26	0	36	30
Untreated [2]			(35)	(40)	(311)	(274)

[1] Application dates: 25/9 + 2/10/89, using 600 l/ha, applied with knapsack sprayer
[2] Mean nos. larvae / 20 plants

In addition, diamondback moth populations were effectively controlled by diafenthiuron where teflubenzuron and other insect growth regulators failed due to resistance. A high level of control was achieved with 5 sprays at weekly intervals in Taiwan (Table 3).
Four applications of diafenthiuron at intervals of 5 days at 40 and 60 g AI / 100 l resulted in higher yield and better quality than the application of chlorfluazuron in Thailand (Table 4).

Table 3 Control of *Plutella xylostella* on cabbage (Taiwan, 1989)

Product	Formulation	Dose [1] (gAI / 100 l)	Mean % efficacy of 4 counts
Diafenthiuron	50 % WP	50	97
Teflubenzuron	15 % SC	40	54
Untreated [2]			(25)

[1] Application: 5 sprays at weekly intervals with a knapsack sprayer using 1000 l spray/ha
[2] % damage

Table 4 Efficacy of diafenthiuron against *Plutella xylostella* on cabbage (Thailand, 1990)

Product	Formulation	Dose [1)] (gAI /100 l)	Mean % control	Yield (tons / ha)
Diafenthiuron	50% SC	60	69	15.5
Diafenthiuron	50% SC	40	50	14.1
Chlorfluazuron	12 % EC	15	11	10.2
Untreated [2)]			(3.4)	6.3

[1)] Application: 4 sprays at intervals of 5 days using 1000 l/ha with a knapsack sprayer
[2)] Number of larvae per leaf

Diafenthiuron was highly effective against the *Plutella xylostella* strain that is highly resistant to pyrethroids as shown in table 5. The first spray was applied to the young larvae which were killed. Although older larvae remained alive, due to the mode of action of diafenthiuron, their feeding activity was stopped.The second application, 7 days after the first, provided 100% control and resulted in a higher yield than the standard treatment.

Table 5 Efficacy of diafenthiuron against *Plutella xylostella* on *Brassica oleracea* (Shanghai, China, 1992)

Product	Formulation	Dose [1)] (gAI / ha)	Mean % efficacy [2)]				Yield (tons/ha)
			13/9	17/9	20/9	24/9	
Diafenthiuron	50 % WP	487.5	97	97	100	100	25
Diafenthiuron	50 % WP	325.5	92	94	97	99	24
Fenvalerate	20 % EC	780	31	5	20	5	20
Untreated[3)]			(19)	(219)	(257)	(259)	18

[1)] Application dates: 10/9/92 + 17/9/92, first and second spraying using 975 l/ha, applied with knapsack sprayer
[2)] Analysis with SSR method (P = 0.05)
[3)] Number of larvae per 35 m^2 plot

Lesser armyworm (*Spodoptera exigua)*

The lesser armyworm (*Spodoptera exigua)* is a serious pest of brassicas in southeast Asia. The attack by this pest may lead to total crop loss, even when control measures are applied, because either compounds lack sufficient activity or the pest is seen and sprayed too late. Diafenthiuron at 50 g AI / 100 l was effective in preventing damage by *Spodoptera exigua* (Table 6).

Table 6 Control of *Spodoptera exigua* on Chinese kale (Thailand, 1993)

Product	Formulation	Dose [1] (gAI/100 l)	% Control			% damage
			3/2	10/2	16/2	
Diafenthiuron	25 % SC	50	90	100	57	3
Abamectin	1.8 % EC	1.8	60	50	28	11
Bacillus thuringiensis[4]		200 [2]	80	75	57	9
Untreated [3]			(10)	(4)	(7)	23

[1] Application dates: 18/1, 23/1, 29/1, 3/2, 10/2, 16/2, using 800 l/ha
[2] g formulated product
[3] Mean nos. of larvae / 20 plants
[4] BACTOSPEINE®

Small white butterfly (*Pieris rapae*)

Good results have also been obtained against *Pieris rapae* on Chinese cabbage after only one spray with diafenthiuron at 25 and 50 g AI /100 l. Results from South Korea are presented in Table 7.

Table 7 Efficacy of diafenthiuron against *Pieris rapae* on Chinese cabbage (South Korea, 1990)

Product	Formulation	Dose [1] (gAI/ 100 l)	% Control 3 DAT	5 DAT
Diafenthiuron	50 %WP	50	98	100
Diafenthiuron	50 % WP	25	83	100
Fenvalerate	5 % EC	5	100	100
Untreated [2]			(90)	(98)

[1] Application: 1/10/90, using 1000 l/ha , applied with knapsack sprayer
[2] Mean nos. larvae / 20 m^2 plot

Anti-resistance strategy

The rapid development of resistance of the diamondback moth to most insecticides has forced the development and establishment of an insecticide resistance management strategy (IRM).

The importance of maintaining the effective life of an insecticide for controlling *Plutella xylostella* and *Spodoptera exigua* as long as possible needs no further emphasis.

Our recommendations for using diafenthiuron on cruciferous crops are as follows:

- Never use it alone continuously.
- Alternate it with effective B.t.'s or other effective products.

The insecticide resistance management (IRM) is an integral part of the IPM. In cruciferous crops, hymenopterous parasitoids, such as *Diadegma semiclausum* and *Cortesia plutellae*, play an important role in controlling the diamondback moth. Field studies have shown that there was no deleterious effect of diafenthiuron on those two beneficial hymenopterans in an integrated spray programme (Table 8).

Table 8 Yield performance of diafenthiuron, in comparison to competitive products, applied under farmer's conditions to control diamondback moth on head cabbage (Philippines, 1993/94)

Product [1]	Formulation	Dose [2] (gAI/ 100 l)	No. of sprays	Damage [3]		Quality (tons/ha)		Yield (tons/ha)
				30 DAT	60 DAT	A	B	
Diafenthiuron	50 % SC	30	2	7.35	3.80	26	11	37
Diafenthiuron + *Bacillus thuringiensis* [4]	50 % SC 50 % WP	30 200[5]	2 1	8	4.6	23	13	36
Methamidophos	60 % EC	100	4	6.20	4.00	19	13	32
Untreated				7.45	6.15	10	15	25

[1] For all treatments: release of 200 cocoons per 500 plants of the hymenopterous wasp *Diadegma semiclausum* 44 and 55 days after the transplanting of the head cabbage

[2] Applications at threshold level of 3 diamondback moth larvae / plant

[3] Damage rating 1 = no leave damage, 2 - 3 = leaves with holes, 5 = moderately damaged, 7 = severely damaged, 9 = leaves skeletonized

[4] Products were used in alternation

[5] g of formulated product

CONCLUSION

Diafenthiuron provides effective control of susceptible and resistant strains of lepidopterous pests in cruciferous crops. There has been no cross - resistance of diafenthiuron from conventional products currently in use. Diafenthiuron can be considered as an ideal tool in anti-resistance and integrated pest management for cruciferous crops.

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ADDITIVE EFFECTS OF SOIL-APPLIED INSECTICIDES AND PARTIAL HOST-PLANT RESISTANCE AGAINST CARROT FLY (PSILA ROSAE) ON CARROTS

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ABSTRACT

A log-dose system was used in three field experiments to assess the performance of carbofuran and phorate on cvs. Clause's Sytan Original and Danvers 126. 32-39 weeks after drilling, 60-75% of untreated Danvers roots were damaged by carrot fly but only 42-49% of untreated roots of the partially-resistant Sytan were damaged. Effects of the insecticides and cv. Sytan were additive: similar decreases in the numbers of larvae given by insecticides on cvs. Danvers and Sytan gave less undamaged roots with cv. Danvers than with cv. Sytan. Concentrations of total phorate residues in mature carrots from the three sites were larger in roots of cv. Sytan than in cv. Danvers. The results confirm that the partially resistant cv. Sytan offers a sound basis for diversified systems of protecting carrots against carrot fly, with insecticides supplemented by other methods of suppressing populations of the pest.

INTRODUCTION

To meet the stringent damage tolerances imposed by the vegetable industry in the U.K., commercial carrot production now depends precariously on the very few soil-applied insecticide treatments available to control carrot fly. The use of more-diversified systems of carrot fly control, with insecticides supplemented by other methods of suppressing pest populations, would help to reduce this vulnerability of carrot production and the potential hazard of environmental contamination with insecticides. The cost of inputs for carrot production may also be reduced and opportunities for higher overall levels of carrot fly control may increase (Wheatley and Thompson, 1981). Some research at Horticulture Research International (HRI) has aimed therefore to develop systems for the protection of carrots against carrot fly based on the integration of genetic and chemical methods of crop protection.

Progress has been made at HRI to identify carrot cultivars consistently less damaged than others by carrot fly larvae. In extensive field trials, cv. Clause's Sytan Original and cv. Danvers 126 represented the extremes of the range of resistance (Ellis and Hardman, 1981), Sytan being significantly less damaged than Danvers 126 and thus offering an opportunity for cv. Sytan to be tested in an integrated system with insecticides. This paper summarises the results of three field experiments in which the performance against carrot fly of two granular

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insecticide formulations applied to the cvs. Sytan and Danvers was assessed using a log-dose system developed at HRI to provide detailed dose/response relationships for the insecticides (Thompson, 1984).

