CONTROL OF SCLEROTINIA SCLEROTIORUM AND BOTRYTIS CINEREA ON RAPE AND SUNFLOWER WITH VINCLOZOLIN

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Summary Experiments over several years showed good control of Sclerotinia sclerotiorum and Botrytis cinerea in rape and sunflowers using vinclozolin (BAS 253 04 F). A single application at full flowering proved best, both in reducing disease and in positively influencing yield. The optimum spray application rate is 0.75 kg a.i./ha vinclozolin. Experiments on seed treatment and granule application in sunflowers gave positive indications, but more experimental work is needed on these methods of applications.

Resumé De bons essais contre Sclerotinia sclerotiorum et Botrytis cinerea ont été obtenus dans des essais pluriannuels avec vinchlozoline (BAS 352 04 F) sur colza et tournesol. Dans le cas d'une application unique, le stade de plus propice a été celui de la pleine floraison, tant en ce qui concerne les possiblilités d'éradication de la maladie que l'augmentation des rendements. En pulvérisation, la matière active sera appliquée à la dose de 0,75 kg/ha. Les essais de désinfection des semences ou d'application sous forme granulée sur tournesoul sont prometteurs. D'autres essais sont toutefois encore nécessaires dans ces domaines.

INTRODUCTION

In recent years the fungal pathogens Sclerotinia sclerotiorum and Botrytis cinerea have been increasingly responsible for diseases in oil seed rape (Krüger, 1976; Hims, 1979; Williams and Stelfox, 1980; Winter and Huber, 1981) and sunflowers (Guillaumin et Pierson, 1976;, Holtzhausen an Westhuinzen, 1980; Wen-Shi Wu, 1981). Up to the present fungicide use to control the pathogens in these crops has been limited or non-existent.

The active substance vinclozolin (code number BAS 352 04 F) has already proved itself in controlling Botrytis and Sclerotinia in vines, vegetables, fruit and horticultural crops (Beetz und Löcher, 1977; Heimes und Löcher, 1979 a, 1979 b; Mappes, 1980) and so it seemed obvious to test it against these organisms in rape and sunflowers. Results are presented from experiments with vinclozolin in these cultures carried out in several countries between 1977 and 1981.

METHODS AND MATERIALS

Rape experiments

The experiments were laid down in randomized blocks with 4 replicates. Plot size was 20-40 m^2 Spray applications were made using knapsack sprayers with T-jet nozzles SS8002. At the time of the spring growth flush the application rate was 400 l/ha, and at full flowering time 600 l/ha (full flowering i.e. 40-60% of the

Table 1

Control of Sclerotinia sclerotiorum on rape 1977-80

Treatment	Rate a.i. kg/ha	Time of application (G.S.)	Sclerotinia attack 0-100	yield dt/ha	yield rel.
West Germany, n* = 35					
Untreated	-	-	41	30,6	100 a**
BAS 352 04 F	0.75	Full flowering***	10	35,5	116 b
France, n* = 4					
Untreated	-	-	48	29,1	100 a
BAS 252 04 F	0.75	Full flowering	34	31,5	108 b

* n = number of trials

** Figures followed by the same letter are not significantly different at P = 0.05

*** 40-60% of the flowers on the rape plant are open - First petals fall on the main shoot.

Table 2

Control of Sclerotinia sclerotiorum on rape 1979/80
Spraying timing trials

West Germany, n = 7

Treatment	Rate a.i. kg/ha	Time of application (G.S.)	Sclerotinia attack 0-100	yield dt/ha	yield rel.
Untreated	-	-	53	28.7	100 a
BAS 352 04 F	0.5	Spring growth flush	51	30.3	105 ab
BAS 352 04 F	0.75	Beginning of flowering	35	31.1	108 b
BAS 352 04 F	0.75	Full flowering	17	33.5	116 c

flowers per rape plant open, on the main shoot petal fall has begun). An assessment of the frequency of diseases was carried out at the time of cutting, or when the seeds in the pods were brown on one side. Experiments were harvested using small plot harvesters.

Sunflower experiments

Small and large plot experiments were carried out (36 m^2 or 5 ha plots) with 3 or 4 replications. In the small plot experiments applications were made as for rape. Large plot experiments were sprayed by helicopter at a rate of 80 l/ha, a flying speed of 40 km/hour and 4 bars pressure. As with the rape experiments the large plot experiments were assessed at ripening. Small plot experiments were assessed thus:

a) Root attack (= early attack, young plants killed as a result of soil-borne infection). Assessed to determine disease frequency - healthy and diseased plants recorded, and

b) Disease of the heads - disease frequency recorded and, in addi tion, disease intensitv classified on a scale 1-4, where

1 = no disease
2 = < 10% disease
3 = 10-25% disease
4 = > 25% disease.

Small plot experiments were not harvested, large plots were harvested using the customary harvesters.

RESULTS

For the control of S. sclerotiorum on rape with BAS 352 04 F (vinclozolin) numerous experiments were carried out between 1977 and 1980. Tables 1 show that at an application rate of 0.75 kg a.i./ha clearly reduced diseases as well as having a positive effect on yield.

The time of application of BAS 352 04 F for the control of Sclerotinia in rape is particularly important. It is clear from table 2, which gives the results of several timing trials, that a treatment at full flowering was the most effective, whereas application during the spring growth flush did not reduce the attack. Yield increases corresponded to the reduction in disease following BAS 352 04 F application.

Results on the control of B. cinerea are comparable with those for Sclerotinia. In table 3 results of 2 experiments in 1979/80 are presented. Here it can be seen that BAS 352 04 F applied at full flowering produced the best results, both with regard to disease control and effect on yield. The rate of 0.75 kg a.i./ha appeared better than of 0.5 kg a.i./ha although yield differences were not significant.

In 2 experiments laid down in 1980 to find the best application time for S. sclerotiorum control no disease occured. However, in both experiments an application of 0.75 kg a.i./ha BAS 352 04 F at full flowering produced significant increases in yield (table 4).

During the period 1977-81 BAS 352 04 F was tested for the control of S. sclerotiorum and B. cinerea in sunflowers.

The diseases were very severe in South Africa in 1981 (table 5), but less severe in Hungary in 1977/78 (table 6). Under conditions of medium to severe early root attack, BAS 352 04 F applied as a seed dressing at 100 g a.i./100 kg

Table 3

Control of Botrytis cinerea on rape 1979/80

West Germany, n = 2

Treatment	Rate a.i. kg/ha	Time of application (G.S.)	Botrytis attack 0-100	yield dt/ha	yield rel.
Untreated	-	-	55	32.6	100 a
BAS 352 04 F	0.5	Spring growth flush	31	34.4	105 ab
BAS 352 04 F	0.75	Beginning of flowering	29	34.0	104 ab
BAS 352 04 F	0.5	Full flowering	30	35.8	110 ab
BAS 352 04 F	0.75	Full flowering	20	37.3	114 b

Table 4

Effect of BAS 352 04 F on the yield of rape 1980 (Disease free situation)

West Germany, n = 2

Treatment	Rate a.i. kg/ha	Time of application (G.S.)	yield dt/ha	yield rel.
Untreated	-	-	32.9	100a
BAS 352 04 F	0.5	Spring growth flush	33.2	101 a
BAS 352 04 F	0.75	Beginning of flowering	34.2	104 ab
BAS 352 04 F	0.5	Full flowering	34.3	104 ab
BAS 352 04 F	0.75	Full flowering	35.1	107 b

Table 5

Control of Sclerotinia sclerotiorum on sunflower 1981
Methods and timing of application (South Africa)

Treatment	Rate a.i. kg/ha	Time of application (G.S.)	% Sclerotinia attack Root	Head frequency	intensity group 3 + 4
Untreated			42	93	60
BAS 352 04 F	0.1/ 100 kg	seed dressing	8	71	32
BAS 352 19 F*	2.0	at sowing	8	84	43
BAS 352 04 F	0.75	bud stage	-	77	30
BAS 352 04 F	0.75	full flowering	-	64	24
BAS 352 04 F	0.5 0.5	beginning of flowering end of flowering	-	55	21
BAS 352 04 F	0.5 0.5 0.5	bud stage beginning of flowering end of flowering	-	52	21

* BAS 352 19 F is a granular formulation of vinclozolin.

Table 6

Control of Botrytis cinerea and Sclerotinia sclerotiorum on sunflower 1977/78

Hungary, n = 7

Treatment	Rate a.i. kg/ha	Time of application (G.S.)	Attack by Botrytis 0-100	Attack by Sclerotinia 0-100	yield dt/ha	yield rel.
Untreated	-	-	27	14	24.0	100
BAS 352 04 F	0.75 0.75	Full flowering Beginning of ripening	4	3	28,8	120

seed gave a clear reduction in early disease. This also affected the attack of the heads by distinctly reducing the proportion of heads in the higher disease classes (table 5).

Application of vinclozolin granular BAS 352 19 F (2.0 kg a.i./ha) has shown similar results as the seed treatment. The granular application clearly reduced any early infection (root attack). However, the late infection on the inflorescence was insufficiently controlled.

Spray treatments during the period of flowering achieved best disease control. A single application (0.75 kg a.i./ha) at full flowering was almost equally effective as two treatments (2 x 0.5 kg a.i./ha) at early and late flowering.

The results of large plot experiments using BAS 352 04 F to control S. sclerotiorum and B. cinerea in sunflowers are given in table 6. Both pathogens were well controlled by 2 helicopter applications (full flowering and beginning of ripening) and respectable yield increases were obtained.

DISCUSSION

From the experimental results the importance of S. sclerotiorum and B. cinerea in rape cultivation can clearly be seen. This is also confirmed by Krüger (1976) and Hims (1979). It is important to observe the time of apothecial development in the development-cycle of Sclerotinia in order to determine the best application time for BAS 352 04 F during the growth period. Ascospore infections can be expected with the appearance of the first apothecia. In previous years the occurence or sporulation of the apothecia coincided almost always with the flowering of the rape. The first petals to fall, trapped in the axils of branches of the rape plants, provide an ideal environment for S. sclerotiorum infection. Initial attack is usually observed here. The application of vinclozolin at this time largely prevents such infections and thus reduces the disease.

With earlier application times there is a risk that insufficient fungicide deposit remains on the plant, while if sprays are applied later infection will probably already have taken place. A rate of 0.75 kg a.i./ha vinclozolin is necessary to provide a sufficient fungicide deposit. This amount is usually sufficient also to satisfactorily control B. cinerea, which attacks later. Depending on the state of the crop 400-600 l/ha water should be used with ground spray machinery. The presence of "tram lines" makes tractor spraying easier and at the same time reduces the likelihood of losses due to wheeling damage.

The results indicate the damaging effect of both S. sclerotiorum and B. cinerea in sunflowers. The extremely severe attack by S. sclerotiorum in Nelspruit was due to the high level of soil infection resulting from several years of sunflower monoculture. This led to mycelial infection in the seedling stage which caused severe disease early on. The good results with the vinclozolin seed treatment in these experiments are attributed to control of this early attack. Under normal conditions such a severe infection would be exceptional. This raises the question as to whether the theory propounded in the literature, namely that S. sclerotiorum can only infect with the help of an exogenous carbon source (pollen or petals collecting in the branch axils of the host plant, Krüger, 1976) is correct. It may be necessary to differentiate more clearly between root diseases in seedlings and the attack on flowering plants.

The best effect with vinclozolin in controlling S. sclerotiorum in sunflowers was obtained with a single application of 0.75 kg a.i./ha at full flowering. Only a double treatment (at the beginning and end of flowering) seemed to improve this result.

Spraying during the flowering stage of sunflower is under field conditions only possible by aerial application. The pre-sowing granule application of vinclozolin did not show a sufficient residual effect to offer an alterative application technique to spraying.

As in rape, it appears that S. sclerotiorum und B. cinerea can occur simultaneously as pathogens on sunflowers, and can combine to cause considerable yield reductions.

The helicopter application of BAS 352 04 F using a reduced quantity of water can be safely carried out, but, in order to obtain efficient and sufficient spray coverage, the state of development of the crop must be carefully considered.

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NOTES

EXPERIMENTS WITH SULPHUR AND OTHER FUNGICIDES TO CONTROL SUGAR-BEET POWDERY MILDEW IN ENGLAND 1977-80

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Summary Spraying sugar beet with sulphur to control powdery mildew significantly increased sugar yield at Broom's Barn in each of the years 1977 to 1980. When sulphur sprays were applied to two varieties differing in susceptibility to the disease, both varieties gave similar increases in sugar yield. However, correct timing of the spray was more critical on the more susceptible variety. In 11 experiments in commercial sugar-beet crops in 1980, sulphur applied just as the disease was beginning to spread increased yield on average by 9%; in three of these experiments where the disease appeared in early August, yield was increased by 21%. In one experiment at Broom's Barn, powdery mildew control and subsequent yield increases were similar with sulphur, nuarimol and triadimefon.

Resumé La lutte contre l'oidium de la betterave à Broom's Barn avec des pulverisations du soufre donnaient des augmentations significatifs en rendements du sucre dans chacun des années 1977 - 1980. Des pulverisations du soufre sur deux variétés de betteraves avec des niveaux differents en susceptibilité à l'oidium donnaient la même augmentation en rendements. Cependant, l'application du soufre dans les premiers phases de la maladie etait plus important avec la varieté la plus prédisposée. Dans onze essais en plein champ en 1980 une pulverisation du soufre au commencement du developpment de l'oidium a augmenté le rendement moyen par 9%; en trois essais ou la maladie se montrait dans la première semaine d'aout l'augmentation en rendement a été 21%. Dans une essai à Broom's Barn des resultats comparables etaient donnees par soufre, nuarimol et triadimefon.

INTRODUCTION

Powdery mildew caused by Erysiphe betae (Vanha) Weltzein has long occurred on sugar beet in England but it was generally considered that its control by fungicides would not be economic. However, work at Broom's Barn from 1971 to 1976 showed that the disease could decrease sugar yield by as much as 15% and that its control with a low cost fungicide such as sulphur was potentially very profitable (Byford, 1977; 1978). These experiments were continued to obtain more data on the optimum time for spraying with sulphur and the economic benefits of spraying in different seasons.

METHODS AND MATERIALS

In large scale trials, plots of approximately 200m^2 were sprayed with a tractor mounted sprayer; small scale trials with 58m^2 plots were sprayed with a gas or hand operated portable sprayer. Plots were arranged in randomised blocks or Latin squares. Fungicides were applied in 400 l. water/ha and sulphur as an 80% w.p. was applied at 11.2kg/ha in 1977 and 1978 and at 10kg/ha in 1979 and 1980, unless stated otherwise.

Powdery mildew incidence was scored using a 0 - 5 index based on percent plants infected and the proportion heavily infected (Byford, 1978). In October and November samples of plants were lifted by hand and yields of tops, roots and sugar were determined.

RESULTS

Trials in 1977 and 1978 tested the effect of applying sulphur at different times to the susceptible variety Nomo (Table 1). The disease was found in the crop in the first week of August 1977 and plants were sprayed on 2 and 12 August, but continuous heavy rain, 110mm between 14 and 31 August, prevented further spraying.

Table 1

Powdery mildew control: Comparison of sulphur sprays on different dates

Broom's Barn 1977 and 1978

	Date sprayed	Mildew score 22 September 1977 0 - 5 scale	Yield Clean roots t/ha	Sugar %	Sugar t/ha
1977	Unsprayed	3.2	52.2	18.2	9.51
	2 August	0.4	54.3	18.6	10.11
	12 August	0.1	55.0	18.7	10.28
	9 September	1.6	54.3	18.5	10.03
	16 September	2.8	51.8	18.4	9.53
	SE±	0.11	0.74	0.10	0.120
1978	Unsprayed		47.7	17.6	8.41
	24 August		50.9	17.6	9.00
	31 August		50.2	17.6	8.85
	8 September		50.3	17.7	8.92
	SE±		0.48	0.09	0.082

The disease subsequently spread rapidly in dry weather in September and two further sprays were applied. In spite of the rain after treatment and the relatively late spread of mildew, sulphur applied on 12 August increased sugar yield by 8%.

In 1978, powdery mildew appeared late in the experimental field at Broom's Barn and the attack was slight. Nevertheless, sulphur applied in late August or early September significantly increased yield of tops, roots and sugar by 10%, 7% and 7%, respectively.

In 1979 and 1980, the effect of the timing of a single sulphur spray was compared on the varieties Nomo and Sharpes Klein Monobeet which had shown most and least infection, respectively, in variety trials at Broom's Barn from 1975 to 1978 (Table 2).

Optimally timed sprays increased sugar yield by 8 - 10% in 1979 when the disease spread in the crop in late August and by 14% in 1980 when the spread was about 10 days earlier. In both years, although powdery mildew increased most rapidly and became most severe on Nomo, the yield increase from spraying was similar with both varieties. However, timing of the spray was more critical with Nomo where

<u>Table 2</u>

Effect of sulphur sprays on different dates, on Nomo and Sharpes Klein Monobeet at Broom's Barn, 1979 and 1980

All sprays with 10kg/ha sulphur except where stated:

	NOMO				SHARPES KLEIN MONOBEET			
Date sprayed	Mildew score 0 - 5 scale mid September	Yield of roots t/ha	Sugar %	Sugar yield t/ha	Mildew score 0 - 5 scale mid September	Yield of roots t/ha	Sugar %	Sugar yield t/ha
1979								
Unsprayed	5.0	59.3	17.8	10.6	4.4	53.9	18.7	10.1
27 July	3.9	56.7	18.4	10.5	2.9	56.7	18.8	10.6
7 August	2.0	58.9	18.6	10.9	2.2	58.3	18.7	10.9
15 August	0.2	62.3	18.5	11.5	0.4	57.9	18.8	10.9
23 August	1.4	61.5	18.7	11.5	0.4	59.2	18.7	11.1
29 August	1.9	62.7	18.5	11.6	0.7	59.5	18.5	11.0
6 September	4.4	59.8	18.3	11.0	2.7	57.5	18.6	10.7
14 September	4.7	55.2	18.0	9.9	3.5	58.1	18.8	10.9
21 September	5.0	58.8	18.2	10.7	4.0	55.4	18.8	10.4
23 August (5kg/ha)	0.9	63.1	18.1	11.4	0.5	58.8	18.7	11.0
SE±	0.41	1.59	0.15	0.27	0.29	1.33	0.12	0.24
1980								
Unsprayed	5.0	42.3	18.3	7.74	2.9	40.7	18.8	7.64
7 August	0.1	47.1	18.8	8.86	0.0	46.2	18.8	8.68
14 August	0.6	46.5	18.6	8.66	0.02	43.9	19.2	8.42
22 August	0.9	46.5	18.9	8.79	0.1	45.0	18.8	8.47
28 August	2.3	43.8	18.6	8.15	0.6	43.9	18.8	8.26
4 September	4.7	44.0	18.5	8.15	1.4	43.4	18.8	8.16
11 September	4.7	42.8	18.5	7.91	2.7	44.8	18.8	8.43
18 September	5.0	41.6	18.6	7.74	3.2	41.5	19.0	7.88
22 August (5kg/ha)	3.1	44.5	18.5	8.24	0.3	45.4	19.0	8.61
SE±	0.45	1.68	0.21	0.307	0.52	1.83	0.20	0.314

1979: Powdery mildew first found near the trial 15 August; spreading in the trial 23 August

1980: Powdery mildew first found near the trial 4 August; spreading in the trial 14 August the yield increase from spraying decreased rapidly when the spray was delayed until after the disease had become established. In 1979 when the disease spread in late August, sprays applied at the end of July were clearly premature.

In these trials an alternative treatment with sulphur at 5kg/ha was applied during the build-up phase of the disease. In 1979 on both varieties and on Sharpes Klein Monobeet in 1980, mildew control and yield increases were the same with both 5 and 10kg sulphur/ha. However, on Nomo in 1980 when spraying was delayed until most plants were already lightly infected, the yield increase given by 5kg sulphur/ha was only half that given by 10kg.

In eleven large scale trials in commercial sugar beet crops in East Anglia in 1980, sulphur was sprayed either at the first development of powdery mildew, two to three weeks later, or on both occasions (Table 3). In three trials in Essex and Suffolk where the disease appeared at the end of July or the beginning of August, the first spray, applied before 10 August, increased sugar yield on average by 21%.

Table 3

Effect of sulphur sprays on yield of sugar beet: sugar factory trials, 1980

a. Mean of three trials in which the disease appeared and the first spray was applied before 10 August:

	Unsprayed	Early spray	Late spray	Both sprays
Yield of roots t/ha	50.0	59.7	54.0	59.7
Sugar percent	18.4	18.7	18.6	18.7
Yield of sugar t/ha	9.20	11.17	10.06	11.19

b. Mean of eight trials in which the disease appeared and the first spray was applied after 10 August:

	Unsprayed	Early spray	Late spray	Both sprays
Yield of roots t/ha	55.8	57.9	55.7	58.5
Sugar percent	17.6	17.8	17.7	17.8
Yield of sugar t/ha	9.78	10.27	9.87	10.37

Although a delayed spray was less beneficial it still increased yield by 9%. In crops where mildew first appeared later in August, a prompt spray increased sugar yield on average by 5%. The effect of spraying twice was variable. In a few trials two sprays gave a greater yield increase than one early spray, but in most cases the second spray gave little or no further yield increase.

In experiments reported previously (Byford, 1977; 1978) several fungicides were tested in addition to sulphur. At Broom's Barn in 1980, the systemic fungicides triadimefon (280g/ha) and nuarimol (280g/ha) were compared with sulphur (Table 4). In a trial where both disease incidence and the yield increase given by fungicides were less than in the adjacent experiment reported in Table 3, triadimefon and nuarimol increased sugar yield by 9% and did not differ significantly from sulphur.

In all the above experiments the main benefit obtained by controlling powdery mildew was in increased yield of roots. In some experiments spraying gave a small but significant increase in root sugar content but in others substantial increases in sugar yield were obtained with a negligible change in the percent of sugar in the roots.

Following the significant increase in sugar yield given by a sulphur spray at Broom's Barn in 1978 with only a low incidence of powdery mildew, the possibility

Table 4

Comparison of fungicides to control sugar beet powdery mildew: Broom's Barn, 1980

Spray treatments	Mildew score 0 - 5 scale 11 September	Yield of roots t/ha	Sugar %	Sugar yield t/ha
Sulphur	0.45	49.4	18.6	9.21
Triadimefon	0.54	48.8	18.5	9.04
Nuarimol	0.42	49.0	18.6	9.09
Untreated	2.85	45.4	18.5	8.39
SED±	0.570	1.28	0.19	0.243

Sprays applied 19 August

that the spray might have a beneficial effect on sugar beet yield independent of the control of powdery mildew, was tested in 1979. In three experiments near Tadcaster, Yorkshire, where powdery mildew is usually scarce, Nomo was sprayed with sulphur on three occasions in August and September (Table 5). At harvest in mid-October, sulphur sprayed beet yielded on average 4% less sugar than unsprayed beet. This result was consistent over the nine comparisons sprayed : unsprayed in the three trials although only one spray in one trial differed significantly from unsprayed.