MATERIALS AND METHODS

Field experimentation

One experiment was done on a sandy loam at Wellesbourne and two on black fen soils in Norfolk, at Feltwell and Methwold. A base fertiliser application of 100 kg N/ha, 230 kg P_2O/ha and 230 kg K_2O/ha was used at Wellesbourne. At Feltwell, fertilisers were not applied to the experiment site but at Methwold a base application of 0 kg N/ha, 53 kg P_2O/ha and 105 kg K_2O/ha was made. Carrot seed (cvs. Clause's Sytan Original and Danvers 126) was sown with tractor-mounted Russell close-row seeder units, sowing 100 seeds/m row in each half of the twin rows. The experiments were drilled in 1978, on 9 May (Feltwell), 10 May (Methwold) and 11 May (Wellesbourne). At Wellesbourne, weeds were controlled by hand-weeding. At Feltwell, 0.75 kg linuron/ha (50% a.i. w.p.; Du Pont Linuron 50 Weedkiller) was applied on 9 May, followed by: 3.3 kg pentanochlor/ha (40% a.i. e.c.; Herbon Solan 40%) on 5 June; 2.6 kg pentanochlor, 1.3 kg chlorpropham and 2.6 kg isophorone/ha (30% a.i. e.c.; 15% a.i. e.c. and 30% a.i. e.c.; Herbon Brown) on 3 July; and 3.3 kg pentanochlor, 1.7 kg chlorpropham and 3.3 kg isophorone/ha on 31 July. Subsequently, the experiment was hand-weeded. At Methwold, herbicide treatments similar to those used at Feltwell were applied on 10 May, 5 June, 3 July and 31 July but, in addition, 3.3 kg pentanochlor, 1.7 kg chlorpropham and 3.3 kg isophorone/ha were applied on 11 September. Aphicides were not used at Wellesbourne; demeton-S-methyl (58% a.i. e.c.; Metasystox 55) was applied at 0.24 kg a.i./ha on 5 June, 3 July and 31 July at Feltwell but only on 5 June and 3 July at Methwold.

Plot layout

Split plot designs were used for the three experiments, the main plots in each of the six replicated blocks at each site being assigned to the two carrot cultivars tested. Plots comprised 9-m lengths of twin rows, 15 cm apart and at 71 cm centres. In each main plot, a systematic grid of untreated 'check' plots was laid down to determine the presence of consistent trends in carrot fly damage over the experiments (Thompson and Wheatley, 1977). Individual insecticide treatments were assigned at random to one plot within the 'grid' in each main plot so that effects of insecticides against carrot fly on each cultivar could be estimated in relation to the appropriate check plots.

Insecticides

Each experiment included treatments with granular formulations of phorate (10% a.i.; Thimet) and carbofuran (5% a.i.; Yaltox). Continuous, exponentially-increasing doses of the insecticides were applied to specially-designed tractor-mounted, vee-belt applicators using an exponentially-grooved trough and incorporated in the soil at drilling by the bow-wave technique (Thompson et al., 1983). Phorate was applied to give a median dose of 26.0 mg a.i./m of each row in the twin row in the first of the 10 contiguous 0.9-m long subplots/plot, the median dose increasing exponentially (x 1.3195/sub-plot) to 315 mg a.i./m row. Similarly, carbofuran was applied at 19.2-232 mg a.i./m row.

Assessment of effects of insecticides against carrot fly

Damage caused by carrot fly larvae was assessed on mature roots harvested on 18 (Feltwell) and 20 (Methwold) December 1978 and 8 February 1979 (Wellesbourne). All plots were separated into 10, 0.9-m long sub-plots and roots of all carrots in each sub-plot were harvested, washed and graded for the presence of carrot fly damage. The numbers of damaged and undamaged roots in each sub-plot were recorded. Data from the first and last sub-plots of each plot were excluded from the subsequent statistical analyses because 'end effects' in the application of insecticides caused anomalous effects (Thompson et al., 1983).

Insecticide residues in carrot roots

Samples of roots taken at harvest in December 1978 (Feltwell and Methwold) and February 1979 (Wellesbourne) from sub-plots 4 and 8 (corresponding to median doses/sub-plot equivalent to 59.7 and 181 mg a.i./m row) from three of the six phorate-treated plots, selected at random, at each site were used for the detection and analysis of parent phorate, phorate sulphoxide and phorate sulphone using methods described by Suett (1971).

Assessment of the additivity of the effects of insecticides and host-plant resistance against carrot fly

Doses of insecticides applied to sub-plots 2-9 inclusive were used to fit regression lines for each cultivar/insecticide combination at each site. To incorporate the effects of carrot cultivars, Phelps and Thompson's (1983) equation (2) was applied as follows. The proportion of undamaged roots of cultivar v on sub-plot j of a plot treated with insecticide i, q_{vij}, and the dose applied, d_{ij} mg a.i./m row, were related according to the model:

$$\ln(-\ln q_{vij}) = \ln(-\ln c_{bv}) + \alpha_{vi} + \beta_{vi} \log d_{ij}$$

where ln denotes natural logarithms and log denotes logarithms to the base 10. The constant c_{bv}, the proportion of undamaged carrot roots in the untreated check plots in block b of cultivar v, represents the base level of carrot fly damage. This allowed calculation of the percentage decrease in the population of carrot fly larvae for each cultivar, compared with its own base level in each block:

$$\% \text{ decrease} = 100\,(1-\exp(\alpha_{vi} + \beta_{vi} \log d_{ij})).$$

The additive effects of partial host-plant resistance and insecticides were assessed by comparing the regression lines for each cultivar (equations (9), (10) and (11) of Phelps and Thompson (1983)).

RESULTS

Damage caused by carrot fly larvae to roots of cv. Danvers in untreated check plots 39 weeks after drilling at Wellesbourne was severe, only 25% being undamaged (TABLE 1).

Damage to cv. Danvers was less severe at Feltwell and Methwold, 37% and 41% respectively being undamaged 32 weeks after drilling. At each of the three sites, untreated roots of cv. Sytan were less damaged than roots of cv. Danvers: at harvest 32-39 weeks after drilling, 51% of Sytan roots at Wellesbourne, 58% at Feltwell and 51% at Methwold were undamaged (TABLE 1).

TABLE 1. Estimated % decreases (± SE) in numbers of carrot fly larvae.

Treatment		Sites (with mean % undamaged roots on untreated plots)					
Insecticide	Dose	Wellesbourne		Feltwell		Methwold	
	(mg a.i./m)	Danvers (25.3)	Sytan (50.5)	Danvers (37.1)	Sytan (57.5)	Danvers (40.8)	Sytan (50.7)
Carbofuran	60	91±0.8	88±1.2	33±3.3	22±3.8	51±3.4	67±3.6
	110	94±0.8	95±0.9	43±3.7	38±3.6	68±3.4	76±3.9
Phorate	60	87±1.0	92±1.0	31±3.9	31±4.3	58±3.0	83±1.7
	110	92±0.8	96±0.8	47±3.0	48±3.4	76±2.3	88±1.4

For all cultivar/insecticide combinations, the regression lines had slopes significantly different from 0. Three possible relationships between the dose-response regression lines of the two cultivars for each insecticide at each site were considered: a common line for both cultivars; parallel lines; and non-parallel lines. A model coresponding to each possibility was fitted for each cultivar/insecticide combination at each site and the residual deviances from the models were compared. A common line described the responses with carbofuran at Methwold and phorate at Feltwell; parallel lines described the regressions for carbofuran at Feltwell and phorate at Wellesbourne and Methwold; and the regressions for carbofuran at Wellesbourne were described best by non-parallel lines ($\underline{P} < 0.05$).

The regression lines obtained with phorate on cvs. Danvers and Sytan at Wellesbourne are shown in FIGURE 1 to exemplify graphically the relationship between (i) the applied insecticide dose, (ii) the estimated effects of the insecticide on the population of carrot fly larvae attacking each cultivar and (iii) the % undamaged roots obtained with each cultivar as a result of the effects of the insecticide and the cultivar itself. It is apparent that, because of the greater susceptibility to carrot fly of cv. Danvers compared with cv. Sytan, a similar decrease in the numbers of larvae provided by an insecticide on cvs. Danvers and Sytan results in less undamaged roots with cv. Danvers than with cv. Sytan, i.e. the scales for % undamaged roots with the two cultivars are offset.

The regressions for each of the insecticide/cultivar combinations were used to estimate effects on the numbers of carrot fly larvae of carbofuran and phorate applied at doses equivalent to 60 and 110 mg a.i./m row. The decreases in the numbers of larvae obtained with cv. Sytan were the same or a little better than with cv. Danvers, except for carbofuran at Feltwell where anyway the efficiency of the insecticide in decreasing the numbers of larvae was low (TABLE 1). Thus, with only one possible exception, the effects of the insecticides and cv. Sytan on carrot fly were additive.