Table 5

Effect of sulphur sprays on the yield of sugar beet in the absence of powdery mildew

Mean of three trials near Tadcaster, Yorkshire, 1979:

Date sprayed	Yield of roots t/ha	Sugar %	Sugar yield t/ha
Unsprayed	54.2	16.6	9.01
8 August	52.5	16.5	8.68
22 August	51.4	16.6	8.53
5 September	52.9	16.5	8.73

It is concluded that the benefit of spraying sugar beet with sulphur is entirely due to the control of powdery mildew. Further tests will be needed to determine whether the small negative effect recorded was normal or the consequence of sulphur spraying in addition to possible local atmospheric pollution.

DISCUSSION

The results reported here confirm the conclusion reached in 1976 (Byford, 1978) that, contrary to previous expectation, spraying sugar beet to control powdery mildew can be economically justified in south-east England. At Broom's Barn sulphur sprays gave significant yield increases in each of the years 1971 to 1980 and increases of up to 25% were obtained in crops where the disease first appeared in late July or early August and spread rapidly.

In 1980 a simple spray warning scheme was operated by the sugar factories in which sugar-beet growers were notified when powdery mildew was first found in their area and were then advised to inspect their own crops and spray with sulphur as soon as the disease was seen to be spreading. As a result, over 15% of the crop in East Anglia was sprayed. It is hoped that a study of the weather in relation to the appearance and spread of the disease at Broom's Barn from 1975 to 1980 will make it possible to give better forecasts.

It is intended that the series of trials in commercial crops started in 1980 and carried out jointly by the British Sugar Corporation and Broom's Barn, will continue for several years. In 1980, a year of relatively high powdery mildew incidence, the largest yield increases from spraying with sulphur were obtained in Essex and Suffolk. In other experiments in East Anglia, spraying increased yield on average by 5%. At 1980 prices, the cost of spraying sugar beet with sulphur (material + application + an estimate of the value of crop lost from damage caused by the sprayer) was equivalent to about 2% of the value of an average crop giving 35t beet/ha at 16% sugar content. On this basis, a single sulphur spray covered the cost of application in all the experiments and gave a profit, ranging from adequate to very large, in all but two.

Publicity given to these results generated much interest amongst beet growers in the use of sulphur and, in 1981, a tendency for growers to spray crops in August without waiting for the disease to appear. The results obtained with sequential sprays at Broom's Barn in 1979 suggest that this may not be the most cost effective approach. Experience, from experiments over a series of years, of the benefits obtained from controlling sugar-beet powdery mildew in East Anglia will, in the long term, determine both the size and the stability of the market for sulphur and other fungicides in the crop.

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SESSION 8B

PEST AND DISEASE CONTROL IN FRUIT AND HOPS

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PROTECTANT AND POST-INOCULATION ACTIVITIES OF FUNGICIDES FOR APPLE MILDEW CONTROL

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Summary Information is needed on the modes of action of fungicides to enable them to be used efficiently in modern supervised control programmes. To supply this information potted MM.106 apple plants, under glass, were inoculated with conidia of *Podosphaera leucotricha*. The plants were sprayed with fungicide either before or after inoculation. The level of mildew infection some 14 to 20 d after the date of inoculation was taken as a measure of the protectant or curative activity of the fungicide. The number of spores produced was taken as a measure of eradicant activity. The results of various tests are summarised to give comparative efficiency ratings for the fungicides.

Résumé Des données sont nécessaires sur le mode d'action des fongicides afin de les utiliser efficacement dans les programmes modernes de lutte supervisée. Afin d'obtenir ces données des pommiers MM.106 en pots en serre ont été inoculés avec des conidies de *Podosphaera leucotricha*. Les plants ont été pulvérisés avec des fongicides avant ou après l'inoculation. Le niveau d'infection 14-20 jours après la date d'inoculation a été considéré comme mesure de l'activité protectrice ou curative du fongicide. Le nombre de spores produites a été considéré comme mesure de l'activité éradicative. Les résultats de divers essais sont résumés pour donner des évaluations comparatives d'efficacité des fongicides.

INTRODUCTION

Modern orchard practice for reasons of economy and efficient disease control must move away from a calendar approach, where spraying takes place every 7 or 10 d regardless of external factors, towards supervised control. A supervised spray programme is based on a rational choice of fungicide. The rate at which it is used and spray date are based on such factors as the quantity of inoculum present in the orchard, the rate of growth of the host plant, the weather and the time of year (Butt and Barlow, 1979).

To operate such a supervised spray programme it is necessary to have full information on the mode of action, persistence and relative effectiveness of the fungicides available for control of the pathogen, in this case *Podosphaera* leucotricha the causal organism of apple powdery mildew. Adequate information to allow direct comparison of fungicides is not always available from the manufacturers so tests were carried out at East Malling Research Station to provide this information. In order to have maximum control over plant growth, spray deposition and inoculation with the pathogen all tests were performed under glass.

METHODS AND MATERIALS

The plants used were small rooted cuttings of the mildew susceptible MM. 106 apple rootstock clone. They were grown in a glasshouse at $20^{o}C \pm 2^{o}C$. Daylength was extended to 16 h in autumn and spring by monochromatic sodium lights. The plants were inoculated either with "dry" inoculum in a settling tower (Kirby and Frick, 1963) or by a wet inoculation technique in which spores were washed off leaves with a surfactant solution (0.5% Triton X 100) and the spore suspension was sprayed onto plants with an aerosol sprayer (Blake et al., 1981). The wet inoculation method is simpler to use and is now used routinely in preference to the settling tower.

The fungicides were sprayed onto batches of five plants again using a small aerosol. The volume applied (1.5 to 2.0 ml/plant) wetted the leaves but did not cause run-off. Unless otherwise stated they were applied at one quarter field strength (FS) where field strength is that recommended by the manufacturer for a routine 7 d high volume spray programme. Spraying was chosen in preference to dipping plants as being nearer to orchard practice. For full details of replication, statistical analyses, spraying, see Blake et al., 1981.

RESULTS

Pre-inoculation or protectant tests

The protectant action was measured by spraying plants at various times before they were inoculated. The plants, including unsprayed controls, were then inoculated together. Records of mildew infection were taken 14 to 20 d after inoculation and are expressed as numbers of colonies per plant. For statistical analysis the results were transformed (log. 1 + x where x = number of colonies) and transformed data are included in brackets.

Table 1 gives the results of a test comparing the protection given to plants by binapacryl or dinocap applied 6 d, 4 d and 1 d before inoculation.

Table 1

Protectant action of binapacryl and dinocap

Fungicide	Day of treatment -6	-4	-1
Binapacryl	2.8(0.47)	2.1(0.26)	0(-)
Dinocap	19.9(1.10)	9.2(0.80)	2.7(0.47)

In Table 1 the results are expressed as number of colonies per plant (5% LSD (transformed data) 0.38) and the number of colonies on unsprayed plants was 4.8 (0.65).

Binapacryl gave better control of mildew than dinocap on each of the days tested but only differed significantly from control plants on days -4 and -1. Eleven fungicides were tested for protectant action and the results are summarised in Fig. 1.

Figure 1

Diagram showing protection given by mildew fungicides

Fungicide	6	4	1	0
Triforine				
Dinocap				
Thiophanate-methyl			←	→
Binapacryl		←	—	→
Bupirimate		←	—	→
Deciquam		←	—	→
Triadimefon		←	—	→
Quinomethionate		←	—	→
Ditalimfos	←	—	—	→
Fenarimol	←	—	—	→
Nitrothal-isopropyl	←	—	—	→
Pyrazophos	←	—	—	→

The arrows (↔) indicate significant control of mildew ($P < 0.05$). Day 0 is day of inoculation.

Post-inoculation tests

The first post-inoculation tests were dose/response tests to compare the activities of the fungicides at field strength - and one half, one quarter and one eighth of that strength. Plants were sprayed 24 h after inoculation. Table 2 gives the results of a comparison of binapacryl, bupirimate and triforine.

Table 2

Dose/response test

Treatment:-	Control	Binapacryl				Bupirimate				Triforine			
Concentration:	---	FS	½	¼	⅛	FS	½	¼	⅛	FS	½	¼	⅛
Numbers of lesions	113	0	0	4.2	7.6	0	0	0	0	6.0	42.8	49.2	26.7
% survival	100	0	0	3.7	6.7	0	0	0	0	5.3	37.7	43.3	23.5
Nos. lesions (Log. 1 + x trans)	2.02	-	-	0.47	0.90	-	-	-	-	0.67	1.61	1.52	1.44

5% LSD (transformed data) 0.52

In this test binapacryl and bupirimate gave significant control of the mildew at all concentrations tested. Triforine gave significant control only at field strength.

In all, eleven fungicides were tested and their performance relative to binapacryl, included as a standard in all dose/response tests, is given in Table 3.

Table 3

Relative activities of fungicides (all at $^{FS}/8$)

Most active	Active	Inactive
bupirimate	binapacryl	triadimefon
fenarimol	deciquam	triforine
pyrazophos	ditalimfos	
thiophanate-methyl	nitrothal-isopropyl	
quinomethionate		

The 'most active' fungicides had less than half the colonies of the binapacryl treated plants; the 'inactive' had more than double.

The post-inoculation control was investigated further by applying fungicides at intervals of up to 13 d after inoculation.

The results of a trial comparing binapacryl and dinocap is given in Table 4.

Table 4

Curative action dinocap and binapacryl at $^{FS}/4$

Fungicide	Day	No. lesions	% survival	Log. (1 + x) lesions
Binapacryl	1	28.4	19.6	1.33
	3	10.0	6.9	0.77
	5	9.6	6.6	0.69
	7	5.4	3.7	0.69
	9	5.8	4.0	0.51
	11	33.8	23.3	1.45
	13	52.0	36.0	1.25
Dinocap	1	18.4	12.7	0.92
	3	9.4	6.5	0.89
	5	1.2	0.8	0.28
	7	2.2	1.5	0.37
	9	3.6	2.5	0.45
	11	6.0	4.1	0.48
	13	23.8	16.4	1.18
5% LSD	--	---	---	0.48
Controls		164	100	2.22

Both the fungicides gave significant control of mildew on each day on which they were applied. Dinocap gave slightly better control than binapacryl in this test, but at most timings the difference was not significant statistically.

To enable fungicides to be compared directly the data from several tests were combined. The mean percentage survival of colonies was calculated for applications of fungicide during the first 5 d of incubation and the materials are ranked on this basis in Table 5. In later trials fungicide was applied only up to day 5 after inoculation.

Table 5

Order of activity of fungicides in curative tests

Fungicide	
Bupirimate	Most Active
Quinomethionate	
Ditalimfos	
Deciquam	
Binapacryl	
Dinocap	
Nitrothal-isopropyl	
Fenarimol	
Thiophanate-methyl	
Pyrazophos	
Triadimefon	
Triforine	Least Active

Eradicant and anti-sporulant activity

The final test of post-inoculation activity was on the eradicant and anti-sporulant action of the fungicides.

Mildew colonies are difficult to wet so fungicides were applied at field strength to plants with sporulating colonies. In this case plants were sprayed to run-off. Discs were cut from leaves at intervals after spraying, placed in bottles containing 30 ml 0.01% Agral solution and rolled on a bottle roller to loosen the spores. Samples were taken daily and the conidia were counted using a haemocytometer. The number of conidia was expressed as a percentage of spores washed from an equal number of discs from an unsprayed plant.

The results of a test comparing binapacryl, bupirimate and triforine as anti-sporulants are given in Table 6.

Table 6

Spores produced on treated plants as a percentage of those on control plants

Day	1	3	5	7	9
Binapacryl	44	55	46	33	75
Bupirimate	38	30	13	16	37
Triforine	53	70	54	100	35

Differences between treatments not significant at 5% level.

The triforine formulation, which wetted the colonies well, had the least effect on subsequent spore production. Bupirimate proved very effective at reducing spore production and rather better than binapacryl. The fungicides included in several tests were compared on the basis of the mean daily spore production expressed as a percentage of controls.

The results are shown in Table 7.

Table 7

Anti-sporulant activity of fungicides

Bupirimate	Most Active
Pyrazophos	
(Binapacryl	
(Ditalimfos	
Deciquam	
Quinomethionate	
Triforine	
Fenarimol	
Nitrothal-isopropyl	
(Thiophanate-methyl	
(Triadimefon	Least Active

Bupirimate was most active, thiophanate-methyl and triadimefon were the least active compounds at controlling spore production.

DISCUSSION

Most of the rankings are in the order which was expected from field trials (Butt *et al.*, 1976; Butt *et al.*, 1979; Cook *et al.*, 1978). The two major surprises concerned triadimefon and triforine. Triadimefon gives excellent disease control under field conditions but is known to need activation by light (Gasztonyi and Josepovits, 1979). This activation may be hindered under glass. Triforine may similarly need activation. As an overall indication of the activity of the fungicides against apple mildew they were rated on a scale of 0 to 4 for their efficiency under the various test categories. The results are shown in Table 8.

Table 8

Overall ratings of fungicides against apple mildew under glass

	Total	
Ditalimfos	14	Most Active
Bupirimate	13	
Pyrazophos)	12	
Quinomethionate)		
Binapacryl	11	
Deciquam)		
Fenarimol)	10	
Nitrothal-isopropyl)		
Dinocap	9	
Thiophanate-methyl	6	
Triadimefon	5	
Triforine	4	Least Active

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A BROAD SPECTRUM FUNGICIDE OF THE TRIAZOLE GROUP FOR USE IN POME AND BUSH FRUIT

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Summary In trials carried out in the U.K. between 1978 and 1980, KWG 0599 applied as high volume sprays at concentrations of 0.0125% - 0.025%, was highly effective against apple scab (Venturia inaequalis) and pear scab (V. pirina) when used in 14 day interval programmes. In 1980, KWG 0599 was applied in high volume spray programmes to soft fruit, and controlled American gooseberry mildew (Sphaerotheca mors-uvae) and leaf spot (Pseudopeziza ribis) in gooseberries and blackcurrants.

When applied up to 108 hours after infection periods, KWG 0599 demonstrated a strong curative action against apple scab.

Résumé Au cours d'essais menés en Grande Bretagne de 1978 à 1980, le KWG 0599 appliqué en pulvérisations de haut volume à des taux variant de 0.0125% à 0.025%, donna de très bons résultats contre la tavelure du pommier (Venturia inaequalis) et la tavelure du poirier (V. pirina) quand appliqué à 14 jours d'intervalle. En 1980, le KWG 0599 fut appliqué en séries de pulvérisations de haut volume sur des fruits rouges et agit contre l'oidium américain du groseillier (Sphaerotheca mors-uvae) et l'anthracnose du groseillier et du cassis (Pseudopeziza ribis).

Quand appliqué jusqu'à 108 heures après les périodes d'infection, le KWG 0599 montra une forte action curative contre la tavelure du pommier.

INTRODUCTION

In Western Europe the success of crop protection measures depends heavily upon the unpredictable weather, and from the fruit grower there is a constant requirement for chemicals with greater efficacy coupled with increased flexibility of application timing. A broad spectrum fungicide possessing protective, curative and eradicative properties would clearly be of considerable interest: KWG 0599 (1-([1, 1'-biphenyl]-4-yloxy)-3,3-dimethyl-1-(1H-1,2,4-triazol-1-yl)-butan-2-ol(IUPAC)) with the proposed common name bitertanol, is an example of such a chemical (Brandes et al, 1979).

KWG 0599 has a broad spectrum of activity when applied to the foliage, controlling powdery mildews, rusts and leaf spot pathogens in a variety of field and glasshouse crops. It has limited systemic properties but shows protective, curative and eradicative action against apple scab (Venturia inaequalis) (Brandes and Paul, 1979). This paper will report small plot field trials carried out by Bayer U.K. in the main fruit growing regions of England between 1978-1980. These trials were designed to investigate rate response of KWG 0599 and the effect of spraying intervals on the control of apple scab (V. inaequalis), apple mildew

(Podosphaera leucotricha), pear scab (V. pirina), American gooseberry mildew (Sphaerotheca mors-uvae) and blackcurrant leaf spot (Pseudopeziza ribis).

METHODS AND MATERIALS

Apples and pears

Three years of work (1978-1980) have been completed with KWG 0599 in the United Kingdom. Plot sizes varied from 2 to 5 trees with unsprayed guard trees between plots to reduce the effect of spray drift, minimise any plot interaction and provide a more uniform inoculum level throughout the trial area.

(a) Protective programmes

The majority of pome fruit trials to date have involved a protective programme approach from bud burst until the danger of scab infection on unprotected foliage was considered to be minimal. KWG 0599, as a 25% wettable powder, was used at concentrations of between 0.0125% - 0.025% a.i. at both 14 and 21 day intervals in 1979 and at 14 days in 1978 and 1980. KWG 0599 was compared with captan (50% w.p.) at the 14 day interval in 1978, 1979 and 1980, dodine (240 g/l. e.c.) at the 21 day interval in 1979 and dithianon (600 g/l. s.c.) at the 14 day interval in 1980. The rates used are listed in Table 1 and follow manufacturers' recommendations.

Trials were replicated 4 times and all treatments were applied by hand lance at high volume (up to 2700 l/ha), leaving the foliage thoroughly wetted and dripping. Application was by mounted or wheeled motor assisted diaphragm pump sprayers (e.g. Allman wheelbarrow sprayer, Rapid Mk V) through twin hollow cone or large bore fan jet nozzles. Treatments were mixed in the spray tank immediately before use.

Where necessary, other crop protection products were included to control pests and diseases not relevant to the trials. They were applied at rates and timings recommended by manufacturers and this work has formed the basis for early compatibility observations.

(b) Curative action

One trial in 1979 at Elm Farm Trials Station (Thurston, Suffolk) was designed specifically to test the curative properties of KWG 0599. The trees, cv. Cox's Orange Pippin, were sprayed at high volume using similar equipment to that already described. The trial was replicated three times with two tree plots separated by guards of three trees. KWG 0599 at 0.025% was applied to separate plots 36, 60 and 108 hours after the commencement of a "light Mills period" (Mills and Laplante, 1954) recorded using a dew balance and thermograph. It was assumed that post Mills period sprays would afford scab protection for 14 days, therefore, no repeat applications were made if successive Mills periods occurred within this interval. An attempt was made to distinguish between protective and curative action of KWG 0599 by using captan at 0.1% as a comparison treatment at the same timings. These treatments were continued throughout the season and were compared with 14 day protective programmes of KWG 0599 at 0.0125% and 0.025%, and captan at 0.1%. Dodine (0.0528%) was applied for comparison in the 36 hours post Mills period treatments as recommended.

(c) Cultivar compatibility trials

Non replicated cultivar trials were conducted each year from 1978 to 1980 at Elm Farm Trials Station on 20 apple and 10 pear cultivars. High volume sprays of KWG 0599 at 0.0125% to 0.05% concentration were applied at 14 day intervals from bud burst until mid July to 4 trees of each cultivar. Disease control and crop growth factors, including yield, were recorded for each of the following cultivars: Apples: Bramley's Seedling, Chiver's Delight, Cox's Orange Pippin, Crispin, Early Worcester, Egremont Russet, George Cave, Golden Delicious, Grenadier, Howgate Wonder, James Grieve, Kidd's Orange Red, Laxton's Fortune, Laxton's Superb, Lord Derby, Lord Lambourne, Newton Wonder, Spartan, Sunset, Worcester Pearmain. Pears: Bristol Cross, Beurre Hardy, Conference, Doyenne du Comice, Glou Morceau, Improved Fertility, Louise Bonne of Jersey, Merton Pride, Packham's Triumph, Williams' Bon Chretien.

Leaf scab and secondary mildew infection levels were assessed in all trials on a percentage cover basis. Three leaves (top, middle and base) from at least 10 separate extension growths per plot were graded using a logarithmic scale.

Fruit scab was similarly assessed on 100 fruits per plot, usually at the normal commercial picking time. Fruit quality assessments were made on size and russet in samples of 100 fruits per plot and overall plot yield was recorded where possible.

Blackcurrants and gooseberries

Replicated trials with KWG 0599 on bush fruit commenced in 1980. Protective programmes were applied as high volume sprays at 10-14 day intervals to plots of 10-12 bushes from grape or early flower until picking. Post harvest treatments were applied depending on infection levels. Applicators were either motor assisted diaphragm pump types as used for the pome fruit trials, or a motorised air assisted knapsack type (K.E.F. Motoblo).

KWG 0599 was applied at rates between 0.0125% - 0.025% and was compared with a tank mix of triadimefon (5% w.p.) with propineb (70% w.p.) at 0.0125% and 0.14% respectively, and either thiophanate-methyl (50% w.p.) at 0.1% or quinomethionate (25% w.p.) at 0.025% in blackcurrants and 0.0125% in gooseberries.

Bush fruit diseases were generally assessed as percentage cover, American gooseberry mildew on 20 new shoots or 500 berries per plot and leaf spot as a whole bush assessment on 4-6 bushes per plot. Later in the season, a combined leaf spot/ leaf fall assessment (Clarke and Corke, 1955) was used.

Non replicated cultivar compatibility trials were carried out in blackcurrants in 1979 and 1980 at Elm Farm Trials Station, with KWG 0599 being applied at rates between 0.0125% - 0.05% every 14 days to the following cultivars: Amos Black, Baldwin, Blacksmith, Cotswold Cross, Malvern Cross, Seabrooks Black, Tor Cross, Wellington XXX, Westwick Choice.

Data analysis

In all replicated trials analyses of variance were carried out except for fruit scab in Worcs. (1979) (Table 1) where fruit numbers were too low and variable within replicates. Data was transformed by $y = \sin^2 x$ and least significant differences (L.S.D.) were computed for 5% and 1% probability levels.

RESULTS

Apples and pears

The results of the protective programme trials on apples are shown in Table 1. Results are from the four trials showing the greatest scab incidence out of ten carried out.