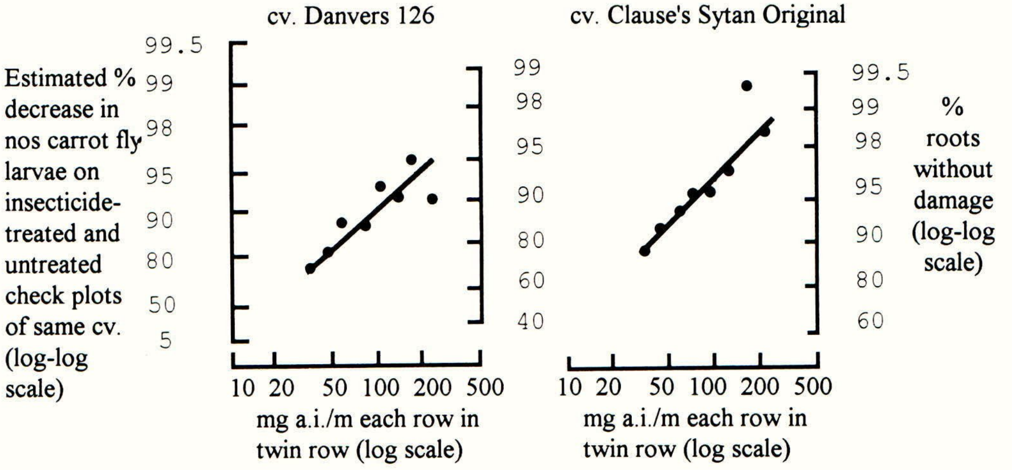

FIGURE 1. The relationship between doses of phorate, estimated effects of the insecticide on the numbers of carrot fly larvae and % undamaged roots of the two carrot cultivars.

The results of the analyses of insecticide residues in mature carrot roots are summarised in TABLE 2 as the means of total phorate residues in roots from the three replicate sub-plots at each site. For each dose of phorate applied at each of the three sites, the concentrations of total phorate residues were larger in roots of cv. Sytan than in cv. Danvers.

TABLE 2. Mean total phorate residues (µg/g) ± SD in mature carrot roots.

Cultivar	Median dose of phorate applied to sub-plots (mg a.i./m row)	Site		
		Wellesbourne	Feltwell	Methwold
Danvers	59.7	0.01±0.003	<0.01	<0.01
	181	0.09±0.038	0.01±0.011	0.11±0.046
Sytan	59.7	0.04±0.023	0.02±0.010	0.05±0.028
	181	0.12±0.040	0.04±0.017	0.26±0.204

DISCUSSION

As the demand for predictable supplies of high quality horticultural produce and constraints on the use of conventional pesticides increase, no one method of protecting crops against major pests and pathogens is likely to be adequately effective; in combination, however, methods may achieve more nearly the required effectiveness. Although the integration of genetic and chemical methods of crop protection has long been advocated, and economic and environmental considerations have become weightier, few attempts have been made to practise the strategy. The results of these experiments represent a valuable addition to the scanty literature on quantitative assessments of the additivity of genetic and chemical components of crop protection systems; they should enable extensive field-scale validation experiments to proceed with confidence. Simultaneously, the precise mechanisms involved in the resistance of carrots to carrot fly will require elucidation. Previous research has indicated some of the factors influencing choice of carrot cultivars by carrot fly and the greater affinity of some cultivars to take up residues of insecticides (Suett, 1975) which may, as suggested by the analyses of phorate in this paper, help to protect the roots against carrot fly. An improved understanding of the mechanisms of host-plant resistance would enable potentially useful resistant, or partially-resistant, germplasm to be exploited in practical, integrated systems of crop protection.

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ORGANOSILICONE SURFACTANTS: TOOLS FOR HORTICULTURAL CROP PROTECTION

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ABSTRACT

Trials on apple have demonstrated that Silwet L-77® organosilicone surfactant (OSi Specialties Inc.; CAS Registry No. 27306-78-1) can be used as a spray adjuvant to increase calcium in fruit, and enables the use of reduced spray volumes. This organosilicone enhanced the efficacy of two organophosphorus insecticides and of a dicarboximide fungicide, so that pest and disease control were maintained despite halving of the pesticide rates. As a result, residues of the pesticides in the fruit at harvest were also halved. Other adjuvants, both conventional and organosilicone, did not match the performance of L-77. Efficacy of the biological insecticide *Bacillus thuringiensis (Bt)* was also enhanced by addition of this surfactant. L-77 had no phytotoxic effects even when applied over full blossom and, notwithstanding up to 18 sprays in combination with a wide range of AIs or at concentrations as high as 0.3%, was not detrimental to fruit finish. The importance of matching organosilicone concentration to application volume, to avoid spray run-off, is highlighted. As a result, screening trials sprayed by hand are unlikely to elucidate potential benefits of L-77 as an adjuvant. Appropriate concentrations of this surfactant for use in high and low volume airblast sprays are suggested.

INTRODUCTION

Adjuvants, whether, tank-mix additives or incorporated as formulants, are widely recognized as an important means of achieving the increases in performance of pesticide sprays necessitated by economic and environmental pressures. Organosilicones have attracted considerable attention as adjuvants for herbicides, but exploration of their potential in horticultural applications has been limited to date.

The often large canopies of horticultural crops, and their extensive use of protectant pesticides, necessitates good spray coverage for effective crop protection. The excellent spreading properties of certain organosilicones like L-77 (Zabkiewicz *et al.*, 1988), suggested its potential value as an adjuvant for horticultural sprays. Because this surfactant has low phytotoxicity (Coupland *et al.*, 1989), its use on crops whose market value is dependent on finish (appearance) was unlikely to be a problem.

EXPERIMENTAL

Those trials from which results are tabulated were sprayed using commercial airblast equipment. Methods for the trial investigating the interaction of surfactant concentration and spray volume using calcium sprays have been reported previously (Stevens & Zabkiewicz, 1990). Likewise for the trial of L-77 as an adjuvant for *Bt* (Suckling *et al.*, 1993). The trial comparing adjuvants utilized 5 sprays applied at approximately 14 day intervals up to the commencement of the 21 day withholding period for chlorpyrifos. Otherwise the trial was similar to those utilising azinphos-methyl (Walker *et al.*, 1992).

RESULTS AND DISCUSSION

General

Between 1987/88 and 1992/93, 12 trials were conducted in New Zealand on apple to evaluate L-77 as a spray adjuvant. In addition to the range of environmental factors encountered during those six seasons, these trials were carried out in seven orchards located in three geographic regions of the country. Half of the trials were performed in commercial rather than research orchards, using treatment blocks up to 1 ha in area. Because multi-AI sprays are the norm for orchard management programs, the trials resulted in L-77 being applied in combination with a wide range of insecticides (azinphos-methyl, carbaryl, chlorpyrifos, hexythiazox), fungicides (captan, dodine, flusilazole, triadimefon, mancozeb, metiram, nitrothal, penconazole), and foliar nutrients (calcium chloride, calcium nitrate, liquidised seaweed). Trials were conducted on five different varieties: Braeburn, Granny Smith, Golden Delicious, Sturmer, and Cox's Orange Pippin. The latter was selected for three trials because it is prone to russet but, despite those trials applying 11, 14 and 18 sprays incorporating organosilicone, no increase in russetting was observed. With the exception of two trials sprayed by hand, sprays were applied using standard airblast equipment, variously in dilute (*c.* 2000 l/ha) and concentrate (*c.* 1000 l/ha) volumes. Optimum concentrations of L-77 in the range 0.05-0.1%, depending on spray volume, were established (see below) but, during an initial trial to assess risk, eight sprays of concentrations as high as 0.3% were applied without phytotoxic affect. In a later trial a spray was applied over full blossom, again without harm.

From this wide range of conditions of use without deleterious affect, it is apparent that L-77 has a high margin of safety on apple. Additionally, this is a robustly efficacious adjuvant; in seven trials investigating the use of L-77 with half rates of insecticides, the presence of, or damage resulting from, at least seven different types of insects on fruit was assessed. In only a single trial was control of one insect significantly less than that provided by the full recommended rate of insecticide applied without adjuvant.

Calcium and L-77 concentration versus spray volume

The incidence of bitterpit, and certain other physiological disorders, that occur during storage of apple (and other fruits and vegetables) has been inversely correlated with the concentration of calcium in the fruit. Accordingly, growers routinely spray apply calcium to their trees.

Addition of a low concentration (0.05%) of L-77 to high volume (2000 l/ha) sprays increased the concentration of calcium in the fruit at harvest (Table 1). This benefit was lost when the concentration was increased to 0.1%. Unlike conventional surfactants, the spreading of L-77 solutions continues to increase appreciably with these concentrations above the surfactant's critical micelle concentration. Thus the high volume in combination with the enhanced spreading of the organosilicone resulted in spray run-off. This was demonstrated by the reinstatement of the benefit when the high concentration (0.1%) was applied in a reduced spray volume (1000 l/ha).

TABLE 1. Interactive effects of L-77 concentration and spray volume on calcium in Cox's Orange Pippin apple fruit at harvest.