Table 1

Control of apple scab using protective spray programmes

			Leaf scab								Fruit scab							
Trial location/Year			Sussex 1979		Worcs 1979		Sussex 1980		Worcs 1980		Sussex 1979		Worcs 1979	Sussex 1980		Worcs 1980	
Cultivar			Crispin		Nehou		Crispin		Nehou		Crispin		Nehou	Crispin		Nehou	
Number of applications 14 day, 21 day			9, 5		8, 5		9		7		12, 6		8, 5	9		7	
Assessment date			26/7		21/8		20/8		17/9		1/11		21/8	24/10		17/9	
Days after last spray			1		18		22		54		65		18	79		54	
Treatments	% a.i.	Target interval (days)	Trans data*	% Control**	Trans data	% Control	Trans data	% Control	Trans data	% Control	Trans data	% Control	% Control	Trans data	% Control	Trans data	% Control
KWG 0599	0.0125		1.8	99	4.2	91	2.7	99	0	100	0.1	100	74	0	100	0	100
KWG 0599	0.01875						1.0	100	0	100				0	100	0	100
KWG 0599	0.025	14	2.3	99	1.9	99	2.6	99	0	100	0.3	100	96	0	100	0	100
Dithianon	0.0564						1.2	100	0	100				0	100	0	100
Captan	0.1		5.1	93	2.1	99	2.8	99	0	100	1.2	99	93	0	100	2.9	98
KWG 0599	0.0125		5.8	92	7.0	86					3.5	94	75				
KWG 0599	0.025	21	6.8	87	6.6	89					1.9	97	80				
Dodine	0.0528		10.0	73	5.7	92					2.7	95	89				
Untreated			21.0		21.8		35.3		32.3		14.4			15.7		26.5	
% Infection on untreated				13		14		34		29		6	6		7		20
LSD 5%			4.4		4.7		3.1		2.6		1.7		NA	0.5		1.4	
1%			6.0		6.5		4.2		3.6		2.3			0.7		1.9	

* data transformed to $y = \sin^2 x$

** % reduction in area of infection

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Table 2

Control of pear scab using protective spray programmes

			Leaf scab		Fruit scab			
Trial location			Thurston Suffolk	Thurston Suffolk	Thurston Suffolk	Thurston Suffolk	Stowupland Suffolk	
Year			1978	1980	1978	1980	1980	
Cultivar			Glou Morceau	Glou Morceau	Glou Morceau	Glou Morceau	Williams' Bon Chretien	
Number of applications 14 day			9	10	9	10	10	
Days after last spray			85	33	91	72	42	
Assessment date			10/10	8/9	16/10	16/10	16/9	
Treatments	% a.i.	Target interval (days)	% Control	% Control	% Control	% Control	Trans data	% Control
KWG 0599	0.0125		98	100	98	99	4.7	90
KWG 0599	0.01875						3.1	95
KWG 0599	0.025	14	99	100	99	100	2.8	96
KWG 0599	0.05		99	100	100	100		
Dithianon	0.0564						0.8	100
Captan	0.1		99	100	100	100	3.7	93
Untreated							15.9	
% Infection on untreated			35	4	9	1		8
LSD 5%			NA	NA	NA	NA	2.8	
1%							3.9	

Table 3

Apple scab control using curative spray applications - 1979

Location				Thurston, Suffolk						
Cultivar				Cox's Orange Pippin						
				Leaf scab					Fruit scab	
Assessment date				27/6			14/8		24/9	
Treatments	% a.i.	Spray timing	Number of applications before assessment	Trans data*	% Control**	Number of applications before assessment	Trans data	% Control	Trans data	% Control
KWG 0599	0.0125	protective programme 12-14 days from bud burst	7	0	100	10	0	100	1.4	98
KWG 0599	0.025			0	100		0	100	0.3	100
Captan	0.1			0.4	100		0	100	0.7	100
KWG 0599	0.025	36 hours after commencement of Mills period	4	0	100	6	0	100	1.2	99
Captan	0.1			2.7	94		0.7	97	3.5	89
Dodine	0.0528			1.7	95		0.4	98	2.0	96
KWG 0599	0.025	60 hours after commencement of Mills period	4	0	100	6	0	100	1.3	98
Captan	0.1			8.1	66		1.2	93	4.6	82
KWG 0599	0.025	108 hours after commencement of Mills period	4	0	100	6	0	100	2.7	93
Captan	0.1			8.3	55		1.5	82	5.9	71
Untreated				13.8			4.1		11.2	
% Infection on untreated					6.0			0.7		3.8
LSD 5%				4.2			1.7		2.0	
1%				5.8			2.4		2.7	

* data transformed to $y = \sin^2 x$

** % reduction in area of infection

Table 2 contains the results following protective programmes on pears. Adequate scab was encountered in only one of three replicated trials. However, data from cultivar compatibility trials provided information from the susceptible variety Glou Morceau which is also shown in Table 2.

KWG 0599 was effective against leaf and fruit scab on both apples and pears at all rates when applied at 14 day intervals. There were indications from the Worcestershire trial in 1979 and the Stowupland trial in 1980 that the concentration of 0.0125% might be less effective than higher concentrations, although differences were not significant.

Applications at 21 day intervals were less effective than at 14 days. KWG 0599 also exerted some control of secondary powdery mildew on apples, but effectiveness was not reliable when used alone against high infection levels.

The specific trial on curative action at Thurston in 1979 (Table 3) confirms recent German work on this particular property of KWG 0599 (Brandes and Paul, 1979). Complete leaf scab control was obtained with KWG 0599 at 0.025% applied up to 108 hours after a "Mills period". A proportion of this was true curative action as shown by the lower level of control achieved at these timings by captan, a protective fungicide. The protective properties of KWG 0599 at 0.0125% and 0.025% were again demonstrated in this trial.

Bush fruit

The results of American gooseberry mildew and leaf spot control from trials on blackcurrants and gooseberries are shown in Tables 4 and 5 respectively.

All concentrations performed similarly against mildew except on blackcurrants at Bridgewater. The mildew control with KWG 0599 on blackcurrants exceeded that of the standard comparisons, but was not markedly superior on gooseberries.

Leaf spot was measured by both degree of infection and leaf fall. Significant differences between concentrations of KWG 0599 were found at Bridgewater (Table 4), Challock and Worcester (Table 5). Only at Bridgewater and in the leaf fall assessment at Challock were the differences clearly rate related, with 0.0125% inferior to both the higher concentrations. Leaf spot control was at least equivalent to the standard comparisons at the two higher rates in all trials.

Crop safety

Yield and fruit quality investigations in pome fruit showed no statistically significant differences between treatments.

Over three years, KWG 0599 appeared safe to all cultivars of pome and bush fruit to which it was applied.

DISCUSSION

Excellent control of leaf and fruit scab in pome fruit has been achieved in the United Kingdom with KWG 0599 when used in a traditional protective programme of 14 day interval spraying from bud burst. German work on the summer cycle of V. inaequalis has suggested that used in this way, KWG 0599 is effective by reducing both the length of the germ tube and the growth of the subcuticular stroma which then browns and disintegrates (Brandes and Paul, 1979).

Table 4

Control of blackcurrant diseases in 1980 trials, cv. Baldwin

		American gooseberry mildew								Leaf spot (Percentage cover assessment)						Leaf spot (Clarke & Corke, 1955)			
Trial location		Colchester Essex		Great Dunham Norfolk		Stanford Bridge Worcs		Bridgewater Somerset		Thurston Suffolk		Colchester Essex		Bridgewater Somerset		Great Dunham Norfolk		Stanford Bridge Worcs	
Number of applications		7		6		7		4		9		7		4		6		9	
Assessment date		4/8		6/8		28/7		29/6		22/9		23/9		29/6		6/8		9/9	
Days after last spray		32		34		21		7		14		50		17		34		20	
Treatments	% a.i.	Trans data*	% Control	Trans data	% Control	Trans data	% Control	Trans data	% Control	Trans data	% Control	Trans data	% Control	Trans data	% Control	Trans data	% Reduction	Trans data	% Reduction
KWG 0599	0.0125	8.8	93	18.1	86	0	100	17.1	85	4.4	97	4.6	97	10.0	91	7.1	96	38.3	100
KWG 0599	0.01875	11.8	85	12.6	93	0	100	14.0	90	0	100	0	100	3.9	99	7.3	96	34.5	68
KWG 0599	0.025	7.7	94	9.7	96	0.7	100	7.7	97	0	100	0	100	0	100	4.0	98	33.1	70
Triadimefon + propineb	0.0125 0.14	15.8	80	34.6	56	1.6	99	23.1	75	0	100	0	100	8.0	94	11.8	91	35.2	66
Thiophanate-methyl	0.1	24.6	49	33.7	58	12.0	86	35.4	45	3.0+	99+	37.3	55	19.4	67	5.9	98	70.9	11
Untreated		38.4		60.0		37.4		51.4		44.5		68.9		35.3		45.0		90.0	
% Infection on untreated			39		75		37		61		45		83		34		50		100
LSD 5%		11.4		9.6		5.7		4.3		17.6		12.7		5.8		4.4		9.9	
1%		15.5		13.1		7.7		5.8		24.0		17.3		7.8		6.0		13.4	

* data transformed to $y = \mathrm{Sin}^2 x$ ** % reduction in area of infection

+ quinomethionate 0.025% was used instead of thiophanate-methyl in this table

Table 5

Control of gooseberry diseases in 1980 trials, cv. Careless

		American gooseberry mildew				Leaf spot						Leaf fall					
		Berries		Shoots													
Trial location		Wisbech Cambs	Worcester Worcs	Thurston Suffolk		Thurston Suffolk		Wisbech Cambs		Challock Kent		Wisbech Cambs		Challock Kent		Worcester Worcs	
Number of applications		5	4	5		9		7		5		7		6		4	
Assessment date		19/6	4/6	29/6		18/9		26/8		1/8		26/8		1/9		14/8	
Days after last spray		9	13	16		31		36		43		36		28		84	
Treatments	% a.i.	% Control**	% Control	Mean shoots infected from 30 per plot	% Control	Trans data*	% Control	Trans data	% Control	Trans data	% Control	Trans data	% Reduction	Trans data	% Reduction	Trans data	% Reduction
KWG 0599	0.0125	96	100	0.33	99	12.6	92	21.3	86	8.0	96	20.5	87	57.8	29	31.7	68
KWG 0599	0.01875	100	99					21.6	86	9.9	95	18.4	90	34.7	67	36.8	61
KWG 0599	0.025	100	100	1.33	95	17.4	83	19.5	89	1.5	100	18.4	90	24.5	77	17.6	88
KWG 0599	0.05			1.33	95	21.0	77										
Triadimefon + propineb	0.0125 0.14	100	100					11.1	95	8.0	97	18.4	90	21.6	82	26.7	79
Thiophanate-methyl	0.1	96	77	20.00+	21+	16.1+	86+	83.5	3	29.6	58	67.2	13	73.7	8	77.8	5
Untreated				25.00		52.1		90.0		50.2		80.3		85.3		84.0	
% Infection on untreated		1.2	10.0		84.9		61.0		100		39		96		99		98
LSD 5%		NA	NA	6.77		21.4		12.3		7.5		5.9		12.3		16.7	
1%				9.63		30.4		16.7		10.2		8.0		16.8		22.7	

* data transformed to $y = \mathrm{Sin}^2 x$ ** % reduction in infection   NA - not analysed

+ quinomethionate 0.0125% a.i. was used instead of thiophanate-methyl in these trials

Research workers have shown that in certain conditions prophylactic spraying against scab is unnecessary and a more sophisticated approach relying on accurate disease forecasting would be more efficient (Mills and Laplante, 1954; Guilliams and Soenen, 1955; Butt and Burchill, 1975, 1976). KWG 0599 could be an ideal fungicide under these conditions, with curative properties demonstrated up to 108 hours after a Mills period. The curative action is achieved by attacking both the subcuticular growth of the hyphae and the formation of conidiophores, resulting in no development of conidia (Brandes and Paul, 1979).

KWG 0599 has been shown elsewhere (Brandes and Paul, 1979) also to have eradicative properties (defined as fungitoxicity after the appearance of the first symptoms) by reducing the development of conidia on scab lesions.

As is often the case during the critical time from bud burst to the end of April, weather conducive to scab development is not ideal for effective orchard spraying and timely applications may be impossible. Thus, the flexible treatment for scab afforded by KWG 0599 may be particularly useful. Coupled with this, KWG 0599 could also provide the grower with a reduction in secondary apple powdery mildew, thus making crop protection measures simpler in situations of low disease pressure.

Bush fruit growers could benefit from the high degree of effectiveness of KWG 0599 on two major diseases, American gooseberry mildew and leaf spot, thus reducing the complexity of spraying programmes.

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A COMPARISON OF ELEVEN FUNGICIDES FOR THE CONTROL OF POWDERY MILDEW (SPHAEROTHECA MORS-UVAE) OF GOOSEBERRY

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Summary Eleven fungicides were compared for their control of powdery mildew (Sphaerotheca mors-uvae) of gooseberry from 1972 to 1981 inclusive. Best control of both shoot and fruit infection was given by bupirimate, fenarimol, pyrazophos, triadimefon and triforine. Quinomethionate and nitrothal-isopropyl were not as effective and the latter reduced fruit size and adversely affected growth. Poor control was given by benomyl and thiophanate-methyl.

Résumé Entre 1972 et 1981 inclus, onze fongicides ont été compares pour leur efficacité en ce qui concerne la lutte contre le mildiou (Sphaerotheca mors-uvae) de la groseille à maquereau. Le meilleur contrôle de l'infection de la tige et du fruit a été obtenu grâce a l'utilisation de bupirimate, fenarimol, pyrazophos, triadimefon et triforine. La quinomethionate et le nitrothal-isopropyl n'avaient pas la même efficacité et le dernier produit a conduit à une réduction de la taille du fruit tout en ayant une influence néfaste sur la croissance. Le benomyl et le thiophanate-methyl ne se sont pas révélés efficaces dans la lutte contre le mildiou.

INTRODUCTION

Powdery mildew (Sphaerotheca mors-uvae) is a serious disease of gooseberry which can cause heavy losses. In years which favour mildew development up to 100% of the fruit may be affected. The fungus can infect the new shoots thus affecting growth and the following year's crop, as well as reducing the current year's yield.

This report gives the results of an experiment for the control of gooseberry powdery mildew which was carried out at the Soft Fruits Station, Clonroche, Co. Wexford, from 1972 - 1981 inclusive. Seven fungicides were compared with an unsprayed control in each year. In a previous experiment, (Ó Ríordáin et al, 1971), triarimol and triforine gave the best control.

MATERIALS AND METHODS

The experimental design was a randomised block. Plots were 56.2 m^2 and had a single row of six bushes of the cultivar Careless. There were eight treatments including an unsprayed control. The fungicides tested and the rates used are given in Table 1. From 1972 to 1976 there were seven replications. In 1977 the experiment was doubled in size to fourteen replications to reduce variability.

Fungicides were applied with a self-propelled automatic sprayer which was constructed at the Soft Fruits Station. A minimum pressure of 11.7 bar and 2250 l/ha water were used. Usually three or four sprays at 14-day intervals were applied before picking, but from 1979 only two were given. Depending on disease severity, up to two sprays were applied after picking. A leaf spot (*Pseudopeziza ribis*) spray programme was applied every year.

Shoot mildew was assessed by counting the number of diseased shoots on each bush up to 1974. As this was very slow a change was made in 1975, when each bush was rated on a 0 – 5 scale (0 = no mildew visible, 5 = all new shoots heavily diseased). Fruit mildew was assessed by counting diseased berries in a 1.4 kg sample of fruit from the centre four bushes of each plot. Results were subjected to analysis of variance and least significant differences (LSD) calculated.

RESULTS

Shoot mildew

In the years 1973, 1976 and 1981 all fungicides significantly reduced shoot mildew over the unsprayed control (Table 1). Overall best control was given by pyrazophos, fenarimol, triforine and triadimefon. No disease developed in 1979 and 1980, and no significant differences between the treatments were found in 1976 and 1977.

Fruit mildew

Levels of fruit mildew were so high in 1975 it was decided to assess this as well as the level of disease on the shoots. No control was achieved of mildew on the fruit in 1975 (Table 2). The following year control plots had 48.7% diseased berries and highly significant reductions in mildew levels were given by bupirimate, fenarimol, nitrothal-isopropyl, pyrazophos and triforine. Quinomethionate and thiophanate-methyl did not give control. In 1977, though disease levels were very low, all fungicide treatments gave highly significant reductions. There was 28.2% mildew on the fruit of the controls in 1978 and while again all fungicides reduced disease significantly, best control was given by triadimefon, pyrazophos, fenarimol, bupirimate and nitrothal-isopropyl. No infected fruit occurred in 1979 or 1980. In 1981 all fungicides gave highly significant control of mildew. Best results were given by bupirimate, fenarimol, nitrothal-isopropyl, pyrazophos and triadimefon.

Fungicides significantly affected fruit size in 1976 and 1981 (Table 3). In 1976 bupirimate and fenarimol gave an increase in fruit size while in 1981 nitrothal-isopropyl and pyrazophos reduced mean fruit size.

Yields

Yields are shown in Table 4. Significant differences due to treatments were obtained in 1976, 1980 and 1981. Increased yields were given by bupirimate, fenarimol, nitrothal-isopropyl, pyrazophos, triadimefon and triforine.

DISCUSSION

The best fungicides for mildew control in the previous experiment (Ó Ríordáin *et al*, 1971) were triarimol and triforine, less effective was quinomethionate. No control was given by benomyl except in its first year of use. In this experiment benomyl continued to give poor results and so it was replaced in 1976. Thiophanate-methyl, a related MBC fungicide, gave better mildew control but not as good as other materials and it was replaced in 1977. It is possible that the failure of the MBC fungicides was due to the development of resistant strains of *S. mors-uvae*.

The best fungicides for control of shoot mildew were bupirimate, pyrazophos, fenarimol, triforine, triadimefon and nitrothal-isopropyl. These also gave large reductions in the level of mildew on the fruit, except in 1975 when no fungicide gave control of fruit mildew and disease levels were the highest recorded. It may be that this was due to the fact that May and June of that year were the driest of the period and so favoured heavy disease development. This changed by August when the shoots were assessed and good control was obtained from a number of fungicides. Somewhat similar results were obtained in Denmark (Noddegaard, 1980) where fenarimol was the most effective and good results were also given by triadimefon, pyrazophos and bupirimate.

In two years fruit size was significantly affected by the fungicide treatments. In 1976 bupirimate and fenarimol increased fruit size while in 1981 nitrothal-isopropyl and pyrazophos reduced the size of berries. Nitrothal-isopropyl would seem to have had a detrimental effect on the bushes as in a number of years the bushes had a reddish colour and lacked young shoots.

Most of the fungicides in this experiment have systemic effects and overall these performed better than the non-systemic materials but due to their limited sites of action the development of resistance is likely, as seems to have happened with the MBC fungicides. To avoid future resistance problems fungicides with differing modes of action should be rotated. Three of the more effective materials tested, fenarimol, triadimefon and triforine have all probably the same mode of action, affecting sterol biosynthesis of the pathogen (Dekker, 1977). Bupirimate and pyrazophos would seem to act differently from each other and from the sterol synthesis inhibitors. Therefore an alternation of one of these three fungicides with either bupirimate or pyrazophos would greatly reduce the dangers of a resistance build up to any of the fungicides.

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Table 1

Effect of fungicides on control of shoot mildew of gooseberry cv. Careless

Fungicide	kg a.i./ha	1972[1]	1973[1]	1974[1]	1975[2]	1976[2]	1977[2]	1978[2]	1981[2]
Benomyl	0.56	0.62	1.00**	1.38	0.64	-	-	-	-
Bupirimate	0.56	-	-	-	-	0.14***	1.47	2.18	1.69***
Carbendazim	0.68	0.14***	1.05**	0.95	0.60	-	-	-	-
Ditalimphos	0.28	-	1.19*	1.17	0.38**	-	-	-	-
Fenarimol	0.07	-	-	-	-	0.19***	1.44	1.86*	1.50***
Nitrothal-isopropyl	1.12	0.48*	0.95**	0.76	0.34**	0.48[3]***	1.58[3]	2.02[4]	1.85[4]***
Pyrazophos	0.21	0.38**	0.74***	1.29	0.40**	0.14***	1.46	1.84*	1.32***
Quinomethionate	0.28	0.57	1.02**	1.33	0.52*	0.60***	1.34	1.89*	1.98***
Thiophanate-methyl	1.12	0.48*	0.86***	1.71	0.40**	1.14*	-	-	-
Triadimefon	0.42	-	-	-	-	-	1.42	1.85*	1.51***
Triforine	0.53	-	-	-	-	0.31***	1.45	1.85*	1.79***
Control		0.86	1.62	1.24	0.86	1.48	1.50	2.23	2.61
LSD 5%		0.35	0.40	1.09	0.30	0.30	0.29	0.30	0.27
1%		0.47	0.54		0.40	0.40			0.36
0.1%		0.62	0.70		0.53	0.53			0.46

[1] Number of mildewed shoots per bush; [2] Shoot mildew rated on a 0 - 5 scale;

[3] As BAS 37900 F (0.28 kg nitrothal-isopropyl and 1.35 kg metiram per ha)

[4] As BAS 'Kumulan' (0.75 kg nitrothal-isopropyl and 2.39 kg sulphur per ha)

*, **, ***, significantly better than the control at $p \leqslant 0.05, 0.01, 0.001$

Table 2

Effect of fungicides on fruit mildew (%) of gooseberry cv. Careless

Fungicide	1975	1976	1977	1978	1981
Benomyl	56.5	-	-	-	-
Bupirimate	-	6.0***	0.00***	2.28***	6.3***
Carbendazim	65.2	-	-	-	-
Ditalimphos	53.6	-	-	-	-
Fenarimol	-	0.5***	0.00***	1.18***	0.8***
Nitrothal-isopropyl	49.6	19.4***	0.04***	2.61***	6.4***
Pyrazophos	63.4	9.1***	0.00***	0.81***	3.5***
Quinomethionate	55.6	42.4	0.09***	6.08***	12.3***
Thiophanate-methyl	55.4	45.6	-	-	-
Triadimefon	-	-	0.00***	0.59***	1.6***
Triforine	-	13.5***	0.00***	6.42***	10.1***
Control	64.5	48.7	1.49	28.17	44.5
LSD 5%	16.5	14.7	0.64	4.07	6.2
1%		19.6	0.85	5.40	8.2
.1%		25.8	1.11	6.99	10.6

*** significantly better than the control at $p \leq 0.05, 0.01, 0.001$

Table 3

Effect of fungicides on size of fruit of gooseberry cv. Careless

Fungicide		Number of berries in 1.4 kg sample	
		1976	1981
Bupirimate		153.0**	166.0
Fenarimol		154.4**	171.7
Nitrothal-isopropyl		158.3	196.4^{+++}
Pyrazophos		176.4	191.0^{+++}
Quinomethionate		171.1	168.4
Thiophanate-methyl		165.6	-
Triadimefon		-	179.4
Triforine		165.7	176.4
Control		171.0	175.5
LSD	5%	12.9	9.7
	1%	16.4	12.9
	.1%		16.7

** Significantly larger than the control at $p \leqslant 0.01$

$^{++}$, $^{+++}$Significantly smaller than the control at $p \leqslant 0.01$, 0.001

Table 4

Effect of fungicides for mildew control on yield (tonnes/ha) of gooseberry cv. Careless

Fungicide	1972	1973	1974	1975	1976	1977	1978	1979	1980	1981
Benomyl	6.51	6.24	8.39	3.86	-	-	-	-	-	-
Bupirimate	-	-	-	-	9.79**	7.13	7.73	9.13	6.92	11.24**
Carbendazin	7.08	7.12	9.21	3.67	-	-	-	-	-	-
Ditalimphos	-	6.50	9.16	3.79	-	-	-	-	-	-
Fenarimol	-	-	-	-	9.77**	7.00	7.48	9.39	6.88	9.81
Nitrothal-isopropyl	6.98	6.85	9.96	3.79	9.70**	6.91	6.87	9.31	6.27	10.32
Pyrazophos	5.90	5.52	8.84	3.93	9.54*	6.62	7.27	8.36	6.76	10.65*
Quinomethionate	7.09	5.64	8.92	4.12	8.59	7.03	7.06	9.12	6.05	9.85
Thiophanate-methyl	5.95	6.10	9.60	3.99	8.97	-	-	-	-	-
Triadimefon	-	-	-	-	-	6.98	7.15	9.06	7.62***	11.58***
Triforine	-	-	-	-	9.48*	6.49	7.08	9.29	7.72***	10.76*
Control	6.73	6.11	9.30	4.17	7.53	6.77	7.28	9.02	6.13	9.30
LSD 5%	1.74	1.44	1.60	0.61	1.51	0.70	0.79	0.84	0.90	1.29
1%					2.02				1.20	1.71
0.1%									1.55	2.22

*,**, *** significantly better than the control at p ⩽ 0.05, 0.01, 0.001

NOTES

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AC 222,705 PYRETHROID INSECTICIDE WITH MITICIDAL ACTIVITY FOR USE IN FRUITS AND HOPS

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Summary Recent results are presented from field trials in pome fruits, grapes and hops with AC 222,705 pyrethroid insecticide. Special attention is given to trials where spider mite infestations occurred simultaneously with infestations of the target insect pests. The benefit of the compound's significant spider mite suppression is discussed.