L-77 (%)	Volume (l/ha)	Calcium * (mg/100 g fresh wt)
0	2000	2.20 a
0.05	2000	2.41 b
0.1	2000	2.19 a
0.1	1000	2.38 ab

* significantly different at P = 0.05 if no letters in common

The trees used in this trial were single leader growth form, approximately 4 m high. The form, the size, and even the seasonal canopy development of trees all may influence the optimum combination of surfactant concentration and spray volume. Regardless, the combinations of 0.05% L-77 in dilute sprays and of 0.1% in concentrate sprays have since been used repeatedly to good effect in trials on different trees in different orchards, and even on other crops, e.g. nectarine. These combinations are recommended, at least as starting points, for persons wishing to spray fruit trees using this adjuvant. Since these combinations equate to a single rate of 1 l/ha, and their performance is comparable, for logistical reasons growers are likely to opt for the lower volume spray that use of L-77 enables.

Pest and disease control and pesticide residues

Azinphos-methyl is one of the insecticides most widely used by apple growers, because it has good activity against leafrollers, the primary pests of this crop in New Zealand, and, having a 14 day withholding period, can be used close to harvest. Control of leafroller and of scale was lost when azinphos-methyl was applied at half recommended rate (Table 2). However, addition of L-77 to half rate sprays restored control to levels comparable to that provided by azinphos-methyl alone at full rate.

The mode of action of this enhancement in insecticidal activity has not been ascertained. It may be related to improved spray coverage on foliage at the droplet level (coverage at the canopy level is a function of spray application), with increased spreading of the spray depositing insecticide on all foliar surfaces, including in the 'nooks and crannies' which these cryptic insects inhabit. Evidence for this appears to be provided by the absence of any benefit of L-77 when identical treatments were applied by hand to trees in the same orchard during the same season (Walker *et al.*, 1992). Clearly, complete coverage by spraying to run-off will negate any advantage that is attributable to the spreading properties of this organosilicone. The important implication of this result is that screening procedures used by the agrichemical industry, which commonly spray to run-off or use high volumes to ensure coverage, are unlikely to reveal the benefits that L-77 may provide under field use conditions.

TABLE 2. Control of pests on Sturmer apple (average of two season's trials) and residues of azinphos-methyl and of captan in fruit at harvest when applied at half rates with L-77.

Treatment		Fruit damaged (%) by *		Residues (mg/kg fresh wt)	
rate	L-77	leafroller	scale	azinphos	captan
recommended	-	0.2 a	0.7 ab	0.49	1.3
half	-	1.9 b	1.2 b	0.23	0.5
half	+	0.4 a	0.3 a	0.28	0.3

* within pests, significantly different at P = 0.05 if no letters in common

L-77 is used as a penetrant with many systemic AIs, and thus concern was that it might increase movement of pesticides into the fruit, jeopardizing production within maximum residue levels (MRL). However, the surfactant had no affect on the residues of azinphos or of captan fungicide, both protectant chemicals, which were approximately halved in line with their application rates (Table 2).

Reliable data on disease control was not obtained in these trials partly because, being directed at residue reduction, they focussed on the latter part of the growing season, when the weather tends to be drier and not conducive to disease development. Nonetheless, the application of half rates of captan with L-77 in these and other trials never resulted in a failure of disease control. In one subsequent trial, control of blackspot (scab) by a program of sprays of half rate captan was equivalent to that of captan alone at full rate, and superior to half rate captan applied with any of three other adjuvants (Table 3).

In the same trial, use of chlorpyrifos to control woolly aphid (poorly controlled by azinphos-methyl) was examined. L-77 was the only adjuvant to maintain control of both aphid and blackspot with half rates of pesticides. The lesser performance of Citowett (conventional surfactant; BASF) and of Latron B-1956 (sticker; Rohm and Haas) is of interest because the latter two were included in this trial as the dominant adjuvants in the New Zealand horticultural market. Of even greater interest is the lack of efficacy in the presence of Boost™ (DowElanco), also an organosilicone surfactant which, like L-77, is sold as an herbicide adjuvant in the New Zealand. The introduction of organosilicones as agricultural spray adjuvants has, as a result of their exceptional properties, done much to correct the misconception that all surfactants are equivalent, exemplified by blanket recommendations for addition of "nonionic surfactant" on the labels of some products. Increasingly, there is awareness that organosilicones differ and, for instance, can often be used at lower rates than conventional surfactants. The results of this trial clearly demonstrate that performance may vary greatly even among organosilicone surfactants. An OSi Specialties' surfactant structurally analagous to Boost similarly failed to match the performance of L-77, but with azinphos-methyl, apparently indicating that this organosilicone structure is not appropriate for use with organophosphorus insecticides.

TABLE 3. Comparison of L-77 with other adjuvants on performance of half recommended rates of chlorpyrifos insecticide and captan fungicide on Golden Delicious apple.

Treatment		Fruit damaged (%) by *	
rate	adjuvant	woolly aphid	blackspot
recommended	none	0.3 a	0.5 a
half	L-77	0.4 a	0.1 a
half	Citowett	6.5 b	5.4 b
half	Boost	6.4 b	4.4 ab
half	Latron B-1956	1.0 a	8.7 b

* within columns, significantly different at P = 0.05 if no letters in common

An alternative approach to address the issue of pesticide residues is the use of pest control products which are exempt from tolerance. Probably the best known of these is the biological insecticide *Bt,* which has a wide range of applications but does not perform well on pip or stone fruit. Previous good results with another biological agent (McElwee *et al*., 1990) suggested that L-77 might be beneficial with *Bt*, and this was found to be the case (Table 4). Similarly promising results have been obtained with this combination on nectarine (G. McLaren, *personal communication*), and further work is in progress on both crops.

TABLE 4. Control of pests on Granny Smith apple by *Bacillus thuringiensis* ±L-77.

L-77	Fruit damaged (%) by	
	leafroller *	mealybug
-	1.8	0.60
+	0.8	0.07

* significantly different at P = 0.05 for insect damage < 5 mm

The results of a small scale, hand sprayed trial during the 1993/94 season indicate that L-77 also may be advantageous as an adjuvant for the naturally occurring insecticide pyrethrum. It is hoped to explore this further in the next season.

CONCLUSIONS

The trial results presented demonstrate that, when used at an appropriate concentration for the spray volume in which it is applied, L-77 is a valuable adjuvant for use on apple. In particular, this organosilicone surfactant appears to be an important tool for tackling the issues of pesticide residues in food crops. The benefits established here invite exploration of its potential as an adjuvant with a wider range of horticultural crops and their applications.

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CROP COVERING TO PREVENT PEST DAMAGE TO FIELD VEGETABLES, AND THE FEASABILITY OF PESTICIDES APPLICATION THROUGH POLYETHYLENE NETS

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ABSTRACT

The control of insect pests on Japanese radish, cauliflower, Chinese cabbage and Iceberg lettuce using polyethylene netting (with mesh sizes of 0.6, 0.8 and 1.35 mm) was investigated in field trials in The Netherlands in 1988-1991. Insect nets (1.35 mm) protected cauliflower, against damage from *Delia radicum*, *Brevicoryne brassicae* and *Lepidoptera spp*., and Japanese radish against *D.radicum*. Similar results were obtained with nets against *D.radicum*, *Liriomyza huidobrensis* and *Contarinia nasturtii* on Chinese cabbage. Lettuce was fully protected against *L.huidobrensis* and aphids with a mesh size of 0.6 and 0.8mm, however summer covering adversely affected yield and quality.

Evaluation of spraying techniques, for application of pesticides through the net, was carried out in 1992-1993. With air assistance and/or coarse droplet size, in excess of 80% of the spray volume penetrated the net.

I. CROP COVERS TO PREVENT PEST DAMAGE

INTRODUCTION

Most vegetable crops are exposed to insect attack from planting (or drilling) until harvest. The damage caused may reduce yield and quality. To control severe infestations, frequent insecticide application may be needed, but these are not always effective, especially against *Delia radicum*, on Japanese radish and Chinese cabbage, aphid species and *Liriomyza huidobrensis* on Iceberg lettuce (Ester *et al*., 1990 and Ester, 1993). Fewer insecticides are now available for "minor crops" and certain soil applied products suffer from accelerated degradation (Van der Steene *et al*., 1989). Alternative methods of insect control have been investigated. Fine mesh polyethylene nets were shown to be economic as they can be used for 8-10 seasons (Bizer, 1987). A number of trials were laid down to evaluate fine mesh netting for the control of insect pests and the effects on yield and quality on a range of crops.

MATERIALS AND METHODS

Trials were carried out at 3 sites during the period 1988-1991. All sites were selected for high insect populations. Covering with nets was compared with untreated plots and treatment with a standard insecticide programme. All treatments were replicated 3 times in a randomised block design, statistical analysis was carried out using "Genstat".