Sommaire Des essais en champs ont donné de récents résultats avec l'insecticide pyrethroide AC 222,705 sur les fruits à pépins et à noyeaux, les raisins et le houblon. Une attention toute particulière a été donnée aux essais où des araignées étaient présentes simultanément avec les insectes en question. L'action significative sur les araignées en ce qui concerne la substance est à discuter.

INTRODUCTION

The synthetic pyrethroids first synthesised by Elliott and his co-workers (1973) have since created major interest in a large field of agricultural uses, due to their outstanding insecticidal activity coupled with favourable toxicological properties. With the large-scale use of this new chemical class, presently represented mainly by permethrin, cypermethrin, deltamethrin and fenvalerate, the activity and persistence against many agricultural pests have been confirmed. Their introduction has not, however, been without problems. Incompatibility in integrated control programmes, the development of resistance of certain pests and flaring of mites following the application of pyrethroids, have been reported.

The pronounced toxicity of pyrethroid insecticides to spider mite predators has been reported by a number of workers following observations of a significant build-up of spider mite populations after use of the compounds. Plaut and Cohen (1978) found severe outbreaks of *Panonychus ulmi* and *Tetranychus urticae* after applications of permethrin in commercial orchards. In a later publication (1980), Plaut and Mansour explained the significant build-up of spider mite populations in Israel mainly as a result of increased fecundity, but to a lesser degree through disturbance of predator-prey balances. Other workers such as Hoyt et al (1978) concluded that spider mite repercussions were due to the detrimental effect of pyrethroids, such as permethrin or fenvalerate to a predatory phytoseiid, *Metaseiulus occidentalis*. Rock (1979) reported the high toxicity of permethrin and fenvalerate to *Amblyseius fallacis* in the laboratory, compared to very low activity to the two-spotted spider mite, *Tetranychus urticae*. Stäubli (1980) considered 90-100% mortality of predatory mites as normal after use of pyrethroid compounds, and reported that: "...in 20% of trials there was a markedly greater acarid population on treated than on control plots. In 30% of trials acarid peaks occurred at the start of the season in control plots but at the end of the season in pyrethroid-treated plots."

Although use of compounds is often difficult to control, some registration authorities, such as the Swiss, have restricted the number of pyrethroid treatments per crop to one or two per season in order to minimize the adverse effects on beneficial organisms. Plant protection advisors in Germany recommend the use of pyrethroid applications for problem pests only, such as codling moths in pome fruits, and discourage their use against early season pests.

American Cyanamid Company's new synthetic pyrethroid, AC 222,705 (proposed common name: flucythrinate), was first made public by Whitney and Wettstein (1979). CYBOLT is the trademark for the compound in most of Europe, Mid-East and Africa. It is the aim of this paper to report that AC 222,705 suppresses spider mite populations when used at insecticidal rates in fruits and hops. A selection of data has been made to present, wherever possible, results from trials where spider mites occurred simultaneously with the target pest. All trials originate from European countries or from southern Africa.

METHODS AND MATERIALS

All results presented originate from field trials with generally 3-4 replicates and conventional randomized layouts. High volume sprays were applied with the exception of the field work done in Holland, where ten times concentrated spray treatments were carried out as per common practice. Application equipment consisted of the motorized sprayers or mistblowers normally used in the respective countries.

The AC 222,705 formulation used was primarily a 10% e.c. w/v. In South African trials, the formulation was a 30% e.c. w/v. The comparative insecticides included were commercial formulations sold in the different countries.

RESULTS

Trials against pests in pome fruits

One of the most serious pests in pears, the psyllid *(Psylla pyri)* has in the past shown great abilities to develop resistance to various types of chemicals. In South Tirol (Italy), for example, compounds such as azinphos, diazinon, methidathion or monocrotophos became largely ineffective by 1972 (Oberhofer, 1973), and as a result, pear acreage has steadily decreased (Werth, 1974). With the commercial introduction in 1981 of the first pyrethroids, permethrin and fenvalerate, in Italy, careful use of this new chemical group seems advisable.

In Switzerland, where the synthetic pyrethroid, fenvalerate, has been in use for only three years (since 1979), there is increasing evidence that pear psyllid control by this chemical group has already declined (A. Schmid, personal communication).

The activity of the compound under Dutch conditions was shown in trials carried out by Ligtermoet Chemie B.V. (table 1).

Table 1

Effect on *Psylla pyri* infestations of one application at 150-250 l/ha (trial nos. FI 80-8 and FI 80-9)
(Pears-Holland)

Treatments	Dosages (g a.i./ha)	Average % leaf rosettes (300/plot) infested with larvae of *P. pyri* FI 80-8, 12 DAT*	FI 80-9, 9 DAT
AC 222,705 10% e.c.	24	11.3	3.5
AC 222,705 10% e.c.	36	13.7	2.8
AC 222,705 10% e.c.	48	7.5	2.0
Permethrin 25% w.p.	75	21.4	13.5
Untreated	-	60.9	19.9

*DAT = days after treatment

AC 222,705 at the lowest rate of 24 g a.i./ha was more effective than the standard permethrin at 75 g on pear psyllids.

The Swiss trial summarized in tables 2 and 3 was carried out by the Federal Research Station at Changins (trial No. 8001).

Both the knockdown effect and the persistence of 3 g a.i./100 l AC 222,705 were as good or better than all other treatments at recommended rates against pear psyllids (table 2).

The side effect on *Panonychus ulmi* is presented in table 3.

Table 3

Effect on *P. ulmi* infestations on day 6 after the second application at 2000 l/ha
(Pears-Switzerland)

Treatments	Dosages (g a.i./100 l)	Total No. of *P. ulmi* on 60 leaves per treatment, 6 DAT_2: mites		eggs
AC 222,705 10% e.c.	3	128	a*	106
Permethrin 25% e.c.	7.5	1678	b	1060
Deltamethrin 2.5% e.c.	1	1204	b	558
Cypermethrin 10% e.c.	7.5	232	a	214
Fenvalerate 10% e.c.	7.5	154	a	220
Untreated	-	410	a	486

* = Values with the same letter are not significantly different at $\underline{P} = 0.05$.

Table 2

Effect on *Psylla pyri* infestations of one and two applications at 2000 l/ha (Pears-Switzerland)

Treatments	Dosages (g a.i./100 l)	Average number of larvae and (eggs) of *P. pyri* per shoot				
		8 DAT_1*	22 DAT_1	37 DAT_1	13 DAT_2**	29 DAT_2
AC 222,705 10% e.c.	3	2.7(37.6)	0.3(3.0)	0.7(56.4)	1.7(11.1)	5.2(85.7)
Permethrin 25% e.c.	7.5	5.6(62.5)	2.6(16.5)	9.6(92.0)	12.4(29.4)	31.2(48.5)
Deltamethrin 2.5% e.c.	1	2.0(32.2)	0.5(7.7)	4.1(68.5)	10.0(23.6)	19.5(71.2)
Cypermethrin 10% e.c.	7.5	2.6(39.5)	0.9(11.2)	8.7(75.3)	12.5(11.1)	14.4(72.3)
Fenvalerate 10% e.c.	7.5	6.3(43.5)	1.1(11.5)	6.9(68.5)	12.7(20.3)	21.8(65.7)
Untreated+	--	80.5(52.0)	33.3(46.1)	33.1(21.0)	2.9(13.4)	-

\+ The untreated control plots had to be oversprayed on July 30 due to heavy infestations.

* DAT_1 = days after first treatment applied June 17, 1980.

** DAT_2 = days after second treatment applied July 30.

Statistical analysis of counts of motile stages showed that the numbers of mites in the permethrin and deltamethrin treatments were significantly higher than all other treatments.

Codling moth, *Laspeyresia pomonella*, is another important pest on pome fruit. The following is a summary of a trial carried out in 1980/81 in South Africa by FBC Agrochemicals (Pty) Limited (Trial SA/CRS/23/80). Pear trees cv. "Bon Chretien" were treated eight times with low rates of AC 222,705 30% e.c. at about 14 day intervals. Repeated sprays, as applied in this trial, are not practiced nor recommended, but served the purpose of accelerating the possible build-up of spider mites.

Table 4 shows the evaluation on codling moth by checking 12 x 250 fruits per treatment at harvest, and the influence on the red spider mite, *Panonychus ulmi*, counted on 12 x 20 leaves per treatment, 7 days after the last and eighth spray.

Table 4

Effect on *L. pomonella* and *P. ulmi* infestations of 8 HV applications (Pears-South Africa)

Treatments	Dosages (g a.i./100 1)	% control of *L. pomonella*	Mean No. *P. ulmi/leaf*
AC 222,705 30% e.c.	0.975	95.9	0.25
AC 222,705 30% e.c.	1.35	99.5	0.17
AC 222,705 30% e.c.	1.80	99.5	0.14
Deltamethrin 2.5% e.c.	0.3125	99.9	1.27
Untreated	-	(23.6*)	0.65

* = % of infested pears

The control of codling moths was excellent with 1.35 and 1.8 g a.i./100 1 AC 222,705 under the conditions of the trial. With regard to the effect on red spider mites, all rates of AC 222,705 gave suppression of mite infestation whereas the standard compound gave higher mite counts than the untreated control.

Trials against pests in grapes

There are a number of important pests in grapes where the use of AC 222,705 is of interest because of its beneficial side-effect, or at least non-flaring characteristic at insecticidal rates to spider mite species. Results of an Italian trial are given below in table 5 (trial No. 8 IR, 1980).

Table 5

Effect on first generation grape berry moth *(Lobesia botrana)*, and red spider mite *(Panonychus ulmi)* infestations of one HV application (Vines-Italy)

Treatments	Dosages (g a.i./100 l)	% control of *L. botrana*, 10 DAT	% control of motile stages of *P. ulmi*, 14 DAT
AC 222,705 10% e.c.	2.5	92.5	74.08 a[+]
AC 222,705 10% e.c.	3.75	92.5	68.16 a
AC 222,705 10% e.c.	5	97.5	66.19 a
AC 222,705 10% e.c.	7.5	100	72.81 a
Deltamethrin 2.5% e.c.	2.5	100	42.95 abc
Acephate 50% w.p.	50	92.5	17.60 bc
Azinphos-methyl 25% w.p.	75	90	61.54 ab
Untreated	-	(40*)	(710**) c

+ = Values with the same letter are not significantly different at $\underline{P} = 0.05$

* = Number of live larvae per 25 bunches/rep.

** = Number of motile stages per 45 leaves (15 x 3 reps.)

The control of grape berry moths was good with 2.5 and 3.75 g a.i./100 l AC 222,705 and excellent with the two higher rates.

Duncan's multiple range test showed that there was significant mite control by all AC 222,705 treatments. Mite populations in the deltamethrin and the acephate plots were not significantly different from those in the untreated plots.

All three generations of grape berry moths were also well controlled in several French trials during the past seasons. Even the low rates down to 2 g a.i. per 100 l spray liquid AC 222,705 gave excellent control and compared well with registered pyrethroid compounds at recommended rates.

In Germany, not only are grape and vine moths of economic importance, but also pests such as *Boarmia rhomboidaria* (willow beauty) and *Sparganothis pilleriana* (grape leafroller) are of considerable local significance.

The results from an official trial in Germany (Landes-, Lehr- und Forschungsanstalt, 6730 Neustadt/Weinstrasse, trial no. Anlage 5, Esslingen, 1980) are summarized in table 6. The grape cultivar was "Sylvaner" and the application date was May 28, 1980.

Table 6

Effect on *S. pilleriana* infestations of one HV application
(Vines-Germany)

Treatments	Dosages (g a.i./100 l)	% control of 2nd stage larvae of *S. pilleriana*
AC 222,705 10% e.c.	1	92
AC 222,705 10% e.c.	2	93
AC 222,705 10% e.c.	3	96
AC 222,705 10% e.c.	4	98
Fenvalerate 30.9% e.c.	6.18	96
Untreated	-	(206*)

* = Total number of living larvae from all three replicates.

Even the lowest rate tested gave effective control (>90%) of grape leafrollers.

Excellent control at similar rates has also been obtained against *B. rhomboidaria* in private and official tests in Germany.

Trials against pests in hops

Only a few trials have been carried out so far against the important hop pests *Phorodon humuli*, the Damson hop aphid, and *Tetranychus urticae*, the two-spotted spider mite. However, it has already been shown that suppression of the two-spotted spider mite is likely to occur after an application with AC 222,705 10% e.c. at 3 g a.i. per 100 l spray liquid. The only available result gave a spider mite reduction of between 36 and 50% over a four week period after treatment. Deltamethrin, which had been included in this trial at 1.25 g per 100 l, reduced the spider mite population by no more than 20%. The standard treatment, cyhexatin, at 25 g per 100 l spray gave >90% control.

Table 7 gives an example of the performance of AC 222,705 against the Damson hop aphid (trial Tübingen, 1980).

All rates of AC 222,705 gave almost complete control of *P. humuli* over four weeks after application.

Table 7

Effect on *P. humuli* infestations of one HV application
(Hops-Germany)

Treatments	Dosages (g a.i./100 l)	Mean number of living aphids per 50 leaves over four weeks after treatment and % control: No. of aphids	% control
AC 222,705 10% e.c.	2	0.1	99.7
AC 222,705 10% e.c.	3	0.4	98.8
AC 222,705 10% e.c.	5	0.2	99.4
Deltamethrin 2.5% e.c.	1.25	0.3	99.3
Untreated	-	34.2	-

Further trials will be undertaken to confirm the use rate for AC 222,705 to control *Phorodon humuli* paying special attention to concurrent spider mite infestations.

DISCUSSION

The synthetic pyrethroids established on the market are highly active, not only against insect pests but also against several beneficial insects and predatory mites. Because the latter are more susceptible than phytophagous mite species, flaring can occur after application of such compounds. In addition, the acaricidal activity of the established pyrethroids on phytophagous mites is not sufficient to give adequate control nor significant suppression when applied at insecticidal rates.

From its early development, AC 222,705 has shown acaricidal activity even at dosages of 2-5 g a.i./100 l spray liquid, which will be recommended for insect control. The results presented in this paper reconfirm these findings. The variables influencing the acaricidal efficacy of the compound include the level of mite infestation at application, the method and quality of the application, other plant protection measures in the crop programme and the activity of predatory insects and mites. Temperature at and following treatment may also play a role, although laboratory studies with AC 222,705 have shown that the negative temperature/ activity correlation is not as pronounced as for other pyrethroids. The above factors and other direct and indirect effects of AC 222,705 on phytophagous mites and their natural enemies are presently being studied in depth and will lead to refinement in the recommendations for this pyrethroid.

CONCLUSIONS

Many highly promising results have been obtained with AC 222,705 against a wide range of insect pests in pome fruits, grapes, and hops. Its broad sprectrum and high level of activity in association with its excellent residual efficacy and especially with its pronounced side-effect on spider mites, indicate that AC 222,705 could be the preferred product for many agricultural uses.

Acknowledgements

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CERTAIN BIOLOGICAL PROPERTIES OF FENARIMOL APPLICABLE TO ITS FIELD USE

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Summary. Greenhouse tests demonstrated that fenarimol is rapidly absorbed by leaf tissue. Simulated rainfall (washoff) applied after foliar sprays of fenarimol did not appreciably reduce disease control of certain plant pathogens. The percent disease control obtained was influenced by the sensitivity of the pathogen to fenarimol, the time washoff occurred after foliar application and the amount of rainfall (washoff) applied. The fungitoxicity of fenarimol is aided by its local systemic movement and vapor activity.

Resumé. Des essais en serre ont demontré que le fenarimol est rapidement absorbé par le tissu foliaire. Des pluies artificielles administrées aprés des pulverisations de fenarimol ne diminuent pas de façon sensible le control de certains agents phytopathogênes. Le pourcentage de maladie controlée dépend de la sensibilité de l'agent pathogêne au fenarimol, et du temps ecoule entre l'application du fongicide et la pluie suivante. L'action fongicide du fenarimol est renforcée par son mouvement systemique et son activité en phase gazeuse.

INTRODUCTION

Fenarimol (α-(2-chlorophenyl)-α-(4-chlorophenyl)-5-pyrimidinemethanol) has enjoyed increasing worldwide use since its introduction into the European fungicide market in 1978. Fenarimol has been used principally on apple for scab and powdery mildew control, and on grapes, cucurbits, tomatoes, peppers and peach for the control of powdery mildew. Biological factors other than its protective and curative antifungal properties contribute to the overall effectiveness of the fungicide. Information describing the local systemic movement, penetration, retentiveness and vapor activity of fenarimol applied to leaf surfaces is presented.

MATERIALS AND METHODS

1. Tenacity/Retentiveness

Greenhouse studies were conducted to determine the rate of penetration of fenarimol into leaf tissue and the influence that varying amounts of simulated rainfall had upon its fungitoxicity.

Fenarimol was applied to all plants in a spray hood designed to apply uniform amounts of chemical per unit of time. In most experiments, both surfaces of the leaves of the test plants received spray. Plants were either inoculated with a spore suspension or in the case of the powdery mildews, conidia were dusted from diseased plants onto the test plants after fenarimol treatment and washoff. Appropriate incubation times were used to assure infection. Two methods of washing plants were used. In tests in which no specific amounts of rainfall were applied, treated plants were flushed with approximately 25 ml of tap water from a Fogg-ett nozzle. In studies in which measure amounts of simulated rain were applied, a machine specifically designed for this purpose was used. After treatment, washing, inoculation and incubation, plants were placed in a greenhouse for the development of disease signs or symptoms.

II. Local Systemic Movement and Vapor Activity

To determine local systemic movement, fenarimol was dissolved in ethanol and placed on Whatman No. 3 filter paper discs (50 µg per 6 mm disc). After drying, the discs were positioned on the second leaf of 15-day-old cucumber plants (cultivar Green Prolific) for the duration of the experiment. The test plants were dusted with conidia from cucumber plants with a high incidence of powdery mildew and held in the greenhouse for disease development. Systemic movement was determined by observing the leaf area free of signs or symptoms of powdery mildew.

To demonstrate the vapor activity of fenarimol, filter paper discs prepared as described above were affixed to aluminium foil discs 14 mm in diameter. These discs were placed either directly onto the leaf surface or elevated 6 or 18 mm above the surface by cork plugs. Vapor action was determined by the powdery mildew assay described above.

RESULTS

I. Tenacity/Retentiveness

Washing fenarimol from leaves immediately after application had only a slight influence upon the control of the bean, cucumber and wheat powdery mildew pathogens (Table 1). Fenarimol was less effective in controlling the apple powdery mildew pathogen when immediately washed from leaves. If allowed to remain on apple foliage for 15 min before washing, fenarimol provided 73% control. The percent control of bean rust, apple scab, cucumber anthracnose and wheat rust was directly related to the allowed drying time. When washed off immediately after application, fenarimol provided no control of the cucumber anthracnose or wheat rust pathogens.

Table 1

Influence of foliar washes upon disease control by fenarimol 12% e.c. when applied at different times after treatment

Wash time		Bean		Apple		Cucumber		Wheat	
		PM	R	PM	Scab	PM	A	PM	R
(min)	mg/1)*:	2.5	40	10	10	2.5	100	5	40
0		95	25	38	52	83	0	83	0
15		98	56	73	58	99	17	92	14
60		98	75	100	70	100	87	100	64
No wash		100	99	100	84	100	100	100	86

PM = powdery mildew: bean-*Erysiphe polygoni*; cucumber-*E. cichoracearum*; wheat-*E. graminis* f. sp. *tritici*. R = rust: bean-*Uromyces phaseoli* var. *typica*; Wheat-*Puccinia rubigo-vera*. A - anthracnose: *Colletotrichum lagenarium*. Scab = *Venturia inaequalis*.

* Concentration of fenarimol in spray solution.

The amount of rainfall applied to leaves after treatment influences the disease control provided by fenarimol (Table 2). Rainfall in amounts of 0.4 to 2.0 cm/h when applied 60 min after fenarimol treatment had no influence upon the ability of the fungicide to control the apple scab fungus. A reduction in disease control was observed, however, when rainfall of 4.0 cm/h was applied 60 min after treatment. When rainfall was applied immediately after fenarimol, control of apple scab was directly related to the amount of rainfall. This was also true of the control of the bean rust fungus regardless of when the rainfall wash was applied.

Table 2

Control of apple scab and bean rust by fenarimol 12% e.c.* when spray is washed from leaves with varied amounts of rain at different post-treatment times

	Percent Control					
	Apple Scab			Bean rust		
	Time (min) between fenarimol treatment and rainfall					
Rainfall (cm/h)	No rainfall	0	60	No rainfall	0	60
0	100	-	-	96	-	-
0.4	-	100	100	-	44	66
2.0	-	80	100	-	31	53
4.0	-	64	85	-	25	50

* 20 mg/l for apple scab; 40 mg/l for bean rust.

Application of fenarimol to only the upper surface of bean leaves resulted in control of the bean rust fungus equal to the level of control obtained when both leaf surfaces were treated. However, no control of this fungus was obtained when the spray was washed from the upper leaf surface. Washing of leaves which received fenarimol on both surfaces resulted in reduced disease control directly related to the amount of rainfall applied (Table 3).

Table 3

Percent control of bean rust by fenarimol* applied to the upper leaf surface or to both leaf surfaces and washed by varying amounts of rainfall

Rainfall (cm)	Percent Control of Bean Rust: Upper Surface	Both Surfaces
0	97	99
2.0	0	53
4.0	0	33
8.0	0	19

Disease incidence in control = 80%.
* 12% e.c. at 40 mg/l a.i.

II. Local Systemic Movement/Vapor Activity

The placement of fenarimol-treated filter paper discs to either side of the mid-vein of cucumber leaves resulted in fan or V-shaped powdery mildew-free areas from the disc to the leave margin with the widest portion at the leaf margin (Figure 1). When treated discs were placed on the mid-vein near the leaf petiole, control of the powdery mildew on the entire leaf was obtained (Figure 2). Regardless of disc placement, little, if any, basipetal movement of fenarimol was observed, as judged by control of disease.

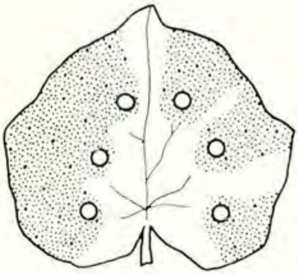

Figure 1

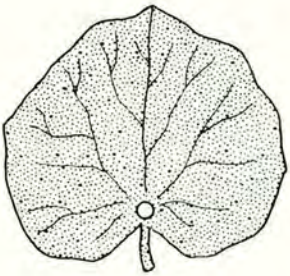

Figure 2

Stippled (Dotted) Area of Leaf Is Free of Powdery Mildew.
Circle Denotes Location of Filter Paper Disc Containing Fenarimol.