<u>Site details</u>

<u>Trial 1</u> Crop - cauliflower, Site - Lelystad, Plot - 6.6 x 9.6m

Transplanting dates : a) 12.4.88 b) 26.5.89

Cultivar: a) Fortados b) Andes

Treatments:
1 - untreated
2 - standard - fonofos - 3.75g A.I./100 plants - drench
3 - Net - 1.35mm mesh size

<u>Trial 2</u> Crop - Japanese white radish (mooli), Site - Breda, Plot - 3.2 x 7.3m

Drilling dates: a) 25.4.90 b) 25.6.90

Cultivar: Summer cross

Treatments:
1 - untreated
2 - standard - chlorfenvinphos - 3kg A.I./ha at drilling + 2 x bromophos-ethyl 0.855kg A.I./ha post emergence
3 - Net - 1.35 x 1.35mm mesh - up to 10 days before harvest
4 - Net - 0.8 x 0.8mm mesh - up to 10 days before harvest
5 - Net - 1.35 x 1.35mm mesh - up to harvest
6 - Net - 0.8 x 0.8mm mesh - up to harvest

<u>Trial 3</u> Crop - Chinese cabbage, Site - Westmaas, Plot - 6.6 x 6m

Transplanting dates: a) 18.5.90 b) 23.8.90

Cultivar: Okido F1

Treatments:
1 - untreated
2 - standard - pre-planting, chlorpyrifos at 2.88ml A.I./square metre, - post emergence, bromophos-ethyl 0.571 A.I./ha (a x 3, b x 4)
3 - Net - 1.35 x 1.35mm mesh - up to 2 weeks before harvest
4 - Net - 0.8 x 0.8mm mesh - up to 2 weeks before harvest
5 - Net - 1.35 x 1.35mm mesh - up to harvest
6 - Net - 0.8 x 0.8mm mesh - up to harvest

<u>Trial 4</u> Crop - Iceberg lettuce, Site - Westmaas, Plot - 6.0 x 6.5m

Transplanting dates: a) 24.5.91 b) 14.8.91

Cultivar: Saladin

Treatments:
1 - untreated
2 - standard - pirimicarb 250g A.I./ha + heptenophos 275g a.i./ha + mevinphos 72.5g A.I./ha - 10 applications
3 - Net - 0.8 x 0.8mm mesh - up to 2 weeks before harvest
4 - Net - 0.8 x 0.8mm mesh - up to 1 week before havest
5 - Net - 0.6 x 0.6mm mesh - up to 1 week before harvest
6 - Net - 0.8 x 0.8mm mesh - up to harvest
7 - Net - 0.6 x 0.6mm mesh - up to harvest

(Note - treatments 2-7 were treated with standard insecticide by plunging plants before planting to ensure they were free of aphids.)

RESULTS

Trial 1 - Cauliflower trials 1988 and 1989

The results of the trials are combined in Table 1. The trial in 1988 was severely damaged by D.radicum, while the trial in 1989 was severely attacked by B.brassicae and caterpillars (mainly Plutella xylostella). The net gave 100% control of D.radicum and B.brassicae and almost complete control of caterpillars, in each case proving more effective than the standard insecticide treatment. This was reflected in an increase in marketable heads.

Table 1

Protection of cauliflower with net (mesh size 1.35 x 1.35mm) compared to a standard insecticide programme.

Treatment	% Plants killed (D.radicum) 24.6.88	% Plants killed (D.radicum) 13.7.89	Percentage attacked plants B.brassicae 13.7.89	Percentage attacked plants Lepidoptera spp. 4.8.89	% Marketable yield 24.6.88	% Marketable yield 4.8.89
Untreated	38 b	1.3 b	39 b	9.3 b	30 a	84 a
Insecticide	5 a	0.3 ab	38 b	6.8 ab	61 b	90 b
Mesh	0 a	0.0 a	0 a	0.9 a	68 b	95 b

In all tables means followed by the same letter in the same column are not significantly different at the 5% probability level.

Trial 2 - Japanese white radish (mooli) trials 1990

Results of the summer trial are shown in Table 2. Nets provided almost complete control of D.radicum, irrespective of mesh size (1.35 or 0.8mm) or time of removal. Similar results were obtained in the spring trial although the damage levels were lower. The standard treatment gave poor results and a low level of class I roots. Length and weight of roots showed very little variation. There was also a light infestation of L.huidobrensis.

Table 2

Protection of Japanese white radish with net of 2 mesh sizes compared to a standard insecticide treatment (August 1990).

Treatment	Roots affected (D.radicum)	% Marketable yield	Length cm per root	Weight g per root
Untreated	91 b	4 a	29 a	314 a
Insecticide	81 b	17 a	32 a	339 a
Mesh 1.35mm; 10 days	1 a	85 b	31 a	318 a
Mesh 0.8mm; 10 days	0 a	90 b	32 a	351 a
Mesh 1.35mm; at harvest	6 a	84 b	32 a	351 a
Mesh 0.8mm; at harvest	0 a	82 b	29 a	274 a

Trial 3 - Chinese cabbage trials 1990

Two trials were carried out in 1990, the results of the second trial are shown in Table 3. Nets gave excellent control of D.radicum, Contarinia nasturtii and L.huidobrensis irrespective of mesh size (1.35 or 0.8mm) and time of removal. The standard insecticide treatment gave good control of D.radicum and C.nasturtii but had higher levels of L.huidobrensis than the untreated. The highest yield of marketable heads was achieved with the 1.35mm mesh removed 14 days before harvest. There was an advancement in crop development (one week) in the covered crops.

Table 3

Protection of Chinese cabbage with nets of 2 mesh sizes compared to a standard insecticide treatment (October 1990).

Treatment	% plants infested			% Marketable yield	Weight g per head
	D. radicum	C. nasturtii	L. huidobrensis		
Untreated	98 b	10 b	40 b	56 a	800 a
Insecticide	2 a	0 a	93 c	82 b	1030 b
Mesh 1.35mm; 2 weeks	0 a	0 a	3 a	98 c	900 ab
Mesh 0.8mm; 2 weeks	0 a	1 a	6 a	93 bc	1000 b
Mesh 1.35mm, at harvest	0 a	0 a	2 a	94 bc	970 b
Mesh 0.8mm, at harvest	0 a	2 a	7 a	94 bc	1010 b

Trial 4 - Protection of Iceberg lettuce with nets of 2 mesh sizes compared to a standard insecticide treatment.

Two trials were carried out in 1991 (July and October), the results of which are combined in Table 4. Mesh sizes of 0.6 and 0.8mm were compared with a standard treatment. Both mesh sizes were effective in excluding Aphis spp. and L.huidobrensis. The standard insecticide treatment controlled Aphis spp. but not L.huidobrensis. Crop quality was adversely affected under covers, the 0.6mm mesh more so than the 0.8mm mesh. Removal of the nets 2 weeks before harvest was less damaging than removal 1 week before or at harvest. This damage was associated with "bottom rot".

Table 4

Protection of Iceberg lettuce with nets of two mesh sizes compared to a standard insecticide treatment (1991).

	Average no. of Aphids per head		% plants with L.huidobrensis	% Marketable yield	
	July	October	October	July	October
Untreated	22 b	27 b	76 b	53 bc	82 c
Insecticide	1 a	5 a	80 b	73 c	73 c
Mesh 0.6mm; 2 weeks	-	0 a	6 a	-	49 b
Mesh 0.8mm; 1 week	1 a	-	-	38 ab	-
Mesh 0.6mm; 1 week	0 a	0 a	0 a	22 ab	20 a
Mesh 0.8mm; at harvest	0 a	-	-	15 a	-
Mesh 0.6mm; at harvest	0 a	0 a	0 a	19 a	27 a

DISCUSSION

Earlier work has shown that non-woven crop covers may be used as physical barriers against insect pests, but use during summer months may result in reduction of yield and quality (Antill et al., 1990). The trials reported show that fine mesh nets (1.35mm) will exclude a range of insect pests (D. radicum, B.brassicae, Lepidoptera spp. and L.huidobrensis) on Japanese white radish, cauliflower and Chinese cabbage. The use of a finer mesh size (0.8mm) did not show any advantage. Removal of the net 10-14 days before harvest proved as effective as covering up to harvest (Haseli, 1987). In each case the use of a net gave an increase in marketable yield over the standard insecticide programme. The trial on lettuce showed that nets of mesh size 0.8 and 0.6mm gave protection against Aphis spp. and L.huidobrensis, but there was a reduction in marketable yield. The yield reduction was associated with damage from "bottom rot". It was less serious where the nets were removed before harvest and where the coarser mesh (0.8mm) was used. In comparable trials with the variety Kelvin, yields of covered plots were comparable with the standard (unreported). In the trials on Japanese white radish, there was an "edge effect" in the covered plots, due to restriction of growth by the nets. This would obviously be reduced in commercial growing by the use of wider net sizes.

The use of nets in place of insecticide is a viable alternative in a number of circumstances: organic crops, crops of high value where quality is vital (e.g. Japanese white radish, Chinese cabbage) and crops where pests cannot be controlled due to the lack of "approved" pesticide recommendations. It should be noted that in additon to insect control, the nets afford protection against birds, rabbits, wind, hail and heavy rain. There is also a benefit in that covered crops may mature earlier.

II. APPLICATION OF PESTICIDES THROUGH NETS

LIMITATIONS OF THE USE OF NETS

When a covered crop needs to be sprayed, it is common practice to temporarily remove the net. This will risk entry of insect pests and cause additional labour costs. Trials were set up to assess the level of interception when using a range of techniques to spray through the nets.

MATERIALS AND METHODS

Trials were carried out in 1992 and 1993. Variables investigated were; spray volume, droplet size, air assistance and net tension. Spraying was carried out using the fluorescent tracer Brilliant Sulfo Flavine (BSF). Amounts retained by the net and on the target beneath were washed in known amounts of water and measured by fluorometry.