When the aluminium foil discs separated the fenarimol-treated discs from the leaf surface a disease-free area of a completely different pattern occurred. The disease-free zone was more or less circular around the treated disc. Further, disease-free areas were obtained across the mid-vein where the disc was located (Figure 3). If the aluminium discs containing the treated filtered paper discs were elevated above the leaf surface, the size of the disease-free zone decreased as the distance from the leaf surface increased. When elevated 18 mm above the leaf, no disease-free zone was obtained.

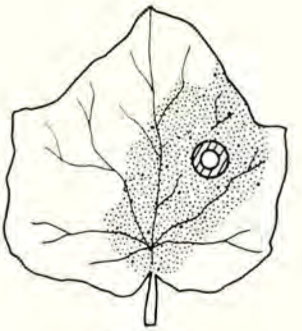

Figure 3

Stippled (Dotted) Area of Leaf Is Free of Powdery Mildew. Larger Circle With Diagonal Lines Is the Aluminium Foil Disc on Which the Filter Paper Disc (Circle) Containing Fenarimol Was Placed.

DISCUSSION

Fenarimol is rapidly bound to leaf surfaces as indicated by the retention of sufficient quantities to provide control of pathogens causing certain powdery mildew diseases despite the washing of treated foliage immediately after application of the fungicide. The amount of disease control provided by fenarimol appears to be related to the sensitivity of the pathogen to the fungicide. For instance, Erysiphe spp. causing powdery mildew were effectively controlled with 2.5 to 5.0 mg/l of fenarimol even though the fungicide was washed off the foliage immediately after application. Under the same circumstances, the less sensitive Podosphaera sp. on apple was only partially controlled. Similarly, the apple scab fungus is more sensitive to fenarimol than the wheat rust, bean rust or cucumber anthracnose pathogens. This relative sensitivity is reflected in the concentration of fenarimol required to provide effective control of these pathogens (Table 1). Control of less sensitive fungi is directly related to the period of drying prior to washoff. Even after 60 min which allows for approximately 75% of this spray droplets to dry, disease control was not equal to that obtained in nonwashed plants. Of importance equal to the time of washoff (rainfall) is the amount of rain applied.

Data from Table 2 indicate that rainfall in the amount of 0.4 to 2.0 cm/h would not reduce the control of apple scab by fenarimol if it came 60 min after the fungicide was applied. Under field conditions, foliar drying would occur more rapidly than under the conditions of these tests. This would suggest that the needed drying period from application to rainfall would be less than 60 min under field conditions.

Szkolnik (1) reported that fenarimol provided curative or post-infection activity but no protective action against the apple scab fungus. All of the tests reported here were conducted as protective tests in which the fungicide was applied prior to inoculation. Szkolnik applied 5 cm of rain at least 3 h after application. In the work reported here apple scab control by fenarimol was less when 4 cm of rain was applied 60 min after fungicide application. Whereas Szkolnik applied fenarimol to only the upper surface of the apple leaves, the fungicide was applied to both surfaces in our work. The impact of spraying either the upper leaf surface or both surfaces on disease control is shown by the data presented in Table 3. Excellent control of bean rust was obtain when either the upper or both leaf surfaces were treated. When only the upper leaf surface was treated and washed, no control of the bean rust fungus occurred. When both surfaces were sprayed and washed, moderate control of bean rust was obtained and it was directly related to the amount of rainfall. The practical field use of fenarimol would suggest that the fungicide is effective as a result of both preventative and post-infection activity.

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THE CONTROL OF CERTAIN PHYCOMYCETE DISEASES OF STRAWBERRIES, APPLES, VINES AND HOPS WITH APPLICATIONS OF FOSETYL ALUMINIUM

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Summary Fosetyl aluminium is a fungicide possessing both upward and downward systemic activity against a range of oomycete plant pathogens. This paper presents results from trials on strawberries, apples, vines and hops where fosetyl aluminium has demonstrated good control of a number of *Phytophthora* and *Pseudoperonospora* diseases attacking the roots, stem bases or leaves of plants, following foliar spray and other types of applications.

Résumé Phosetyl Al est un fongicide à systémie complète (ascendante et descendante) principalement actif sur les champignons appartenant à la famille des Oomycètes.

Une synthèse de l'expérimentation conduite avec ce fongicide sur fraisier, pommier, vigne et houblon est proposée. Dans ces essais phosetyl Al a fait preuve d'une excellante efficacité pour lutter contre les diverses maladies étudiées (*Phytophthora* spp ou *Pseudoperonospora* spp).

Les exemples choisis illustrent parfaitement les propriétés systémiques du produit et notament sa systémie descendante puisque grâce à des pulvérisations foliaires ainsi qu'à d'autres formes d'applications on peut lutter contre des maladies se situant au collet ou sur les racines des plantes.

INTRODUCTION

Fosetyl aluminium (aluminium tris[ethyl phosphonate]) is a systemic fungicide effective against a range of oomycete plant pathogens (Bertrand *et al*, 1977. Williams *et al*, 1977). The unique feature of this material is that it is systemically active in both an upward and downward direction and has thus enabled new strategies to be used in the control of certain diseases, particularly those infecting the plant roots or stem bases. In the past, the chemical control of these pathogens, where at all possible, has frequently involved incorporating large quantities of material in the root zone, but with fosetyl Al it has been shown that foliar spray programmes will effectively control certain economically important root dwelling fungi. Trials are now far advanced in certain tropical crops such as citrus and avocados where foliar applications have controlled a range of *Phytophthora* spp. causing root rot, collar rot and gummosis (Frossard *et al*, 1977. Laville, 1979. and Beach *et al*, 1979). This paper will summarise the current situation regarding the use of fosetyl Al to control certain soil and root inhabiting pathogens of more temperate crops.

METHODS AND MATERIALS

Strawberries

Red core (Phytophthora fragariae) trials

Both replicated and grower trials were carried out. Fosetyl Al was applied at a rate of 3 kg a.i. per hectare in a volume of 1000-1120 litres. All the trials were carried out on established crops using naturally occurring infections.

Crown rot (Phytophthora cactorum) trial

This was a small plot replicated experiment using the variety Sivetta. The plants were soaked prior to planting in the nursery and again just before transplanting into infected soil. The soaking time used was 30 minutes. The sprays were applied at a volume rate of 2000 l/ha.

Apples and Vines

The results presented are from replicated trials where foliar sprays were applied at high volume to run-off. Soil treatments were applied in 10 litres of water per plot and watered in with a further 50 mm.

Hops

Replicated trials were carried out to control both primary and secondary infections of hop downy mildew (Pseudoperonospora humuli). Early season foliar sprays and drench treatments were applied at a volume rate of 100 mls/plant. The through season foliar sprays were applied to run-off.

Most trials used naturally occurring infections but on some occasions artificial inoculation was used to ensure adequate infection levels.

In all trials an 80% w/w a.i. formulation of fosetyl Al ('Aliette') was used and untreated controls were included. Appropriate standard materials were used where such a material existed.

RESULTS

Strawberries

A) Red core, caused by Phytophthora fragariae

This disease can severely reduce strawberry yields particularly under wet growing conditions in autumn and spring. The fungus enters the plant via the root tips and colonises the central stele which subsequently develops a characteristic red colour. The Scottish Horticultural Research Institute (Montgomerie et al, 1979), the Agricultural Development and Advisory Service (Lovelidge, 1979) and several other European research institutes (Chalandon et al, 1980) have all demonstrated the effectiveness of foliar sprays of fosetyl Al in controlling this disease and these findings have been confirmed in the trials results given below.

Table 1

The control of strawberry red core using autumn applied sprays on established crops - UK - 1979-80

Treatment	Site No.	Variety	% reduction in No. of infected plants	% reduction in No. of infected roots per plant
Fosetyl Al 3.75 kg 80% a.i. wp/ha applied in 1000 l/ha	1	Red Gauntlet	100	100
	2	Gorella	40	67
	3	Cambridge Favourite	94	92
	4	Domanil	100	100
Mean level of infection on controls			60%	20%

Disease assessments were carried out during the spring of the year following treatment.

The increase in plant vigour as a result of the above treatments is reflected in a count of the number of new collar roots produced by the treated and untreated plants:-

Table 2

A comparison of the number of new collar roots produced by fosetyl Al sprayed and unsprayed strawberry plants growing in red core infected soil

Treatment	Site No.	Variety	Mean No. of new collar roots per plant	
			Untreated	Treated
Fosetyl Al 3.75 kg 80% a.i. wp/ha applied in 1000 l/ha	1	Red Gauntlet	11.6	13.8
	2	Gorella	8.1	10.5
	3	Cambridge Favourite	8.8	9.6
	4	Domanil	5.2	5.4
Mean for all sites			8.4	9.8

The foliar sprays were applied in autumn 1979 and the roots were counted in spring 1980.

Further trials are under way to establish whether or not the efficacy of fosetyl Al against red core can be improved by soaking the plant roots in a solution of the fungicide prior to planting out or by combining an autumn season spray treatment with an additional application the following spring.

B) Crown rot caused by *Phytophthora cactorum*

This is another soil-borne disease that attacks strawberry crowns and fruits and causes severe losses in central and southern Europe.

The results reported below are from a trial carried out in Belgium (Gilles, 1980) to control the collar rot phase of the disease.

Table 3

The control of strawberry crown rot using foliar sprays, soaks and drenches - Gorsem Experimental Station Belgium, 1980

Treatment	Treatment type	Dose rate a.i.	Number of applications	% Diseased plants
Fosetyl Al	Post plant spray	2000 g/ha	2	9.2
	Soak	2.5 g/l	2	0
	Soak + post plant spray	2.5 g/l + 2000 g/ha	1 + 1	0
	Drench	0.1 g/plant (4000 g/ha)	2	6.4
Untreated control		-	-	30

Apples

Apple trees grown in areas of high soil moisture content or on susceptible rootstocks can frequently suffer from a collar rot infection caused by the soil-borne fungi *Phytophthora cactorum* and *P. syringae*. The disease has caused severe losses in certain districts, attacking mainly mature trees. Interest in the possible use of fosetyl Al to control this problem was stimulated by the results against collar rot of citrus whilst in the United Kingdom Dr. D.R. Clifford of Long Ashton Research Station, Bristol, has obtained the results given in Table 4. The trial was set up in a cider apple orchard with a considerable collar rot problem and both bark painting and foliar spray applications were evaluated.

Table 4

The control of natural collar rot infections in cider apple trees, Long Ashton Research Station trial 1980-81

Treatment	Dose g a.i./l	Treatment dates	% trees which on 4.6.81 had:- Died	Deteriorated	Improved
Untreated	-	-	55	18	27
Foliar sprayed					
Fosetyl Al	2	25.6.80	0	10	90
"	2	12.9.80	0	7	93
"	2	25.6.80 + 12.9.80	0	0	100
Bark painted					
Fosetyl Al	50	25.6.80	25	13	62
Metalaxyl	50	25.6.80	46	0	54

A trial to evaluate the efficacy of foliar sprays of fosetyl Al in controlling artificial infections of collar rot (*P. cactorum*) on apple trees was carried out at the Rhône-Poulenc Research Station at Emerainville, France in 1980. Table 5.

Table 5

The control of artificial collar rot infections on apple trees using foliar sprays - France 1980

Treatment	Dose rate g a.i./l	Treatment dates	Length of infection canker (mm) on: 12.8.80	12.9.80
Untreated	-	-	30	31
Fosetyl Al	2	12.6.80 + 12.8.80	22	20
"	2	12.6.80 + 12.7.80 + 12.8.80	15	11

The trees were inoculated *via* 9 mm long wounds on 12.5.80.

Trials are continuing to determine the optimum application timing and spray regime required to control this pathogen on apple trees.

Vines

Fosetyl Al is used widely for the control of downy mildew on vines (*Plasmopara viticola*) and a trial carried out by Marais *et al* (1981) in South Africa has shown that foliar sprays are also effective in controlling a root rot caused by the soil inhabiting fungus (*Phytophthora cinnamomi*).

Table 6

The control of *Phytophthora cinnamomi* (root rot) on nursery vines. Oenological and Viticultural Research Institute, Stellenbosch, South Africa - 1976-77

Treatment	Dose rate a.i.	No. of treatments (14 day intervals)	% stocks at the end of trial that were: Dead	Infected
Foliar sprays				
Untreated	-	-	12.0	32.5
Fosetyl Al	2.8 g/l	4	3.2	13.0
Metalaxyl	0.5 g/l	4	12.2	32.8
Soil drenches				
Untreated	-	-	22.3	41.3
Fosetyl Al	1.4 g/m^2	4	21.8	38.5
Metalaxyl	0.25 g/m^2	4	8.7	11.0

Hops

Downy mildew, caused by *Pseudoperonospora humuli*, overwinters in the crown of the hop rootstocks and appears in the spring as systemically infected shoots known as 'basal spikes'. These produce spores which, under suitable weather conditions, give rise to secondary infections on the leaves and cones. Experiments carried out in Yugoslavia (Dolinar, 1980) have shown that early season sprays or drenches with fosetyl Al will markedly reduce the number of basal spikes produced (Table 7) and trials undertaken in Germany (Table 8) confirm that a through-season spray programme of fosetyl Al will protect the plants from secondary infections.

Table 7

The control of Hop Downy Mildew Basal Spikes using foliar sprays and drenches. Hop Research Institute, Zalec Yugoslavia 1979

Treatment a.i.	Type of Application	Number of primary basal spikes on 15 plants		
		20/5	30/5	10/6
Fosetyl Al 0.3 g/plant/	Spray	0.5	1.0	1.0
application	Drench	6.0	7.0	7.0
Dithiocarbamate 0.06%	Spray	9.0	12.0	14.0
Untreated	-	15.0	18.0	19.0

Two treatments were applied, the first when the shoots were c 3 cm long and the second when they were 20 cm tall.

Table 8

The control of secondary infections of Hop Downy Mildew using foliar sprays. Federal Republic of Germany Official Trials 1977 and 1979

Treatments	1977*			1979**			
	No. of Treats.	Disease index leaves	Disease index cones	No. of Treats.	Disease index leaves	No. of diseased cones/50 plants June 4	No. of diseased cones/50 plants June 23
Fosetyl Al 0.2% a.i.	8	1	1	3	3.0	18	65
Dithiocarbamate	16	1	1	5	4.8	30	165
Untreated control	0	1.6	6.0	0	5.2	85	245

Disease index 1 = healthy plant
9 = 100% disease attack.

* Results 1977 mean of 3 trials

** Results 1979 mean of 2 trials.

DISCUSSION

The above results clearly demonstrate the ability of fosetyl Al to control certain soil-borne and root inhabiting diseases by foliar spray applications.

With red core of strawberries an effective autumn spray treatment recommendation is by now an established practice in many countries. Work is currently in hand to discover if an autumn spray, combined with a follow-up spring application, would be even more effective in years of severe disease attack. Soaking the plant roots in a suspension of fosetyl Al immediately prior to planting is also showing promise for crops established in the autumn. The control of crown rot of strawberries can also be achieved using programmes similar to those outlined above.

The potential for the control of collar rot in apples has also received a great boost as a result of the experiments reported above. Much remains to be done however to define more clearly the optimum time for spraying the trees, the treatment regime required to obtain reliable collar rot control, and the influence of such a spray programme on the level of *Phytophthora* storage rots on fruit from trees treated in this manner. In the trials carried out so far, bark painting with fosetyl Al would seem to be somewhat less effective than the foliar sprays, always providing that the tree has an adequate foliar canopy to absorb sufficient fungicide.

Phytophthora root rot of vines, although of limited economic importance, can also be controlled effectively by foliar sprays of fosetyl Al, a useful bonus when using this material to control downy mildew. By contrast soil drenches would appear to be of very limited value.

Fosetyl-Al sprays or drenches of the emerging hop bines will control the primary systemic infections of downy mildew and through-season protection against secondary attack can be achieved using a 14 day spray programme as opposed to the 7 day programme frequently recommended for dithiocarbamate materials.

Fosetyl Al is well tolerated by a wide range of crops and no phytotoxic symptoms were observed in any of the above trials.

With its unique downward systemic activity fosetyl Al offers potential to growers for controlling a range of soil-borne and root infecting diseases of both temperate and tropical crops using application technology and methods with which they are familiar. Work is continuing to extend the use spectrum of this material so that its properties can be exploited to the full.

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SESSION 8C

PESTICIDE RESISTANCE IN PESTS AND PATHOGENS

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POSSIBILITY OF FLY RESISTANCE TO BACILLUS THURINGIENSIS EXOTOXIN

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Summary A preparation containing *Bacillus thuringiensis* exotoxin for microbial control of flies was tested for development of resistance against *Drosophila melanogaster*. A 20-fold resistance developed in 40 generations in fruit-flies reared in medium containing 0.5 to 1.0 % of the preparation. 0.2 to 0.5 % of the preparation gave a 12-fold resistance. Flies reared in 2 % and 3 % of the preparation were very weak and did not develop resistance and become fitter during 20 generations of selection. These data are discussed in relationship to the intended use of the exotoxin in controlling houseflies.

INTRODUCTION

Bacillus thuringiensis strains and their endotoxins are used worldwide for control of lepidopterous insect pests. The discovery of the thermostable exotoxin in *B.thuringiensis* cultures (McConnell and Richards 1959) increased the insecticidal use of *B.thuringiensis*-preparations because it is effective against species of *Diptera*, *Hymenoptera*, *Coleoptera* and *Orthoptera*. Preparations containing exotoxin replaced the chemical insecticides in trials for flycontrol in the early sixties, but Sebesta et al (1969) claimed that the exotoxin was lethal to mice so its commercial use was delayed, even though toxicity data were extremely limited. However, tests carried out between 1970 and 1980 at the Department of Microbiology, University of Helsinki, show, that allergenic, toxic or cytogenetic damage caused by exotoxin in amounts normally used to control insect pests are negligible (Carlberg 1973, Meretoja et al. 1977, Linnainmaa et al. 1977, Kähkönen et al. 1979). Furthermore the optimal batch culture conditions for exotoxin production have been determined (Holmberg et al. 1980) so that a commercial preparation for fly control in Finland will be registered in 1981. Controlling insects by microbial means provides an attractive alternative to conventional insecticides when resistance has created a control problem.

Resistance to microbial control agents has been obtained in the laboratory (e.g. Burges 1971). Eight-fold resistance to *B.thuringiensis* exotoxin after 27 generations of selection and 14-fold after 50 generations of house-flies has been reported by Harvey and Howell (1965), while Wilson and Burns (1968) obtained a 6-fold resistance after 25 generations of house-fly selection. In these different spore powder preparations were used.

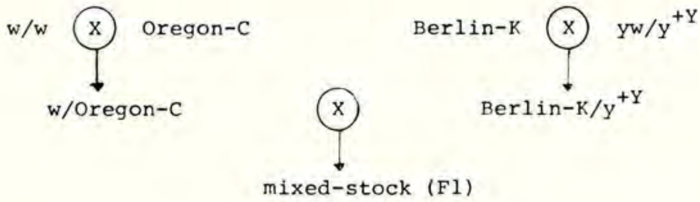
The aim of our investigation has been to test the potential for resistance to the commercial B.thuringiensis preparation to be used for control of flies.

METHODS AND MATERIALS

Drosophila stock

Drosophila melanogaster was chosen as the test insect since it develops faster than the house fly (2 weeks contra 3-4 weeks). A mixed stock more resembling a natural population was obtained by mating four laboratory strains, thereby decreasing homozygoty.

The mixed strain (F1) was hybridized by the following mating procedure:



Source of exotoxin

Bacillus thuringiensis var. thuringiensis, serotype 1 (ATCC strain No. 10792) was fermented in a 1.5 m^3 fermentor (Fermac, Rintekno Oy, Finland). For the resistance investigation the bacterial culture was centrifuged and the supernatant containing exotoxin dispensed in 25 ml portions in flasks and autoclaved. The flasks were then stored at -18 ^oC. Before use the preparation was brought to room temperature and then suspended in Drosophila culture medium.

Drosophila culture and test medium

The flies and their larvae were cultured in the following medium.

50 g semolina, 100 g malt, 15 g dried yeast, 7 ml propionic acid, 10 g agar powder, 1 l water

Semolina, malt, agar and water were mixed and boiled for 15 minutes. Yeast and propionic acid were added and the boiling continued for 5 minutes. The medium was bottled and solidified over night at room temperature and then stored in a refrigerator at 6 ^oC. For the selection and bioassay procedure the exotoxin preparation was added to the medium just before the bottling.

Selection procedure

The flies were reared in 200 ml glass bottles each containing 50 ml culture medium and held in a dark incubator at 26 °C. For the selection 6 bottles were used for each concentration, plus an untreated control. The initial concentrations were 0.2 % and 0.3 % (Groups 1 and 2). To maintain selection pressure the concentrations were increased until the F20 generation, after which the concentration was held at 0.5 % and 1 %. From the F19 generation of group 2 two new groups were separated: group 3 reared in 2 % and group 4 in 3 % of the exotoxin preparation. (Table 1).

Table 1

Concentrations of the exotoxin preparation in Drosophila rearing medium

Generation	Concentration %			
	Group 1	Group 2	Group 3	Group 4
F2 - F3	0.2	0.3		
F4 - F7	0.3	0.5		
F8 - F15	0.4	0.7		
F16 - F40	0.5	1.0		
F20 - F40			2.0	3.0

Bioassay procedure

For bioassay the flies were bred in a plastic cage (25 x 21 x 13 cm) one wall of which had a nylon net to allow for ventilation and manipulation. For each bioassay about 500 - 1000 adult flies were allowed to mate in the breeding cage and lay eggs onto open petri dishes, filled with culture medium, placed on the bottom of the cage. Each morning new petri dishes replaced the old ones, which were covered and held for six hours at 26 °C to permit hatching. 100 1st instar larvae were transfered with a sable hair brush from the petri dish and placed to 100 ml bottles which had been filled with about 30 ml of culture medium to which exotoxin preparations were added, giving five to nine dosage levels. Three replicates were made at each concentration, including the control.

The developed adults were anesthetized and counted daily. LD_{50}'s and b values were estimated from dosage mortality data using a Hewlett Packard HP 9830A Computer.

Bioassays were made of the control and the selected generations F10, F20, F 25, F30 and F40 in groups 1 and 2, where strong cultures were established. The populations from 3 and 4 were very weak, so that it was impossible to obtain enough flies for bioassay. These populations did not become any fitter during 20 generations.

RESULTS

The LD_{50} values estimated from five dosage-mortality tests are shown in Table 2. The resistance rations (RF in Table 2) are obtained by dividing the LD_{50} values of the selected populations by the LD_{50} value of the control population. Results are based on the number of adult flies which emerged. The control population was more sensitive to the exotoxin at each generation. Resistance to the exotoxin increased slowly, more in group 2, reared in medium containing 0.5 % to 1.0 % B.thuringiensis preparation than in group 1, reared in 0.2 % to 0.5 % of the preparation. Figure 1 shows the probit lines for group 1 and 2. The probit mortality is plotted against log dosage expressed as the % of B.thuringiensis preparation in rearing medium. The probit lines of group 2 show clearly the changes in slope during the course of the development of resistance as schematically presented by Burges (1971). In the F20 generation (line 1) the slightly increased slope indicates that the mean resistance has increased. In the generations F30 and F40 (lines 3 and 4) the slopes are significantly lower indicating that the development of true resistance has begun.

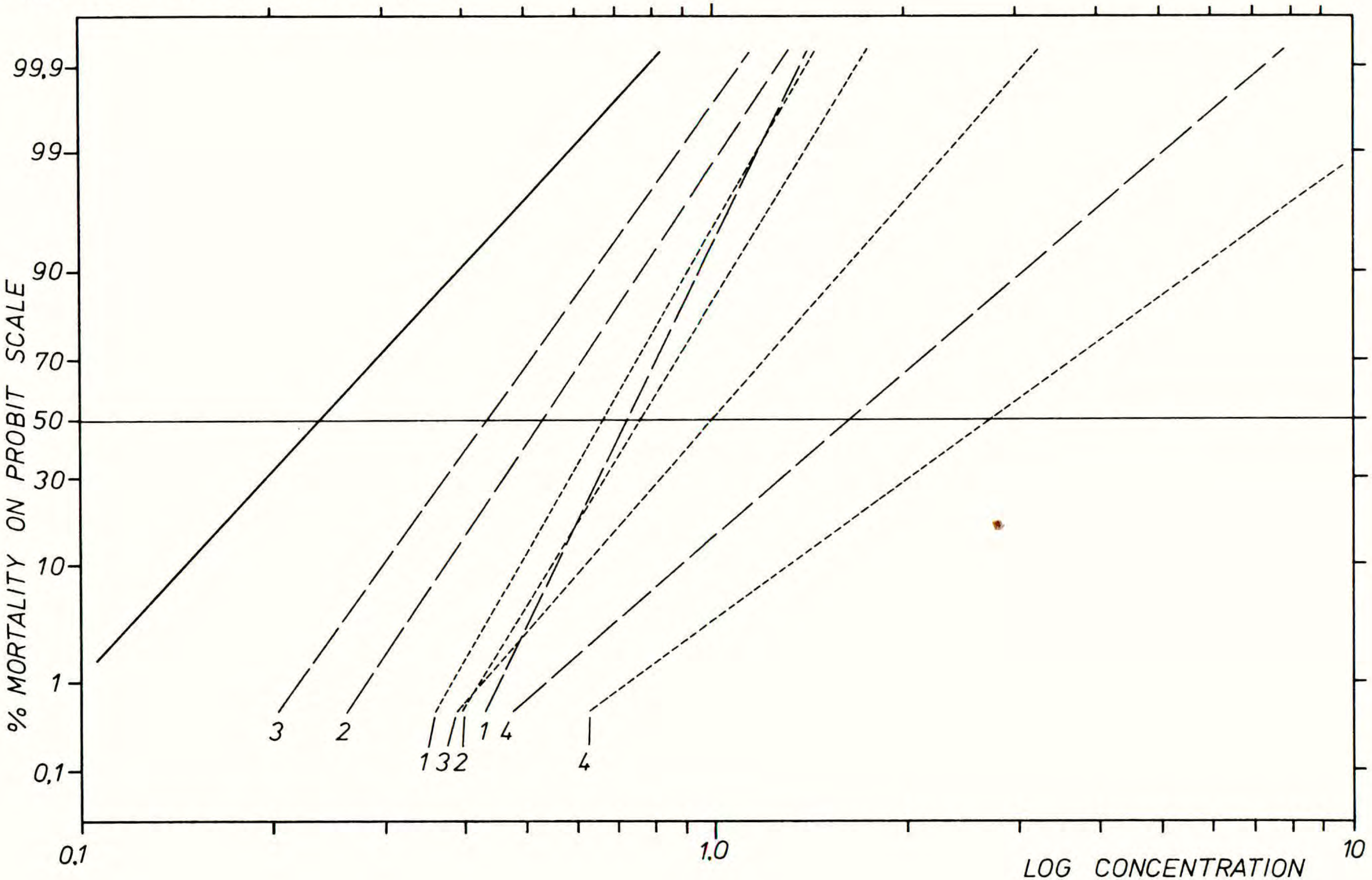
Table 2

LD_{50} values, b values, (slope) and the resistance factor (RF) for Drosophila melanogaster reared in the medium with different concentrations of Bacillus thuringiensis -preparation

	LD_{50} %	90 % C.L. Lower	Upper	b	RF
F1	0.24	0.22	0.26	1.18	
F10					
Control	0.15	0.10	0.20	1.29	
Group 1	0.45	0.40	0.50	1.49	3.0
Group 2	0.51	0.46	0.56	1.42	3.4
F20					
Control	0.14	0.12	0.15	1.12	
Group 1	0.73	0.66	0.80	2.06	5.2
Group 2	0.67	0.61	0.73	1.75	4.8
F25					
Control	0.12	0.10	0.13	0.90	
Group 1	0.54	0.49	0.59	1.58	4.5
Group 2	0.76	0.68	0.85	1.63	6.3
F30					
Control	0.10	0.09	0.11	1.17	
Group 1	0.44	0.40	0.48	1.65	4.4
Group 2	1.00	0.93	1.07	1.15	10
F40					
Control	0.14	0.13	0.15	1.05	
Group 1	1.64	1.34	1.99	0.87	12
Group 2	2.73	2.13	3.49	0.74	20

Figure 1

Probit lines for F1 generation (———), group 1 (—— ——) and 2 (- - - -). 1:F20, 2:F25, 3:F30, 4:F40. The probit mortality is graphed against log dosage (% of B.thuringiensis preparation in rearing medium).



DISCUSSION

The results of our experiments with fruit flies confirm the results of Harvey and Howell (1965) and Wilson and Burns (1968) concerning development of resistance to Bacillus thuringiensis exotoxin in flies. Resistance develops slowly, the rate depending on concentration, so that 1 % of B.thuringiensis preparation in the Drosophila rearing medium has the most marked effect (RF value for generation F40 = 20). However, flies reared on 2 % and 3 % preparations did not develop resistance such that they became noticably fitter during 20 generations.

If the results of our laboratory experiments with Drosophila are applicable to other insects, strong resistance to the exotoxin, which will be registered for housefly control in Finland in 1981, is unlikely to occur. Early application of exotoxin in the spring is effective against the comparatively small housefly populations of that time, reducing the likelihood of their increasing in size. Also under climatic conditions in Finland, houseflies pass through only a few generations per year. Small populations and a slow breeding cycle reduce the chances of build-up of resistance. Lack of cross-resistance between exotoxin and chemical insecticides has been observed in a strain of Drosophila (unpublished data) as well as in houseflies collected from piggeries which would favour practical housefly control.

The research continues, including an investigation concerning the rate at which the resistance disappears when Drosophila flies from generation F40 are reared in medium without exotoxin.

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DEVELOPMENT OF BIOLOGICAL METHODS OF PEST CONTROL

IN THE UNITED KINGDOM GLASSHOUSE INDUSTRY

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Summary This report details a wide investigation of the suitability of biological means of pest control on crops grown under glass. Reliable programmes for the use of Encarsia formosa and Phytoseiulus persimilis on major crops are described, and the introduction of new techniques for controlling leaf miner (with Opius/Dacnusa parasite mixture), aphid and whitefly (with Vertacillium lecanii fungus) and thrips (with Amblyseius mackensiei predator) are outlined.

INTRODUCTION

Biological control techniques in glasshouse crops have been known of for many years (Speyer, 1928), but the efficiency of pesticides during the 1950's and 1960's inhibited their development.

By the late 1960's, red spider mite (Tetranychus urticae (Koch)) had become the major pest in the United Kingdom glasshouse industry. In 1968, ten ha of cucumbers were successfully treated with the predator Phytoseiulus persimilis (Authias-Henriot). In 1972 a larger acreage was treated and the parasite Encarsia formosa (Gahan) added to control the glasshouse whitefly (Trialearods vaporarimum (Westw.)). However, this expansion of the technique revealed the lack of development work done because the results were 70% successful only on some of the treated area (Umpelby and Sly 1978). This trend of expansion of the techniques with similar results continued in 1975 and 1976 (Gould 1977). The inclusion of a whitefly parasite in the programme was in response to increasing whitefly resistance to pesticides (Wardlow, et al 1976) confirmed by laboratory work (French, et al 1973). Whitefly resistance to the new pyrethroids has not yet been found (Wardlow 1981) but has been reported in red spider mite (Stone, et al 1977).

The work done to date can best be summarised by crop:

Tomatoes Whitefly can be controlled by one or two introductions of E.formosa if the whitefly is first introduced onto a clean crop but there is considerable commercial reluctance to introduce the pest into a clean crop. An alternative method is to make regular introductions at the start of a natural infestation. It is, however, important to have adequate light (Parr, et al 1974), and temperature (Day and Collingwood 1973). Red spider can be controlled by introducing P.persimilis at the first sign of the pest (Parr 1971), unless it is the aggressive strain of Tetranychus urticae (Foster and Barker, 1978) or Tetranychus cinnabarinus (Binns 1978).

Cucumbers Cucumber growers are equally reluctant to introduce pests into a clean crop and so dribble methods have been tried introducing various numbers of E.formosa at different times with varying degrees of success (Parr 1968, 1971, Anon 1969, Gould, et al 1975). Red spider control can be achieved by regularly introducing the predator when the pest becomes evident (Anon 1973, Gould 1968). Aphids (notably Aphis gossypii) and thrips (Thrips tabaci) are still controlled by various chemicals.

House Plants Red spider has been controlled by P.persimilis (Hussey and Parr 1965, Gould and Light 1971) and mealy bug by Cryptoloemus montronzieri (Simmonds 1977).

Strawberries The control of red spider with P.persimilis in protected structures has been demonstrated (Gould and Vernon 1978, Williams 1978).

METHODS AND MATERIALS

The following parasites and predators were used in the present work:

Encarsia formosa Parasitised whitefly scales on cucumber leaves were used in 1977. From 1978 parasitised whitefly scales mounted on cards were used (commercial name 'Enstrip').

Phytoseiulus persimilis Predators at all growth stages, with some red spider mites to provide a food source, on french bean leaves were used in 1977 to 1979 on all crops, and on tomatoes in 1980 and 1981. All other crops in 1980 and 1981 received the P.persimilis mixed with sawdust for application by the "pepperpot" method (commercial name 'Spidex').

Opius pallipas/Dacnusa sibirica A mixture of two leaf miner parasites supplied as parasitised leaf miner pupae. The proportions of the parasites in the mixture varied with the time of year.

Amblyseius mackensiei Predators at all growth stages mixed with bran for application by the "pepperpot" technique for thrip control were used (commercial name 'Thrippex').

Vertacillium lecanii A wettable powder based on cereal flour containing more than $1x10^8$ spores per gram of the fungus Vertacillium lecanii. Two strains were used, coded V2 with greater activity against aphids as the commercial product 'Vertalec' and V6 with greater activity against whitefly as the product 'Mycotel', and their activity has been reported (Hall 1975, Kanagaratnam, et al 1978).

Control of lepidopterous species, particularly tomato moth caterpillar Lasonobia oleracea, in chrysanthemums and strawberries was achieved with the fungus Bacillus thuringiensis. In 1977 and 1978 the commercial product 'Thuricide' was used, and in 1979-1981 the commercial product 'Bactospeine' was used. The efficacy of this product is well established (Anon 1976) and the results of individual applications are not reported here.

Details of individual crop trials:

Tomatoes

Year	No. of Sites: Whitefly	Whitefly and Red Spider	Location
1977	10	3	Sussex/Hampshire
1978	21	9	National
1979	31	10	National

At all sites in each year, four introductions of 20,000 E. formosa per ha were made at 14-day intervals. Further introductions were made either if there was no evidence of black scales by the end of the series, or if the number of whitefly increased due to an invasion from outside the greenhouse. P.persimilis was introduced as necessary, their numbers being adjusted to one predator to every five spider mites.

In 1979 and 1980 six trials were carried out to control leaf miner Liriomyza bryoniae. In 1979 two trials received one application of 1,800 O.pallipas/D.sibirica per ha in July. In 1980 this was repeated on one site, and three further sites were treated in January-March. Further larger introductions were made on these three sites during the year.

Cucumbers

Year	No. of Sites: Red Spider only	Whitefly and Red Spider	Location
1978	53	8	Lee Valley, Humberside, Sussex
1979	44	18	Lee Valley, Humberside, Sussex
1981		10	Lee Valley

P.persimilis was introduced as the pest was seen, on the same basis as for tomatoes, with the need for subsequent introductions being determined by regular crop monitoring. Where the crop monitoring was inefficient and damage was severe, the bad patches were sprayed with either petroleum oils or cyhexatin. In 1978 E.formosa was introduced as for tomatoes. In 1979 and 1981 this was amended to six introductions of 15,000 per ha each at seven day intervals. In 1981, V.lecanii was used in seven trials as a follow up to E.formosa for whitefly control at the rate 1 kg/1,000 l. sprayed HV to the top only of the plants. Also in 1981 A.mackenziei was used in six trials at a rate of 125,000 per ha for control of thrips. In four trials application was made before damage reached index 2 but in the other two, damage indices reached 3-4 on some plants before treatment. In all the trials E.formosa and P.persimilis also controlled whitefly and red spider mite.

House Plants

Year	No. of Sites: Red Spider	Whitefly	Thrips	Aphids	Mealy Bug	Crop
1979	-	2	-	-	-	Fuchsia
1979	3	-	-	-	-	Hedera, Dieffenbachia, Croton, Ficus
1979	1	1	-	-	-	Hibiscus
1979	1	-	-	-	-	Orchids
1980	2	-	-	-	-	Hedera
1980	1	-	-	-	1	Ficus
1981	1	-	1	-	-	Croton
1981	-	-	-	1	-	Hibiscus

All the biological agents were introduced at the first sign of the pest. P.persimilis was introduced once at 100,000 per ha, E.formosa at 25,000 per ha four times at 14-day intervals, A.mackenziei at 125,000 per ha once, V.lecanii sprayed at 5 kg product per 900 l. per ha, and C.montronzieri introduced as necessary, aiming at one predator per three mealy bugs.

Chrysanthemums

Year	No. of Sites	Biological Control Agents Used
1979	1	P.persimilis
	2	P.persimilis (1 half rate) O.pallipas/D.sibirica
1980	4	P.persimilis
	7	P.persimilis, O.pallipas/ D.sibirica
1981	3	P.persimilis (half rate), V.lecanii
	3	P.persimilis, V.lecanii
	8	P.persimilis, O.pallipas/ D.sibirica, V.lecanii
	1	P.persimilis (1 half rate), V.lecanii, A.mackenziei

All the trials except the first and last were on all-year-round crops. Each trial was made over at least a twelve-week period with fresh plantings each week. The first and last trials were in the same house planted over a four-week period. P.persimilis and V.lecanii were used on a routine basis irrespective of the pest level. V.lecanii was applied at 5 kg product per 900 l. per ha two weeks after planting. All the trials were covered with black polythene at night. P.persimilis was applied at one predator per three cuttings three weeks after planting except the five trials marked where it was introduced on a 1 to 6 cuttings basis. O.pallipas/D.sibirica was introduced at the first sign of leaf miner (Phytomyza atricornis) feeding marks at a rate of 1,250 per ha three times at 14-day intervals.

Roses In 1979 P.persimilis was used in four trials in Sussex, Lancashire and Guernsey, and in 1980 one trial in Suffolk, for red spider control. Introductions were made on the same basis as for tomatoes and cucumbers.

Peppers P.persimilis to control red spider mite was used in three trials in Sussex in 1979, and five in 1980 in Sussex, Surrey and Essex. Introductions were made on the same basis as tomatoes and cucumbers. In 1981 one trial was carried out with V.lecanii for aphid control.

Strawberries

Year	No. of Sites	Location	Type of Structure
1978	1	Sussex	Glasshouse, small plastic tunnels
1980	10	Sussex, Hampshire, Bedfordshire, Humberside	Glasshouse, walk-in and small plastic tunnels
1981	3	Sussex, Hampshire	Glasshouse, walk-in plastic tunnels

P.persimilis was introduced on the basis of one predator per plant at the first sign of red spider mite activity. In 1980 and 1981 this was preceded in most trials by one spray of cyhexatin. In the second series of two trials in 1980, application of one per plant was made in September to newly planted runners.

The results of the trials are expressed as successful or unsuccessful. This is defined as follows:

Whitefly The threshold between success and failure is defined as 80% of the whitefly scales parasitised, and control maintained at this level for the season without sooty mould formed on the plants at any time in the season.

Red Spider For cucumbers and peppers success is defined as no plants ever achieving a damage index of 1.0, and less than 1% of the number of plants needing chemical acaracide.

On roses, house plants and chrysanthemums success is defined as no leaves being so damaged as to result in the flowers being downgraded from Class I under the EEC Grading rules.

On strawberries success is defined as no subsequent spraying of an acaracide being necessary in that season.

Leaf Miner Success is defined as at least 90% paratisation with less than one mine per plant on chrysanthemums, and no mines on tomatoes from the next generation of the pest which normally occurs 4-6 leaves up the plant.

Aphids Success is defined as all aphids being infected within twelve days of appearance on the plant, and no further spraying.

RESULTS

Tomatoes The control of whitefly with E.formosa has been outstandingly successful. Of 84 trial sites there were six failures in 1978, and three in 1979, a success rate in terms of area treated of 97% in 1978 and 99% in 1979. The failures were due to the pest being too advanced, i.e. having developed to third instar larvae on some plants before the E.formosa was introduced. Red spider mite was successfully controlled although in 1979 five of the sites (all in Sussex and Hampshire) developed populations of either Tetranychus cinnabarinus or the aggressive strain of T.urticae. These had to be controlled by spraying cyhexatin at 50gm/1,000 l. HV monthly as a supplement to the P.persimilis population already established at the time of the outbreak. This programme completely eradicated the problem in four of the sites although the fifth site still has the problem albeit at a reduced level.

The mid summer applications of O.pallipas/D.sibirica were all completely successful. Infestations started earlier in the year were not successful despite introducing quantities up to 20,000/ha.

Cucumbers Three sites failed to achieve satisfactory control in 1978, and whilst ten sites were completely successful in 1979 a further five were held at a satisfactory level by spot treatment of chemicals to control high levels of whitefly adults. The amended introduction programme was clearly advantageous, but when used again in 1981, seven sites failed to give satisfactory results. On these seven sites Vertacillium lecanii was used as a spray to the tops of the plants to control whitefly adults. The product failed in two sites, but in five sites 90%+ control of adults was achieved and further adults hatching from lower leaves of the plant became infected shortly after reaching the tops of the plant. By reducing the number of adults and thus whitefly eggs being laid, the balance between the E.formosa and whitefly was maintained.

In all trials a satisfactory level of red spider control was achieved but the results demonstrated the importance of regular crop monitoring because where this was not carried out adequately, spot spraying with an acaracide became necessary.

Two of the A.mackenziei trials were lost because toxic chemicals were used in the crop but the others were very successful. In none of the trials did the damage increase after the A.mackenziei was introduced and new leaves did not develop damage greater than damage index 0.1.

Peppers All trials were completely successful.

House Plants With the exception of whitefly control on Fuchsia all trials were completely successful. Whitefly start to attack Fuchsia in April and as it is grown at a temperature of 10°C. the trials failure were anticipated, (Day and Collingwood 1973).

The A.mackenziei in Crotons was slow to take effect and 14 days after the application, tetrachlorvinphos was applied at 125gm/1,000 l. HV to give some thrip control whilst the A.mackenziei population became established.

Chrysanthemums In all cases the use of P.persimilis at the rate of one predator to three cuttings was completely successful, even though at times the red spider was present in large numbers, (Bassett 1980). None of the applications at 1 per 6 cuttings was successful. In the 1979 trial a further application of the same number of predators restored the balance. In the first three 1981 trials supplementary application of either P.persimilis, dicofol applied ULV, dienochlor or cyhexatin had to be made for full control of the pest.

The O.pallipas/D.sibirica was successful in 1979 but in 1980 failed to give acceptable control in four of the seven trials. A high level (75%+) of parasitisation was eventually achieved but the number of leaf mines formed by the pest was unacceptable. In two cases the failure was due to an invasion of large numbers of leaf miner from an adjacent house, and in the other two cases the introductions were made after the first feeding marks, and thus many of the pests were beyond the parasitation stage.

In 1981, two of the eight trials failed because the introduction was too late.

All trials with Vertacillium lecanii were successful, although in two trials some plants were oversprayed with pirimicarb to control an invasion of Myzus persicae from outside when the crop was in colour. In all trials Aphis gossypii was the last species to become infected with the fungus.

Roses Two of the 1979 trials and the 1980 trial were successful, but in the other two 1979 trials the balance between predator and pest necessary to control the red spider mite population, was achieved only by frequent introductions of large numbers of predators. 2.5 million P.persimilis per ha were used in the five month season. There was no correlation between success or failure of the predator and the use of sulphur.

Peppers All of the trials were completely successful as a result of applying an average 100,000 P.persimilis per ha.

Vertacillium lecanii failed to control Myzus persicae.

Strawberries The 1979 trial gave good red spider mite control for the first three weeks, but the crop then very quickly became infested with large numbers of the pest which could not be controlled by the predator.

This phenomenon was repeated in two of the 1980 trials. In the six other trials cyhexatin was sprayed before introduction and these trials were completely successful. These results were confirmed by the 1981 trials.

Two trials on newly planted runners in 1980 resulted in the plants remaining clean for the rest of 1980 and well into 1981 with only a light infestation (2-3 per plant) of red spider mite present after the first harvest in July.

DISCUSSION

In this five year series of trials, reliable programmes have been developed for the major pests on the major crops of the United Kingdom glasshouse industry. The use of biological agents in place of broad-spectrum insecticides has not resulted in any significant increase in other pests, apart from the outbreaks of toxic strain of red spider mite in 1978 and 1979, although no further outbreaks have been reported. The incidence of leaf miner in tomatoes is rare in the United Kingdom although all trial sites had a history of the pest prior to using biological control. The reasons for the variable results against leaf miner are not understood, and due to the very occasional incidence of this pest in the United Kingdom further work is being carried out in Holland (Koppert 1981).

In cucumbers E.formosa use has been modified to give a better control but it is not completely reliable. The whitefly strain of Vertacillium lecanii offers great promise for control of large numbers of whitefly adults to maintain the balance between pest and parasite and further work with this product is recommended. Red spider mite has been well controlled and the number of predators used per hectare per season has fallen considerably over the years but there was considerable variation (200%) between individual trials. It is possible that there may be a correlation between pest levels and crop management during the previous autumn. A study to investigate this correlation should be made.

The most notable problem has been the increase of Thrips tabaci. This has been particularly associated with the use of NFT and Rockwool growing systems, which involves covering all or most of the soil surface with plastic. In these situations there are populations of thrips larger and earlier than normal which are not subject to attack by various other predaceous mites encountered in the conventional straw bale growing system. Treatment of the ground surface with HCH early in the year has led to HCH vapour damaging the populations of E.formosa and P.persimilis. Treatment with tetrachlorvinphos did not damage the P.persimilis because an O-P tolerant race was used (contrary to an earlier report (Parr 1971)) but it is highly damaging to E.formosa.