Net sizes evaluated:

A	0.6mm mesh	75-78g/square metre	fibre 0.16mm
B	0.8mm mesh	55 g/square metre	fibre 0.16mm
C	1.35 mm mesh	56 g/square metre	fibre 0.21mm

Spray techniques:
1 200 l/ha - 2.5 bar pressure - VMD 300µm. Nozzle - Hardi 4110-14
2 as 1 with air assistance
3 600 l/ha - 2.1 bar pressure - VMD 500µm. Nozzle - Hardi 4110-30
4 as 3 with air assistance
In each case forward speed was 5km/h.

RESULTS

Percentage of spray volume passing through the net (to nearest 5%)

	Mesh size	0.6	0.8	1.35
Application	200 l/ha	40	40	50
	200 l/ha + air	60	60	80
	600 l/ha	65	65	80
	600 l/ha + air	85	90	95

Net tension - Comparisons of spray retention with the net "slack" or "taut" showed that with 0.6mm and 0.8mm mesh sizes, the slack net retained more spray. With the 1.35mm mesh size, the effect was only marginal.

DISCUSSION

With standard application volumes at 200 l/ha, at least 50% of the spray is intercepted by the net. This would be unacceptable. For the 1.35mm mesh size, (the standard material for crop covering), the interception is reduced to 20% by either the use of air assistance or by increasing the volume to 600 l/ha with a large droplet size. To achieve acceptable penetration of finer mesh sizes (0.6 and 0.8mm), it is advisable to use 600 l/ha with air assistance. Tests on net tension also showed that for these finer meshes, the net should be taut.

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PESTICIDE APPLICATION TO PLANT PROPAGATING MATERIAL

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ABSTRACT

An experimental apparatus was constructed that enabled low volume sprays to be applied to a flow of plant cuttings in laboratory conditions. Experiments to assess the feasibility of using sprays to control insect pests on plant cuttings used chrysanthemum cuttings at flow rates in the range 40 to 125 s^{-1} which were passed through a counter current of a tracer dye spray at liquid flow rates up to 100 ml min^{-1}. The visualisation of fluorescent dye deposits showed that good levels of an even coverage could be obtained although there were some "shadowing" effects and a lack of penetration into curled leaf surfaces and leaf nodes. Measurements of the deposits recovered from treated leaf surfaces showed that 0.25 μl cm^{-2} could be deposited at the higher spray volume rates. It is concluded that spray treatments with appropriate formulations could be used to control insect pests in plant propagating material.

INTRODUCTION

The large international trade in plant material poses a substantial potential risk to British horticulture from the import of foreign pests and diseases. Government statistics show that the total value of growing indoor plant material imported into the United Kingdom in 1990 was more than £55M, having risen from some £15M in 1981. To minimise this risk, the authorities in the UK restrict the import of plant material and in many cases require treatments to have been carried out to exclude known pests.

Methyl bromide fumigation is a widely used treatment for the control of insect pests which, when correctly applied, gives good penetration and high levels of control without wetting plant surfaces which could in turn, encourage mould and fungal growth. However, there is pressure to reduce the reliance on methyl bromide fumigation because:

(a) of environmental and safety considerations; and
(b) the effective dose "window" for methyl bromide fumigation is relatively small with a risk of phytotoxic damage at dose levels above the window and failure to adequately control the pest at lower dose levels.

These considerations are particularly important because treatment normally takes place in the country of export where regulations can be lax, training in application methods inadequate and because there is currently no effective method for monitoring the standard of fumigation treatment.

The work described in this paper assessed the feasibility of using spray treatments as a technique for treating plant material and particularly cuttings prior to transportation.

EXPERIMENTAL APPARATUS AND TECHNIQUES

Spray treatment rig

The application system was based on two twin-fluid nozzles (Lechler type 156.689.30.06) which were arranged to spray upwards into a treatment area (Figure 1). Plant material was delivered from an upper feed conveyor mounted approximately 850 mm above the nozzle positions and arranged such that a sample of plant material for treatment could be loaded onto the conveyor prior to the start of an experimental run. A lower conveyor with a drive system linked to the feed conveyor (Figure 1) moved treated material into a collection tray. Both conveyors were driven from an adjustable hydraulic motor system at a surface speed of approximately 0.1 m s^{-1}.

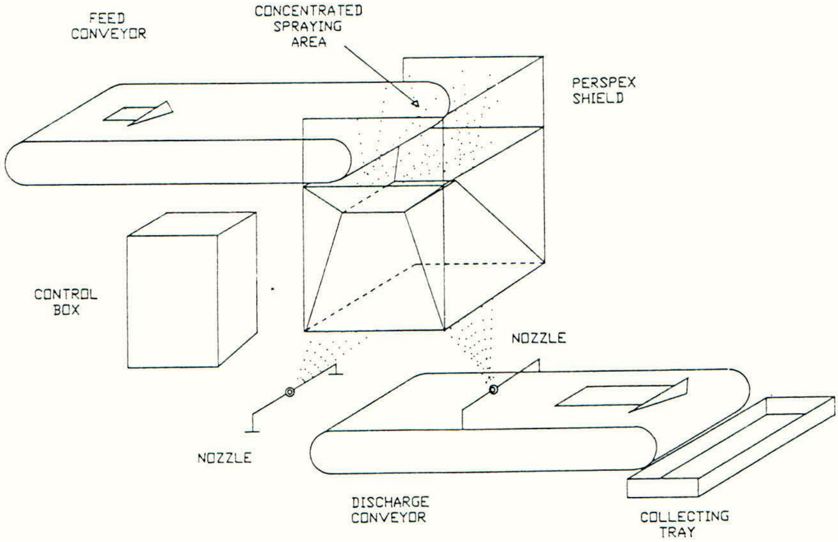

Figure 1 : Diagrammatic layout of spray treatment rig

Twin-fluid nozzles were chosen for this application because they have:
(i) the ability to operate over a wide range of flow rate and spray quality (droplet size distribution) combinations depending upon the input air and liquid pressures;
(ii) relatively high entrained and nozzle air flows which would help in the mixing of spray and a counter-flow of plant material;
(iii) the ability to operate at low flow rates with a low risk of nozzle blockage; and
(iv) the flexibility to work with a wide range of formulation types by introducing the chemical into the water (as with conventional spraying) or mixing it with the air delivered to the nozzle (as in a commercial design of tobacco leaf sprayer).

In the experimental rig, a laboratory supply of compressed air was divided between two separate control valves: one directly controlled the air feed to the spray nozzles and a second regulated the feed to a pressurized liquid container. The flow of liquid into the two nozzle spray delivery system was also controlled by a needle valve and a variable gap flow meter was used to set and monitor the total flow rate of dilute pesticide (or tracer dye) delivered into the treatment chamber.

Initial experiments examined both the operating parameters of the nozzle system and the geometrical arrangement of the treatment chamber so as to maximise the contact between the spray and plant material including the use of deflecting baffles. The configuration used for much of the experimental work reported in this paper used the twin-fluid nozzles in a conventional arrangement with clean air and diluted pesticide or tracer dye in water fed to the separate nozzle ports. A convergent/divergent treatment chamber section was used as shown in Figure 1: baffles were found to give an uneven flow of plant material resulting in some localised over-dosing. Estimates of the fall speeds of chrysanthemum cuttings suggested that they had a terminal velocity of approximately 4 m s^{-1} and counter-current air flows in the treatment chamber were designed to substantially slow the falling cuttings and hence maximise contact with the spray.

Measurement of droplet size and velocity distributions

Measurements of the droplet size and velocity distributions were made using a phase Doppler spray analyser (Dantec Ltd) and sampling along a diameter through the spray cloud and at right angles to the centre-line of the nozzle at a distance of 500 mm from the nozzle. Measurements were made in a sampling chamber with the nozzles operated from the same control system as built into the experimental rig.

Visualisation and measurement of spray deposits

Experiments used solutions and suspensions of fluorescent tracer dyes to visualise overall spray coverage and the distribution of spray on treated plant material observed under ultra-violet light. Most of the work used a 0.4% solution of Uvitex 2B in de-ionised water applied to imported unrooted chrysanthemum cuttings (variety Snowdon).

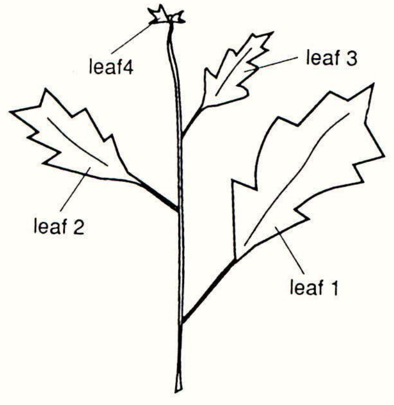

Figure 2 : Diagram of a chrysanthemum cutting showing leaf positions taken for spray deposit analysis

Deposits on cuttings sprayed with dye were quantified by washing the treated leaves and determining the amount of recovered dye by fluorimetry using a Turner fluorimeter (Sharp, 1974). Prior to each run, the instrument was calibrated against standard solutions prepared from dilutions of the original dye. The deposit levels were determined on samples comprising five cuttings with the leaves on each cuttings being numbered (Figure 2), separated and bulked into separate leaf samples for each original sample taken. Deposits on stems were not assessed. All leaf washing used 20 ml of purified water and 0.1% of a non-ionic surfactant to recover dye deposits and the area of treated leaves was determined after washing using an image analysis system fitted with a conveyor belt sampling system (Delta T Devices Ltd).