Accordingly the development in Holland of A.mackenziei as a predator of thrips is welcome and trials this year have shown the potential benefit of this predator. A.mackenziei is also predaceous on red spider mite (Koppert 1981) but no significant reduction in the quantity of P.persimilis needed was noted.

The development of a biological control programme for all-year-round chrysanthemums is the most complex of the biological systems so far using up to five agents. This degree of complexity involved considerable skill in monitoring the crop which in turn has led to considerable educational problems because growers had been accustomed to using one application of aldicarb on the crop. Poor monitoring was the main cause of the large number of failures to discover leaf miner in time, which in turn highlights the importance of early introductions when using the O.pallipas/D.sibirica mixture. The trials have shown consistently that the rate of P.persimilis cannot be reduced below one per three cuttings despite economic pressures.

The variability of results in roses has been confirmed, but no correlation with the use of sulphur has been found. It seems more likely the breeding rate of P.persimilis slows down when used on roses, a phenomenon which has been observed in Holland (Koppert 1981) although there is no definite evidence for this suggestion.

High numbers of red spider mite overwinter in dead leaves and other trash in strawberries leading to large infestations appearing on the crop very quickly. To control these populations with predators alone would be uneconomical. The two approaches of applying an early spray of cyhexatin or of introducing the predator the previous autumn have proved successful.

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NOTES

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HOUSEFLY RESISTANCE TO PYRETHROIDS IN THE VICINITY OF HARPENDEN

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Summary Samples of houseflies from 29 animal breeding farms in the neighbourhood of Harpenden were collected once or more during 1980, and bred for one generation in the laboratory. F_1 flies were tested with permethrin, bioresmethrin and the pyrethrins with and without piperonyl butoxide as well as with a discriminatory dose of DDT with and without FDMC.

Although the observed distribution of LD_{50}s of the field strains to the pyrethroids lay well outside the LD_{50}s of the susceptible laboratory strain, there was good indirect evidence that most local populations were controllable with pyrethroids. The survey demonstrated in a few cases the potential for a very rapid increase in tolerance to pyrethroids, either through selection following the application of residual sprays, or through the dispersal of houseflies from farms with control failure. Control failed either where natural pyrethrins were used excessively or photostable pyrethroids continuously. According to the DDT/FDMC test *kdr* was rare or absent in most of the populations.

INTRODUCTION

Although the development of control strategies to prevent or delay the build-up of resistance to insecticides by insects is very desirable (Anon, 1979), the practical problems involved in establishing which factors are important in causing resistance renders such studies very difficuilt. This is why the descriptive properties, and consequently the predictive powers of most of the theoretical models so far produced (Comins, 1977a,b; Georghiou and Taylor, 1977a,b; Curtis, *et al* 1978; Plapp, *et al* 1979) have not been tested under practical conditions.

The recent introduction of photostable pyrethroids to control houseflies (*Musca domestica* L.) on animal farms in the United Kingdom has provided us with an opportunity to investigate the value of modelling in the management of resistance. Difficulties associated with this work are likely to be less with houseflies, whose resistance and genetics are better understood than that of other insect pests. It should thus be easier to analyse the causes of resistance in this species both in the field and in laboratory simulations, and identify the most important factors using well-documented evidence.

This paper describes the response of housefly populations to pyrethroids on animal farms in the vicinity of Harpenden before widespread use of these materials in the district. The information obtained from this initial survey was necessary to understand and model subsequent changes in susceptibility resulting from the continued application of these insecticides for housefly control.

METHODS AND MATERIALS

i) Housefly bionomics and distribution

A total of 63 pig-breeding farms and 15 poultry units, mostly within 15 miles of Harpenden, were visited during 1980. These represent most of the animal farms in the area likely to support populations of houseflies. In summer, sizeable populations were present on most of the pig farms and in one poultry house which offered the flies undisturbed sites for breeding. Houseflies were few or absent from battery-style poultry units and from dairy farms unless pigs were also kept on the premises.

Housefly numbers varied considerably between farms, reflecting variations in the design of rearing units, the number of animals present, and the attitude of farmers to animal hygiene. On pig farms flies bred in faeces and spilt food in farrowing and early weaner houses, and also in dung heaps out-of-doors during the summer.

Adult numbers increased slowly during the late spring and early summer, and reached a peak between late July and early September. Thereafter, population sizes declined rapidly and by late November adults could be found on only 11 of the original 63 pig farms. These were all intensively-run units with farrowing sows and early weaners kept in heated buildings throughout the year.

ii) Insecticidal usage on local farms

During summer most farmers used organophosphorus (OP) insecticides, mainly trichlorphon and tetrachlorvinphos, in spite of the generally recognised inadequacy of these compounds to control houseflies effectively in the survey area. Our bioassays (to be published elsewhere) confirmed the ubiquitous strong resistance of houseflies to the OPs used locally.

Farmers seldom relied solely on pyrethroids for housefly control. They usually used pyrethrins/piperonyl butoxide (py.pb.) space sprays intermittently and with good effect when excessively large populations were not controlled adequately by other insecticides.

Where pyrethroids were the sole means of housefly control, py.pb. was effective when used infrequently (farm 29, fig. 2), but ineffective on farm 11 where it had been applied daily in 1979. At the time of the survey photostable pyrethroids were used regularly only on farm 6 where they had been applied first in 1976. In 1980 permethrin was virtually ineffective against houseflies on this farm.

iii) Laboratory measurement of the response of field-collected strains

Samples of houseflies from 29 of the 78 farms visited were collected once or more during 1980, bred for one generation under standard laboratory conditions, and F_1 flies were tested with insecticides of several chemical groups. The distribution of the farms sampled is shown in Figure 1. Kill was recorded 48h after treatment and subsequent holding at 20°C. Similar tests were done on the standard susceptible Cooper strain which has been reared for 15 years at Rothamsted without insecticidal pressure.

Permethrin, bioresmethrin and natural pyrethrins (25% pale extract, Wellcome Foundation Ltd.) were applied topically in acetone (0.5µl/fly) with and without pre-treatment with piperonyl butoxide (1.0µg/fly) to females 3 to 4 days old anaesthetized with diethyl ether. Up to 6 doses (2 replicates of 15 flies) were used when testing pyrethroids.

DDT resistance was determined with a discriminating dose (2.5μg/fly, 3 replicates of 20 flies) equal to 10 times LD99 of the susceptible strain. The presence of kdr (knock-down resistance), the mechanism conferring singly most pyrethroid resistance as well as moderate resistance to DDT (Farnham, 1977) was investigated by pre-treating the flies with FDMC (1,1-di-(4 chlorophenyl)-2,2,2 trifluoroethanol, 1μg/fly) to inhibit DDT-ase (Oppenoorth, 1965) followed by the discriminating dose of DDT as above.

Bioassay results are expressed as LD_{50}s because most of the treatments with pyrethroids produced a homogenous response of F_1 flies, i.e. straight log. dose-probit lines, and standard errors of LD_{50} values seldom exceeded 15%.

RESULTS

i) Response to pyrethroids

Even the most susceptible field strains were at least 2-3 times more tolerant at LD_{50} of all the pyrethroids tested than the Cooper strain (Fig. 2).

For the three pyrethroids and the py.pb. mixture the LD_{50}s of most of the populations tested approximated normal distributions when plotted on a logarithmic scale (Fig. 2). The few LD_{50} values lying outside and exceeding these distributions were for farms 6 and 11, where prolonged use of pyrethroids had resulted in control failure, and for farms 2 and 13 which are geographically close to farm 6. Pyrethroids had never been used on these latter two farms.

Differences between the modal response at LD_{50} of all samples tested and the response of the four most tolerant populations (farms 2,6,11,13) were much greater with permethrin and bioresmethrin than with the pyrethrins with and without piperonyl butoxide, agreeing with Keiding's (1978) observation that levels of resistance to the natural pyrethrins are lower than those to the synthetic analogues. The strong selecting power of permethrin is further illustrated by the very rapid change in LD_{50} of the fly population on farm 3 which after switching from py.pb. to permethrin rose from 0.053μg/fly (sample 3A, tested with permethrin) to 0.42 μg/fly (sample 3B) just 10 days following a single application of the photostable compound as a residual surface treatment.

ii) Response to DDT and DDT/FDMC

Between 40% and 75% of the flies from most farms survived the discriminating dose of DDT (Fig 3A). Most of this resistance was caused by the presence of DDT-ase because pre-treatment with FDMC killed all or most of the flies on 25 of the farms (Fig.3B).

Of the two farms with the highest survival to DDT/FDMC (farms 6 and 27) only flies from farm 6 resisted pyrethroids (Fig 2), hence treatment with a discriminating dose of DDT/FDMC does not necessarily constitute a diagnostic test for kdr.

DISCUSSION

This survey, which established the mean level and, more important the distribution of tolerances to pyrethroids of local housefly populations was essential before attempting to interpret and model subsequent changes in susceptibility which will occur when these compounds become more widely used. Although the observed distribution of LD_{50}s of the field strains lay well outside the LD_{50} of our laboratory strain, the fact that py.pb. sprays gave good control on farms where they were used intermittently, suggests that most local populations were controllable with pyrethroids. This difference between the laboratory and field populations, though of little practical importance, demonstrates that standard susceptible strains may not reflect the lowest levels of tolerance that occur in the field.

The increase in tolerance to pyrethroids of field strains was not due to kdr, which according to the DDT/FDMC test is not at a high frequency in most of the populations. Our results have also shown that this test, in the absence of confirmatory bioassay data with pyrethroids, may reveal the presence of DDT-resistance mechanisms other than kdr (Sawicki and Farnham, 1967).

The survey demonstrated in a few cases the potential for a very rapid increase in tolerance to pyrethroids, either through selection following the application of residual sprays as on farm 3, or through the dispersal of houseflies from farms with control failure to neighbouring farms where insecticides may not be in use. Although still rare, complete control failure occurred either where natural pyrethrins were used excessively or where photostable pyrethroids were used continuously; both strategies result in flies being in very frequent contact with pyrethroids and intensify the selection of more tolerant genotypes. There is therefore a strong need to minimize this contact by using photostable pyrethroids as little as possible. Evidence accumulated during this survey suggests that although most local farm populations conform to a normal distribution of tolerances and can be controlled by pyrethroids, the excessive use of these compounds could quickly lead to extensive control failure.

Acknowledgements

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Figure 1 Map to show the distribution of 19 animal farms in the vicinity of Rothamsted from which fly populations were collected. This excludes 10 outlying farms in Bedfordshire and east Hertfordshire

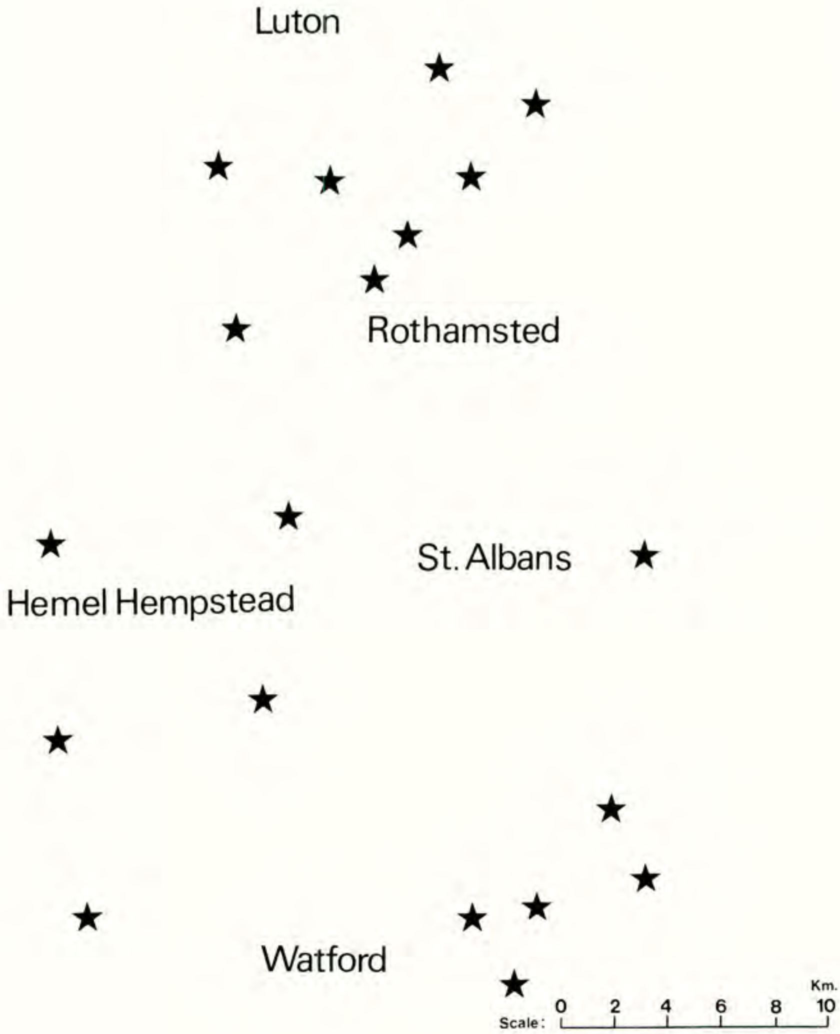


Figure 2 The distribution of log. LD_{50} values of populations tested with pyrethroids. Filled-in squares represent five collections (Farms 2, 3B, 6, 11, 13) which are referred to specifically in the text. The superimposed curves are normal distributions fitted to the data excluding those for the above five farms. S = susceptible Cooper strain

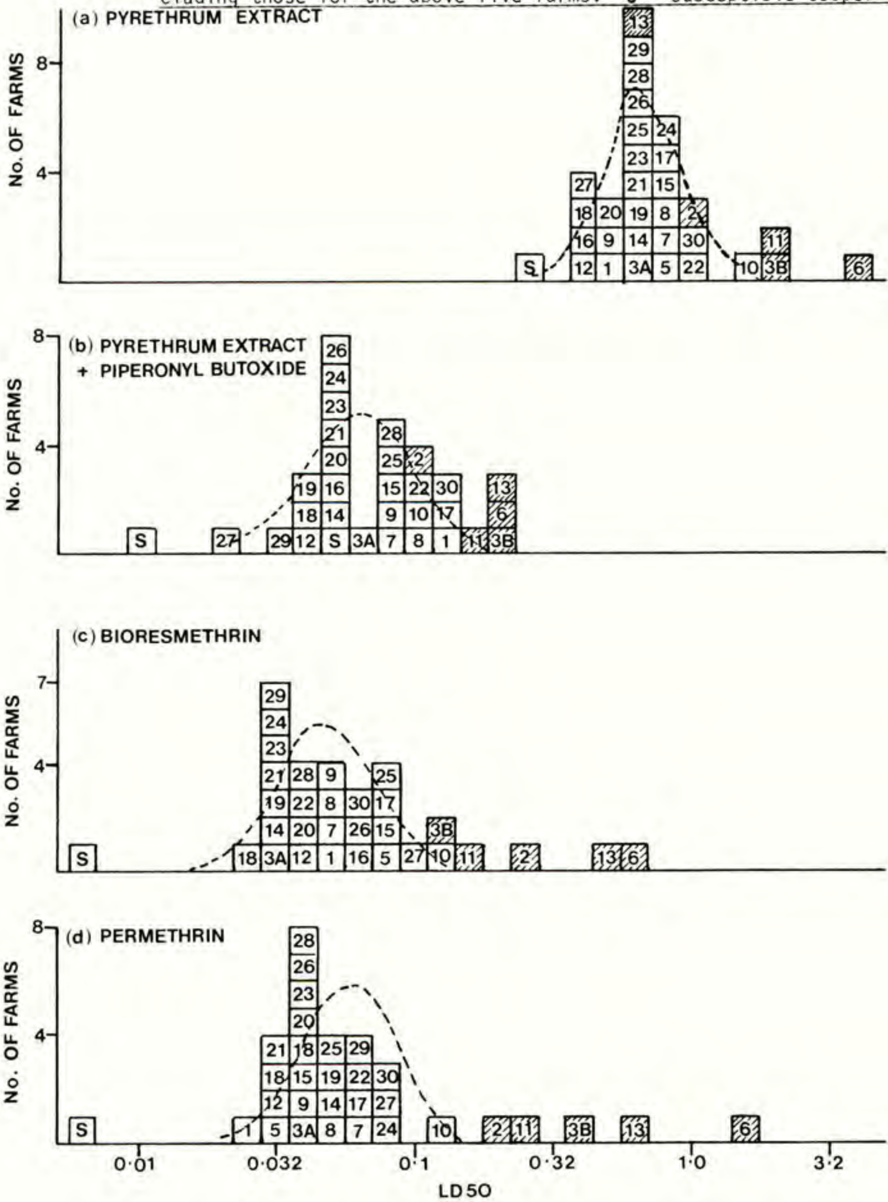
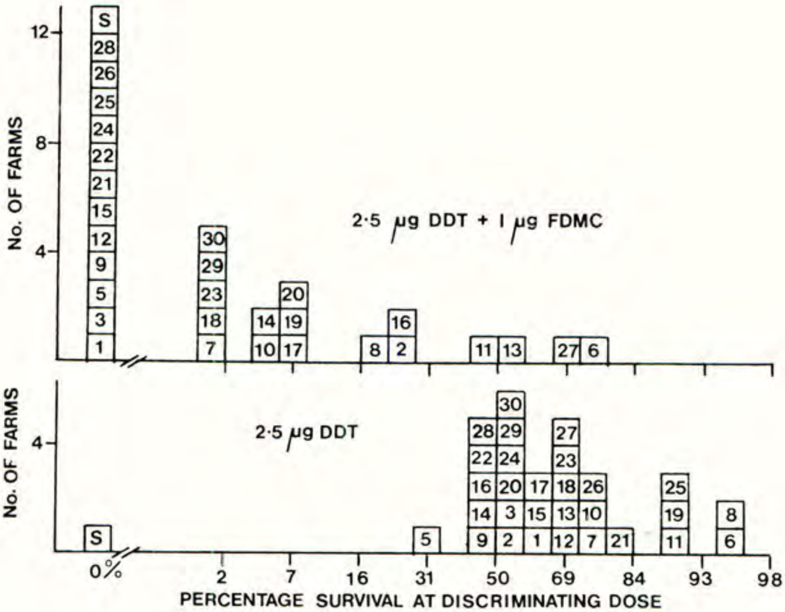


Figure 3 The distribution of values for probit survival to a discriminating dose of 2.5 ug DDT/fly with and without pre-treatment with 1.0 ug FDMC. S = susceptible Cooper strain



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RESISTANCE TO PIRIMIPHOS-METHYL IN CHEESE MITES

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Summary Pirimiphos-methyl is the acaricide most widely used against stored-product mites in the UK today. Resistance to this compound in *Acarus chaetoxysilos*, *A. farris* and their intermediates is widespread in English cheese stores. *A. chaetoxysilos* is confined to cheese stores whereas *A. farris* is also found elsewhere, including grain stores. Resistance to pirimiphos-methyl has not been detected in mites from other situations. Of seven alternative compounds tested against the resistant mites, dienochlor, gamma-HCH and bioresmethrin/pb were effective, but cross-resistance to three organophosphorus acaricides was demonstrated.

INTRODUCTION

Mites are undesirable in cheese stores for several reasons. They can reduce substantial quantities of traditional cheese to dust (Eales, 1918; Robertson, 1952). More commonly they consume only a small part of the cheese, but may reduce their value considerably. Nowadays, traditional, or rinded, cheeses have largely been replaced with rindless block cheeses which are less attractive to mites. However, all Stiltons and a small proportion of Cheddars and Cheshires are still made in the traditional way. With modern standards of hygiene and cleanliness, even low numbers of mites on a cheese may make it unsaleable. Furthermore, mites are powerful allergens (Wraith, Cunnington and Seymour, 1979) and heavy infestations have been linked with outbreaks of dermatitis in sensitive workers in cheese stores.

Strict attention to hygiene in the stores is unlikely to do more than reduce an infestation. Fumigation with methyl bromide can kill all mites, but is costly, and some buildings cannot be fumigated.

For many years the organochlorine compound, gamma-HCH was applied to cheeses and gave satisfactory control of mites in cheese stores. However, resistance to this compound was first detected in mites from a Cheshire store in 1970 by Wilkin, (1973). He suspected that the unsystematic 'spot treatment' method of pesticide application had favoured the build up of resistance. In a search for alternative acaricides, the organophosphorus compound, pirimiphos-methyl was the most promising and in 1973 was cleared by the UK Pesticides Safety Precautions Scheme (PSPS) for treatment of the fabric of cheese stores. Producers were advised to treat whole areas at a time and to spray at least every six months. Pirimiphos-methyl is an excellent wide-spectrum acaricide, now commonly used in the UK to kill many species of stored-product mites both in cheese stores and numerous other environments (Wilkin, 1975 & 1979).

The present investigation started in August 1979 because of a reported failure of pirimiphos-methyl to control mites in a traditional Cheddar store in Dorset. Pirimiphos-methyl had been regularly and successfully used until recently when it apparently lost its effect. Mites were collected and identified, using the key of Griffiths (1970), as Acarus chaetoxysilos, with fewer Acarus farris, and some intermediate individuals presumed to be hybrids. This was the first report that A. chaetoxysilos and A. farris are interfertile and may produce hybrids.

MATERIALS AND METHODS

The Dorset mites (population 6) were reared in the laboratory on wheat germ and dried yeast according to the method of Solomon & Cunnington (1964). Subsequently, ten other cultures (populations 7-16) were collected from stores making or grading traditional Cheddar, Cheshire or Stilton cheeses (Table 1). Most storekeepers had also been using pirimiphos-methyl regularly, but none suspected control failure. In general, levels of infestation were markedly lower than on previous visits (Wilkin, 1973 & 1979). However, one Stilton store had a heavy infestation.

A. chaetoxysilos, A. farris and intermediates were present in all cultures from Cheddar and Stilton stores, except three in which A. farris individuals could not be found among a sample of more than 30 identified. However, they may have been present at low levels. Population 16 from a Cheshire store was unusual, containing A. farris alone.

For comparative tests, a culture of mites never exposed to pirimiphos-methyl was required. Population 1, collected from a Derbyshire Stilton store and reared at Slough since 1973 fulfilled this requirement although it had been determined as resistant to gamma-HCH shortly after collection. Four other laboratory stocks with limited exposure to pirimiphos-methyl were included in the trials. It had been assumed that several of our laboratory stocks were pure cultures of A. chaetoxysilos. However, closer examination of individuals showed that they were all mixed populations. Population 1 contained mostly A. chaetoxysilos, together with a few A. farris, and intermediates.

Attempt to produce a pure population of A. chaetoxysilos

An attempt was made to produce cultures of A. chaetoxysilos from populations 1 and 6 by setting up at least 30 pairs of resting tritonymphs (Wilkin, 1973). After eggs were laid, the adults were removed and identified. Only if both parents were A. chaetoxysilos were the progeny bulked together with those of similar pairs to form a new culture.