Some comparative measurements of the deposits on treated leaf surfaces were also made with a surface fluorimeter.

RESULTS

Visual assessments of deposit distribution

The results from the spray deposit visualisation study showed for nozzle flow rates between 25 and 75 ml min^{-1} and with chrysanthemum cuttings delivered at rates of between 60 and 90 s^{-1}, a good coverage of most of the targeted cuttings was achieved. There was some evidence of shadowing (one leaf preventing an even coverage of an adjacent leaf) particularly in the lower spray volume treatments. No improvement in coverage was observed when operating the spraying system at air and liquid pressures above 1.0 bar. Although this probably created very fine sprays, these were not well deposited on the cuttings.

Dye deposits recovered from the treated leaf surfaces

The main experiment examined the effects of increasing the liquid flow rate to the nozzles whilst maintaining a constant pressure (1.0 bar) and flow rate of cuttings (82 s^{-1}), and the results are summarised in Figure 3. The lowest deposit levels were consistently recorded for the smallest leaf of the cutting and total spray deposits increased with nozzle flow rates as expected. The results in Table 1 show the figures normalised to the maximum total nozzle flow rates used. At the lowest flow rate of 20 ml min^{-1}, the spraying system was relatively inefficient at achieving spray transfer and deposition onto plant cuttings and there was some evidence to show that normalised deposits tended to increase with nozzle flow rate.

Table 1 : Measured spray deposits at different spraying system flow rates normalised to the maximum flow rate of 100 ml min^{-1}

Nozzle flow rate ml min^{-1}	Measured deposits, μl cm^{-2} per 100 l min^{-1} of nozzle flow rate			
	Leaf 1	Leaf 2	Leaf 3	Leaf 4
20	0.260	0.180	0.110	0.08
40	0.272	0.248	0.213	0.158
60	0.213	0.257	0.250	0.120
80	0.219	0.206	0.188	0.118
100	0.327	0.278	0.215	0.232

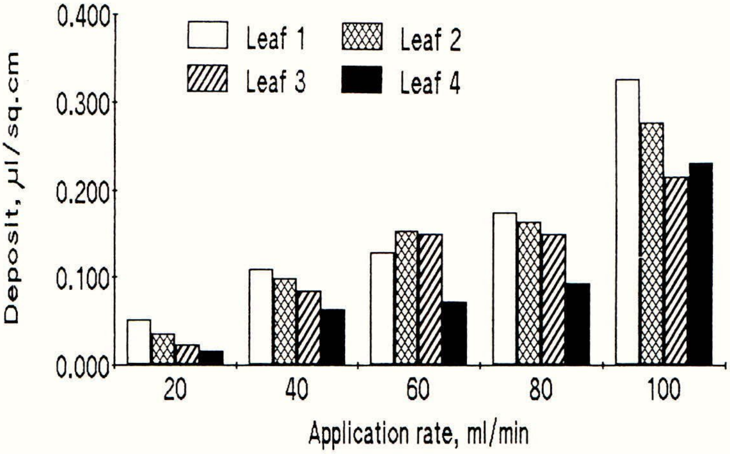

Figure 3 : Spray deposits washed from the leaves of chrysanthemum cuttings sprayed with different total nozzle flow rates

Results from the surface fluorimeter measurements

Results of deposits on 1.0 cm^2 sampled leaf areas showed that 12% of these had very low levels of deposit probably due to leaf shadowing effects. Deposits on the lower sides of leaves were more variable than upper leaf surface deposits possibly due to surface differences. There was no significant difference in deposit levels on the two sides of sampled leaf surfaces.

Measurements of the droplet size and velocity distributions produced by the spraying system

Measured droplet size distributions for the spraying system operating with a pressure of 1.0 bar and at flow rates between 20 and 100 ml min^{-1} showed that the system tended to create a finer spray at the lower flow rates as expected with volume median diameters increasing from 37 μm to 61 μm as flow rates increased from 20 to 100 ml min^{-1}. The droplet size/velocity distributions for the five flow rates showed little variation with flow rate and only a small reduction in entrained air and small droplet velocities at the high flow rates. Mean droplet velocities, weighted by spray volume, were in the range 2.1 to 2.5 m s^{-1} with no consistent trend with flow rate settings.

DISCUSSION OF RESULTS AND CONCLUSIONS

The results from the study indicate that the use of spray treatments using the approach developed is a viable alternative to existing methods of insect pest control. Comparisons with published data (Last & Parkin, 1987; Wyatt *et al.*, 1985) indicates that the experimental application system was achieving relatively high levels of spray deposit both in respect of other methods of applying spray chemicals and the requirements for insect control with different types of formulation and target leaf surface. Some further work is required to identify possible pesticide molecules for insect control in plant material and to develop appropriate formulations for these materials. This work aimed at achieving the highest possible coverage of pesticide on leaf surfaces whilst using low liquid volumes so as to minimise any surface wetting effects. The quantity of material needed to give effective insect control on treated plant material would be a function of the activity of the pesticide material and the nature of the formulation.

The experimental treatment of cuttings was conducted on a small-batch treatment basis with batches of single cuttings being placed on the input conveyor prior to the commencement of a treatment run. During the course of relatively short runs, most of the surfaces surrounding the treatment area did not become heavily contaminated with spray liquid. However, during extended running periods, the contamination of the side walls particularly in the constriction section immediately in front of the spray nozzles, would be very considerable and would need some re-design to ensure that excess spray liquid did not contaminate treated materials. Two possible approaches to controlling this contamination would be:

(i) to use air streams close to the surfaces so to minimise spray impaction on these surfaces; or
(ii) to examine methods of ducting spray collected on these surfaces and re-circulating it so that the potential for contamination of treated cuttings is minimised.

In designing the constriction section it was recognised that it would be necessary to prevent cuttings (or other plant material for treatment) contacting the side walls and the experiments conducted showed that this had been successfully achieved.

The use of additional purging air flows close to the walls in the treatment zone would add to the counter-current air flow that was generated by the spray nozzles. The measurements with the phase Doppler spray analyser suggested that droplet and air velocities within 500 mm of the nozzle orifice were in the order of 2.3 m s^{-1}, and within the experimental apparatus the counter-flow generated by the nozzles was seen to carry significant quantities of airborne spray out of the top of the apparatus. A method of re-circulating this spray-laden air flow or of recovering the fine spray droplets would be required if this principle were to be scaled-up for practical use.

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CONTROL OF SCIARID FLY (*LYCORIELLA AURIPILA*) WITH THE ENTOMOPATHOGENIC NEMATODE *STEINERNEMA FELTIAE*, IN COMMERCIAL MUSHROOM CROPS

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ABSTRACT

Sciarid flies are serious pests of the commercial cultivated mushroom (*Agaricus bisporus*). The larval stages of the flies feed on the mycelium and tunnel into the caps and stems of mushrooms. Larval stages of *Lycoriella* spp. are susceptible to infection by the insect parasitic nematode *Steinernema feltiae*.

Nematodes species within the family *Steinernematidae* are suitable organisms for agents for biological control because of the following attributes: wide host range, ability to kill host within 24-48 hours under optimum conditions, suitable for large scale commercial formulation, durable infective stage capable of storage at room temperature, distribution and persistence, no evidence of insect immunity and environmentally safe.

Ciba started work with *S. feltiae* in 1992 as a potential biological product for sciarid fly control in mushroom crops, in association with biosys and AgriSense-BCS Ltd..

STEALTH, Ciba's latest biological control product, was launched in April 1994 as a result of this association.

INTRODUCTION

Species of *Lycoriella* (Diptera: Sciaridae) are serious pests of the commercial cultivated mushroom (*Agaricus bisporus*) in the production facilities of Europe, North America and other parts of the world. The larval stages of the flies feed on the mycelium and tunnel into the caps and stems of mushrooms, ultimately reducing the quality of the caps and therefore reducing marketable yield.

In the US, Canada, Asia and Australia the dominant species is *L. mali* (Fitch) whereas in the UK it is *L. auripila* Winnertz. Both of these species cause similar problems. The adult flies are often observed on walls of mushroom farm buildings, entering the mushroom houses where eggs are laid in the freshly pasteurised or spawned compost, or in the casing layer after spawn running. The emerging larvae feed on the compost destroying structure and water retention capacity, causing inhibition of mycelial colonisation, resulting in yield losses. Further damage incurred by feeding larvae is the consumption or hollowing out of primordia.

The adult flies are known to be vectors of mycophagous and saprophagous nematodes and mites. They are also a nuisance to the mushroom pickers.

In the UK, mushrooms are the most valuable protected crop and traditionally sciarid flies have been controlled by applications of pesticides - diazinon and diflubenzuron. There are recorded resistance problems with these chemicals; chemicals have also been reported to cause yield depressions in the absence of pest attacks.

The nematode *Steinernema feltiae* (Filipjev) (= *bibionis* after Poinar, 1990) occurs in nature on various dipteran hosts. Larval stages of *Lycoriella* are quite susceptible to infection by the insect parasitic nematode *S. feltiae*.

Steinernema feltiae

Steinernema nematodes are associated with the bacteria *Xenorhabdus* spp. and it is because of these associated bacteria that steinernematids are able to kill and develop in most insects (Poinar, 1990). The relationship between the nematode and bacterium is symbiotic because the nematode cannot reproduce inside the insect without the bacterium and the bacterium cannot enter the insect hemocoel to cause infection without the nematode.

The free-living stage of the nematode is ensheathed in a cuticle retained from the previous moult and carries the bacterium within its intestine. The infective stage locates insects by detecting insect excretory products, carbon dioxide levels and temperature gradients. It initiates infection and is the only stage in the nematodes life cycle that survives without feeding outside the insect in the soil. The infective stage enters the insect via the mouth, anus or spiracles and penetrates mechanically into the body cavity where it releases the bacterium. The bacterium proliferates and causes septicaemic death of the insect within 24-72 hours (probably by the production of proteolytic enzymes), establishes an environment favourable to nematode reproduction, and inhibits the growth of many foreign microorganisms. The nematodes feed on the multiplying bacteria and dead host tissue, usually passing through 2 generations. Eventually when the nutrient source is depleted, the developing juveniles from the second generation, males and females, emerge from the insect cadaver. These are the infective stage nematodes which proceed to seek new hosts.

Xenorahabdus spp. are reported to occur in nature only inside nematodes and infected hosts (Akhurst & Boemare, 1990).

Formulation

The development of entomopathogenic nematode-based products has been hindered by difficulties in formulating products that are easy to use and have an acceptable shelf life. The oxygen and moisture parameters required by each species are critical and must be assessed for the optimum formulation type, ingredients, packaging size and storage conditions.

Nematode metabolism is temperature driven: warm 20-30°C environments increase metabolic activity, thus reducing nematode pathogenicity and viability. Therefore to increase shelf life, most nematode products are kept refrigerated (Georgis,1990).

MATERIALS AND METHODS

In this study the ability of *S. feltiae* to control *L. auripila* was evaluated in commercial mushroom units.

Steinernema feltiae

Steinernema feltiae strains were supplied by Biosys, who have developed advanced formulations of nematodes suitable for commercial distribution and application.

Nematodes were formulated as either 'tea-bag' formulation or a novel flowable. In the "tea-bag" formulation the infective juveniles were carried by polyacrylamide gel beads contained within a polyester organzer bag. When stored under refrigerated conditions the nematode metabolism is reduced in this system, improving storage stability (Georgis, 1990).

The flowable formulation is more convenient to use than the 'tea-bag', contains less packaging and is more stable under unrefrigerated conditions. The formulation consists of infective juveniles suspended in a gel forming polymer. The polymer is contained in a paper pouch divided into 10 channels supported on a plastic frame and is stored horizontally to ensure the nematodes are equally aerated. The polymer immobilses the nematodes to provide a 6 month refrigerated shelf - life. When required the pouch is removed from the frame and the flowable polymer poured into water to make a spray solution. This formulation is considered to be practical since the polymer containing the nematodes dissolves rapidly once diluted in tap water (Georgis, 1992). The work reported here was carried out mainly with the "tea-bag" formulation. Additional work has shown that the formulation types are equivalent regarding efficacy and crop safety.

Immediately prior to application, the nematodes underwent quality control checks, i.e. microscopic examination and *Galleria mellonela* last instar baiting (Bedding & Akhurst, 1975), to assess nematode viability and infectivity.

Experimental Design and Treatments

The treatments comprised of untreated, a chemical standard (diflubenzuron, 10g AI / ha) and *S. feltiae* (7.5×10^9 nematodes / ha). All trials had plot sizes of approx. $2.0m^2$ using a randomised complete block design and four replicates. The trials at Thakeham used a tray cropping system and the trials at Colchester and Canterbury used a shelf system.

Treatments were applied as a drench either to the casing layer or to the compost, within the normal watering regime of the grower. More reliable control has been found with applications to the casing layer (trials not reported here). At the Canterbury site, the growers commercial equipment was used to apply the treatments, the treatments for the other sites was applied using a watering can delivering a volume of 5 litres of nematode + water solution per plot.

Fly Emergence

Natural infestations of sciarid flies provided the pest populations in these trials, these were monitored using in-situ sticky traps. Nylon mesh covers (32x32x20cm) were positioned over each plot, within which was suspended an Agralan yellow sticky trap

(6.5x8.0cm). At weekly intervals the traps were changed, and the number of flies that were stuck to the trap were identified and counted.

Mushroom Yield

The mushrooms were harvested by commercial pickers following the normal regime of the grower. The saleable mushroom yield was recorded per plot, the data being presented as the cumulative total yield over three picks.

RESULTS

Steinernema feltiae Quality Control

Quality control data performed on a batch of nematodes formulated in the flowable system showed nematodes to be viable and infective over at least a six month period under refrigeration (Table 1). The data in Table 1 show the number of *Galleria* larvae in each test either alive or dead 7 days after exposing to nematodes. Subsequent microscopic examination of the larvae for nematode colonisation enabled their classification into nematodes absent, or low, medium or high infestation categories. The microscopic examination in all cases showed a high proportion of very active juveniles.

TABLE 1: Quality Control - *Galleria* baiting of a single batch of flowable formulation.

Treatment	Test date	*Galleria*		Nematodes	Nematodes present		
		Alive	Dead	absent	Low	Medium	High
Untreated	14/9/93-21/9/93	50	0	-		-	-
S. feltiae	14/9/93-21/9/93	0	100	0	37	31	32
Untreated	29/11/93-8/12/93	100	0	-	-	-	-
S. feltiae	29/11/93-8/12/93	0	60	1	13	23	22
Untreated	4/3/94-12/3/94	49	1	1	-	-	-
S. feltiae	4/3/94-12/3/94	0	100	3	34	11	51

Fly Emergence

Sciarid flies infestation varied from moderate to very high in the trials. These infestation levels related mainly to the time of year that the trials were carried out (sciarid fly attacks are greatest in warm weather). Control of flies by *S. feltiae* at the rate of 7.5 x 10^9 /ha was very good, superior to that given by the chemical standard. Overall levels of control given by treatments on a full commercial scale would be expected to be greater than that given in these trials because of the influence of the presence of untreated plots in trials.

TABLE 2: Cumulative sciarid fly counts. Results from three trials at Thakeham and one at Colchester.

Treatment	Thakeham 1	Thakeham 2	Colchester	Thakeham 3
Untreated	710	782	86	89
Diflubenzuron	573	635	54	109
S. feltiae	336	373	40	55

Yield (Table 3)

Three separate flushes were picked in all the trials taken to yield. The yield from the diflubenzuron treatment was significantly reduced (P>0.05) compared to the untreated at the almost pest-free Canterbury site; this trend was also seen at the Colchester site. However, with a heavy pest infestation (Thakeham 1) there was an increase in yield over the untreated.

S. feltiae applied at the rate $7.5x10^9$ nematodes /ha to the casing caused no significant reduction in yield at any site, including the almost pest-free Canterbury site. Yields from this treatment were comparable to the untreated and consistently better than the diflubenzuron standard.

TABLE 3: Cumulative mushroom yields after three pickings, kg /m^2.

Treatment	Thakeham 1	Colchester	Canterbury
Untreated	13.47	9.81	15.32
Diflubenzuron	14.41	8.47	12.53
S. feltiae	15.63	9.74	15.76
LSD (P>0.05)	7.03	3.49	1.07
Pest Infestation	HIGH	MODERATE	LOW

DISCUSSION

Tests on the flowable product showed that nematodes were still highly infective for at least six months under refrigerated conditions, confirming that advances in the formulation of Steinernematid products has led to a significant increase in shelf-life under optimum storage conditions. This has been found to also be the case under room temperature conditions and therefore this has further increased the products commercial potential.

S. feltiae is sufficiently tolerant of conditions existing in the closed environment of mushroom houses and has been shown in these trials to effectively control sciarid flies (*L. auripila*) in mushroom crops. Persistence of nematodes in casing material has been investigated by Richardson & Grewal (1991) showing that there is sufficient nematode persistence to maintain adequate fly control for the duration of a mushroom crop. The data presented here also show that *S. feltiae* has no adverse effect on crop yield or quality.

S. feltiae are safe to use by operators (Poinar,1989) and safe to the environment, making them attractive for use as insecticidal products. *S. feltiae* is ubiquitous in natural occurrence (Hominick & Briscoe, 1990) and is benign in terms of effects on non-target arthropods (Georgis *et al.,* 1991). The formulations of *S. feltiae* tested here were found to be easily applied with the same equipment used for the application of conventional pesticides, making them ideal commercial products. As a result of these data and the advances in the formulation of Steinernematid products a commercial product based on the flowable formulation of *Steinernema feltiae* has been marketed by Ciba under the trade name STEALTH, for the biological control of sciarid flies in mushroom crops.

ACKNOWLEDGMENTS

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