In the event, neither new culture contained A. chaetoxysilos alone and so the original mixed cultures were used for testing.

Tests with pirimiphos-methyl

All the populations were tested against 8 ppm pirimiphos-methyl applied to wheat (Table 1). The method employed was that used for the detection of resistance to gamma-HCH (Wilkin, 1973) except that a dust formulation was used. The dust was weighed out, added to the grain in a Kilner jar and mixed thoroughly. The dose of 8 ppm was chosen because in previous tests it was lethal to all stored-product mites. Mites surviving 14 days' exposure to the treated grain were considered resistant.

Population 6 was also tested at 16, 32, 64 and 128 ppm pirimiphos-methyl in order to determine the level of resistance. Survivors were reared and their progeny re-tested at higher doses in an attempt to produce a homozygous resistant strain.

Tests with alternative pesticides

Seven other compounds, most of which were known to be effective against laboratory cultures of several *Acarus* species, were tested against populations 1 and 6 using the same method as for pirimiphos-methyl except that e.c. or w.p. formulations were substituted if a dust was unavailable (Table 2). A hand sprayer was used to apply water-based formulations to 500 g of wheat placed in a thin layer on a tray (Wilkin & Hope, 1972). The dosage rate selected was the highest considered safe, on the basis of mammalian toxicity. Promising compounds were subsequently tested against other strains of mites.

After all tests, some survivors were mounted on slides and identified.

RESULTS

Attempt to produce a pure population of A. chaetoxysilos

Production of a single species population failed, although the original parents from populations 1 and 6 possessed the characters of *A. chaetoxysilos* laid down in the key of Griffiths. Both new populations, designated 1A and 6A, had a higher proportion of individuals identified as *A. chaetoxysilos* than the parent populations, but intermediate forms were still present. Moreover, population 6A contained a few individuals identified as *A. farris*. This suggests that the original parents were genetically impure.

Body setae were the sole characters used to identify intermediates, which ranged from those very close to one taxon to those approaching the other taxon (Fig 1). Occasionally the appearance of only one body seta was sufficient to classify the individual as an intermediate.

Tests with pirimiphos-methyl

At 8 ppm pirimiphos-methyl there were survivors in all populations containing *A. chaetoxysilos* which had been collected between 1979-1981, whereas all populations collected previous to 1979 were killed. However, population 16, consisting of *A. farris* alone and collected in 1981, was also killed. The proportion of survivors was generally low (about 25%) except for populations 6 and 7 of which 75% survived.

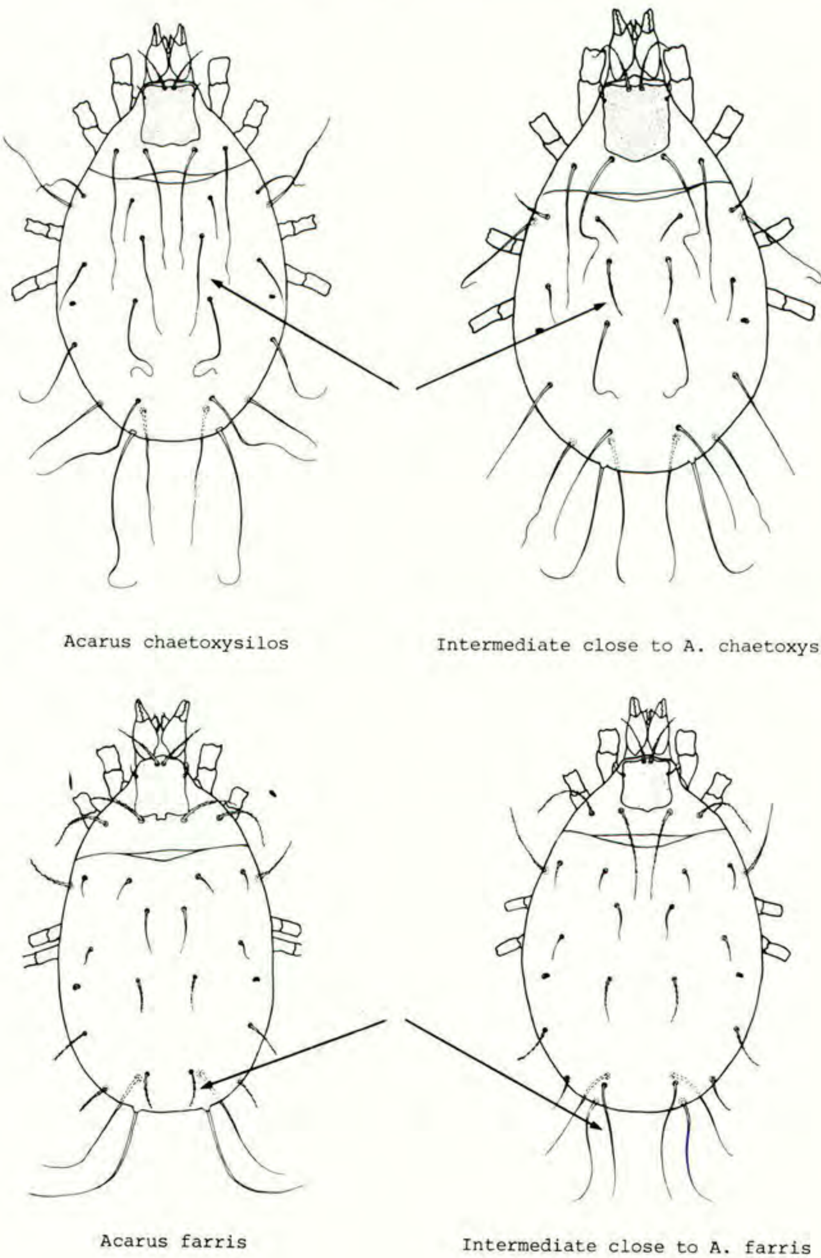
About 25% of population 6 survived 64 ppm pirimiphos-methyl, but none survived 128 ppm. Using the culture bred from survivors of 64 ppm in three further selections, it was possible only to raise the level of resistance so that 25% survived 128 ppm. This indicates that a homozygous resistant strain was not obtained. The work was further hampered by slow breeding of survivors in culture.

Tests with other pesticides

Dienochlor, gamma-HCH and bioresmethrin/pb all controlled both populations 1 and 6. However, the organophosphorus compounds chlorpyrifos-methyl, etrimfos and methacrifos gave complete kill of the former population but only 75% kill of the latter. Propargite was not totally effective against either.

Survivors in these tests, and those with pirimiphos-methyl represented both species and intermediate forms.

Figure 1. Dorsal appearance of some mites from population 6. Arrows indicate setae used to distinguish examples of intermediate forms.



Acarus chaetoxysilos

Intermediate close to A. chaetoxysilos

Acarus farris

Intermediate close to A. farris

Table I

Test against 8 ppm pirimiphos-methyl in cheese mites: Acarus

	Origin of population	Number of population	Type of premises	Species present	Date collected	Category of kill*	Resistant/ susceptible (R/S)
Populations collected pre-1979	Hartington, Derbyshire	1	Stilton store	A. chaetoxysilos A. farris + intermediates	1973	4	S
	Wells, Somerset	2	Cheddar "	"	1973	4	S
	Bath, Somerset	3	" "	"	1976	4	S
	Glastonbury, Somerset	4	" "	"	1976	4	S
	Inverness, Scotland	5	Castle Stuart store	"	1978	4	S
Populations collected 1979/81	Bridport, Dorset	6	Cheddar store	"	1979	1	R
	Newton St Cyres, Devon	7	" "	"	1980	1	R
	Wells, Somerset	8	Cheddar grading centre	"	1980	3	R
	Harby, Leicestershire	9	Stilton store	"	1981	3	R
	Saxelby, Leicestershire	10	" "	"	"	3	R
	Melton Mowbray, Leicestershire	11	" "	"	"	3	R
	Hartington, Derbyshire	12	" "	"	"	2	R
	Thorpe End, Melton Mowbray, Leicestershire	13	Stilton store	A. chaetoxysilos + intermediates	"	3	R
	Long Clawson Leicestershire	14	" "	"	"	3	R
	Hose, Leicestershire	15	" "	"	"	3	R
	Crewe, Cheshire	16	Cheshire grading centre	A. farris	"	4	S

* < 10% (0); ≏ 25% (1); ≏ 50% (2); > 75% (3); 100% (4)

Table 2

Effect of alternative pesticides against pirimiphos-methyl-resistant and susceptible mites

Pesticide & formulation	Class of compound	Dose ppm	Category of kill*	
			Population 1	Population 6
Dienochlor	Organochlorine	30	4	4
Gamma-HCH dust	"	5	4	4
Bioresmethrin/pb[x]	Pyrethroid	10	4	4
Chlorpyrifos-methyl e.c.	Organophosphorus	6	4	3
Etrimfos dust	"	8	4	3
Methacrifos‡	"	8	4	3
Propargite	Organosulphite	20	3	3

* 75% (3); 100% (4)

‡ 98% trans isomer

x piperonyl butoxide

DISCUSSION

Laboratory tests have confirmed that a failure of pirimiphos-methyl to control mites in a cheese store was due to resistance. The species involved were A. chaetoxysilos, A. farris and intermediate forms. Populations of these mites from other cheese stores were also resistant to pirimiphos-methyl, but mostly at a lower level. So far, this resistance has only been detected in English cheese stores, but A. farris is a pest of other commodities including grain, to which they could spread. Furthermore, Griffiths (1964) showed that A farris will hybridise with A. siro, an important pest of grain. The female F_1 hybrids are infertile but the male F_1 hybrids show limited fertility when back crossed to either parent species. Thus, gene exchange between the species could occur, albeit rarely. It is possible therefore that genes for resistance in A. farris or even A. chaetoxysilos could be passed to A. siro via hybrids. The potential spread of resistant mites, and the development of resistance in other species is an alarming prospect as no alternative acaricides are immediately available.

It is not surprising that resistance in storage mites to both pirimiphos-methyl and gamma-HCH should first be detected in cheese stores. The frequency of fabric treatments is probably higher in cheese stores than in most other situations and, if the acaricide is not applied thoroughly selection for resistance could be accelerated. A further complication is the considerable traffic in cheeses, and therefore probably in mites, between many stores (Wilkin, 1979). Storekeepers rarely co-ordinate their treatments, and cross-infestation of stores must be common. It is therefore quite possible for resistant mites in one store to be transported to others. However, during collection of the 1981 Stilton cultures it was noticed that, with a few exceptions, the standard of treatments had improved and levels of infestation were lower, compared with previous findings (Wilkin, 1973 and 1979).

It was interesting that the discriminating dose of gamma-HCH killed populations 1 and 6, especially since the former was resistant when first tested in 1973. Subsequent work has shown that other recently collected cultures were marginally resistant to gamma-HCH. This indicates that a low level of resistance to gamma-HCH may still be present in cheese store populations.

Another organochlorine, dienochlor, was also effective against populations 1 and 6. This pesticide is used against spider mites on ornamentals in glasshouses in the UK and has the advantage of a low mammalian toxicity, but it is not cleared by the UK PSPS for use in food stores. It has been tested against other species of storage mites, and appears to be equally effective against gamma-HCH-resistant and susceptible populations (L.M. Stables, unpublished). Thus there is no detectable cross-resistance to dienochlor, although a low level of cross-resistance would not be detected using the current technique. In previous work (Anon, 1978) using a dipping technique, a low level of cross-resistance between gamma-HCH and dieldrin was demonstrated in A. siro and Glycyphagus destructor.

Cross resistance between pirimiphos-methyl and the other organophosphorus compounds, chlorpyrifos-methyl, etrimfos and methacrifos was clearly demonstrated in population 6. These results were disturbing, since chlorpyrifos-methyl and etrimfos are effective against many stored-product species and are now cleared by the PSPS for use in certain situations (Anon, 1975, Stables, 1980, Stables et al, 1979).

Although the pyrethroid, bioresmethrin/pb was effective against populations 1 and 6, it gave very variable results against cheese mites in practical trials (Anon, 1981). Propargite, an organosulphite effective against other species and genera (Stables, 1980) was not totally effective against either population.

Wilkin (1979) reported A. chaetoxysilos as the dominant species in his survey of cheese stores, and this was also true in the present work. He also found A. farris regularly, but intermediate forms were not recorded. In each of 15 populations containing A. chaetoxysilos and collected from cheese stores between 1973-1981, intermediates were found during the current work, and they were probably also present in Wilkin's cultures. The authors do not know of a 'pure' population of A. chaetoxysilos. The tritonymph method failed to produce such a culture, since two individuals identified as A. chaetoxysilos occasionally produced offspring morphologically similar to A. farris, or intermediate between the two. There was the further possibility that the species and their intermediates would respond differently to pesticides and that survivors might be a single species. However, no differences in levels of resistance or response to other pesticides have yet been found in the two species or the intermediate forms, and so it has not been possible to separate them by any method.

Cheese mites have developed resistance to two excellent pesticides within 10 years. It is essential that if another compound becomes available, the risk of resistance occurring again is minimised so that maximum control is maintained. In addition, consideration should be given to the possibility of using physical and biological control methods against these mites to lessen the need for pesticides.

Acknowledgements

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THE SPREAD OF RESISTANCE AMONG HOUSEFLIES FROM FARMS IN THE UNITED KINGDOM

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Summary Resistance tests have been carried out on 27 strains of houseflies from farms in 15 counties in England. Three quarters of the strains tested were highly resistant to trichlorphon, tetrachlorvinphos, bendiocarb, gamma-HCH and DDT and none was susceptible. Only 3 strains were susceptible to pyrethrins plus piperonyl butoxide, and 8 of the remaining 24 strains were highly resistant. Of these 8 strains, 7 came from farms where permethrin had been used. The findings help to explain the widespread reports of control failures with various organophosphorus and carbamate compounds used as surface sprays or baits in farm animal houses.

INTRODUCTION

Houseflies (Musca domestica) in the United Kingdom (UK) were known to be resistant to DDT, gamma-HCH and cylodienne insecticides in 1955 (Green). For more than 20 years since then, satisfactory control with insecticides has been achieved mainly with organophosphorus compounds and natural pyrethrins. Control failures with organophosphorus insecticides were first reported by the Ministry's Regional Pests Service in 1977. Tests at Rothamsted Experimental Station in 1978 on flies from two farms in Suffolk showed that both strains were resistant to organophosphorus and organochlorine compounds (A.W. Farnham, personal communication). Later in 1978 a dramatic control failure was experienced with a mist treatment of natural pyrethrins (pyrethrum) plus piperonyl butoxide (PB), at another site in Suffolk. Tests at Rothamsted demonstrated that these flies were resistant to pyrethrins and synthetic pyrethroids (Sawicki et al., 1979). This history of resistance was similar to that previously experienced in Denmark (Keiding, 1976). It was important to attempt an assessment of the extent and seriousness of insecticide resistance by testing housefly populations from all over the UK. Samples of flies were therefore collected by the Regional advisers and sent to the Slough Laboratory, where resistance tests began in October 1979.

METHODS AND MATERIALS

The resistance screening programme was based on the method described by the WHO Expert Committee on Insecticides (United Nations : WHO, 1970).

Susceptible flies were reared at 28°C and 60% r.h. Flies from farms were reared at 28°C and uncontrolled r.h., and through at least one generation before testing. After a feed of fresh milk, flies were transferred to the test conditions of 20°C and 50% r.h. Replicate batches of 3-5 day-old female flies were prepared and left to acclimatise overnight. Each batch was provided with a drinking pad soaked in 10% sugar solution and was kept under constant illumination (130 lux-candles). A minimum of 5 batches of 20 flies was treated at each dose level. Flies were dosed individually with 0.5 µl of insecticide dissolved in pentan-3-one. Carbon dioxide was used to immobilise flies during sex separation and treatment. Natural pyrethrin solutions were prepared from a decolourised extract containing 24.1% total pyrethrins formulated with technical piperonyl butoxide (PB) at 1:10 a.i. Solutions of the remaining compounds were prepared from concentrates containing more than 90% a.i.

Dose-response lines for susceptible flies were obtained with each of the insecticides used in the screen. These data were processed on a Varian computer using a maximum likelihood program devised at this laboratory by A.J. Prickett. Replicate responses of 0 or 100% were pooled at a given dose level, together with single replicates in which 1 or 19 insects responded. Expected responses of <4% or >96% were included in the regression computation but excluded from the chi-squared tests for goodness of fit. Concentrations computed to knock down 99.99% of susceptible flies 48 h after treatment, were chosen as discriminating doses (DD) to detect resistance. Multiples of the DD enabled better estimates of resistance to be made and were chosen according to the seriousness of resistance expected.

RESULTS

The distribution of the housefly strains tested is shown in Figure 1. The dose-response data for susceptible flies and the discriminating doses (DD) derived from computed KD99.99 values, are given in Table 1.

Table 1

Dose-response data for susceptible houseflies, 48 hours after topical treatment at 20°C

	µg ♀ fly						
Toxicant	KD50	(95% limits)	KD99.9[a]	Slope ±	(S.E.)	Chi^2	DF
Trichlorphon	0.212	(0.202 , 0.222)	0.62	7.8	(0.74)	29.0	23
Tetrachlorvinphos	0.0316	(0.0297, 0.0334)	0.13	6.1	(0.60)	25.6	23
Bendiocarb	0.227	(0.198 , 0.258)	2.5	3.6	(0.49)	50.8	23
Pyrethrins + PB	0.0251	(0.0233, 0.0267)	0.11	5.8	(0.56)	8.7	15
Gamma-HCH	0.0177	(0.0166, 0.0189)	0.062	6.9	(0.71)	4.2	10
DDT	0.0681	(0.0642, 0.0716)	0.16	10.2	(1.22)	5.5	5

[a]Discriminating dose

The 48 h KD responses of the farm strains to trichlorphon, tetrachlorvinphos and bendiocarb at the DD x1 and x8, and to pyrethrins + PB at the DD x1 and x2, are given in Table 2. The resistance categories show that none of the strains tested was susceptible to trichlorphon, tetrachlorvinphos, or bendiocarb. More than 3/4 of the strains tested were either highly resistant or very highly resistant to these compounds. Only 3 strains were susceptible to pyrethrins + PB and over 1/4 of the strains were highly resistant or very highly resistant to this formulation.

Differences in the responses at the DD x1 and the upper dose were highly

Figure 1

The distribution of housefly strains collected from farm animal houses in England

Table 2

The 48 hour responses to topically applied discriminating doses (DD), of housefly strains collected from farms in the United Kingdom

Strain	Trichlorphon % KD at DD x1	Trichlorphon % KD at DD x8	R cat.[c]	Tetrachlorvinphos % KD at DD x1	Tetrachlorvinphos % KD at DD x8	R cat.	Bendiocarb % KD at DD x1	Bendiocarb % KD at DD x8	R cat.	Pyrethrins + PB % KD at DD x1	Pyrethrins + PB % KD at DD x2	R cat.
A	O	12	+++	O	73	++	-	-		28	100	+
B	5	22	+++	11	58	++	79	91	+++	100	-	O
C	1	82	+	20	98	+	-	-		41	95	+
D	1	21	+++	1	66	++	-	-		89	-	+
E	1	15	+++	3	71	++	-	-		8	60	++
F	3	55	++	33	92	+	-	-		100	-	O
G	O	O	+++	O	2	+++	O	O	+++	O	9	+++
H	4	60	++	30	74	++	65	87	+	99	-	+
I	O	2	+++	11	30	++	4	7	+++	27	84	+
J	2	6	+++	1	10	+++	18	29	++	7	56	++
K	15	96	+	58	100	+	91	93	+	91	-	+
L	2	3	+++	2	19	+++	7	13	+++	2	18	+++
M	2	19	+++	3	7	+++	13	20	+++	72	88	+
N	6	40	++	16	48	++	30	31	++	97	100	+
O	6	85	+	45	100	+	94	99	+	100	100	O
P	1	40	++	5	41	++	49	55	++	84	100	+
Q	5	37	++	24	99	+	5	6	+++	8	30	++
R	5	78	+	23	93	+	67	74	++	95	100	+
S	5	42	++	33	97	+	26	34	++	94	100	+
T	1	26	++	49	67	++	16	19	+++	27	85	+
U	O	11	+++	O	3	+++	21	29	++	18	83	+
V	O	27	++	10	54	++	41	57	++	13	70	++
W	3	45	++	25	71	++	38	58	++	98	100	+
X	1	31	++	1	5	+++	9	12	+++	6	31	++
Y	8	50	++	9	57	++	29	53	++	91	100	+
AA	19	83	+	29	94	+	43	53	++	36	61	++
AB	1	19	+++	2	78	+	O	1	+++	82	95	+

[c] Resistance category:
O = Susceptible (100% KD at DD x1)
+ = Moderately resistant (>75% KD at upper dose)
++ = High resistance (25-75% KD at upper dose)
+++ = Very high resistance (<25% KD at upper dose)

significant (P = <0.01) with trichlorphon, tetrachlorvinphos, and pyrethrins + PB in 63 out of 75 tests. However, differences of similar magnitude only occurred in 2 out of 22 tests with bendiocarb.

Gamma-HCH and DDT were tested at the DD x6 and x4 respectively. Of the 27 strains shown in Table 2, 21 were found to be very highly resistant to gamma-HCH and the remaining 6 were highly resistant. With DDT, 26 strains were very highly resistant and 1 was highly resistant. Resistance to DDT has apparently persisted in housefly populations despite the gradual withdrawal of DDT, for most disinfestation purposes in the UK, over the last 12 years (Wilson, 1969). DDT at the DD x4 was also compared with a 1:1 mixture of DDT + FDMC[b] (0.64 µg of each toxicant). FDMC is known to synergise DDT by inhibiting dehydrochlorination (Oppenoorth, 1965). FDMC failed to synergise DDT against 7 of the 8 strains most resistant to pyrethrins + PB in Table 2. Conversely, FDMC synergised DDT (P = <0.01) against 15 of the other 19 strains tested.

DISCUSSION

Trichlorphon attractant bait has been used in the UK since 1957, and therefore serious resistance has taken at least 20 years to appear. Bendiocarb bait has only been available since 1980 but serious resistance and control failures are already occurring. With bendiocarb, the similar responses obtained at the DD x1 and the upper dose suggest a flat dose-response. This contrasts with the results for trichlorphon, tetrachlorvinphos and pyrethrins + PB and may help to explain the rapid growth of resistance to bendiocarb experienced in animal houses. A poor dose-response to bendiocarb was also shown by the susceptible strain (Table 1) and this compound gave the lowest slope and the highest KD99.99 of all the toxicants tested.

The very low responses of some farm strains to the DD x1 (Table 2) suggest that individuals fully susceptible to all four toxicants were rare or absent in many infestations. The seriousness of resistance is indicated by the low responses to the upper doses. Several strains categorised as very highly resistant to trichlorphon came from premises where farmers reported that trichlorphon bait had failed to achieve control. Similarly with pyrethrins + PB, strains categorised as highly resistant in Table 2 have been obtained from sites where pyrethrin mists were ineffective at normal rates of application.

The correlation between the synergism of DDT by FDMC and the resistance to pyrethrins + PB found in this investigation, suggests the presence of a genetic factor of the recessive <u>kdr</u> type. When selection pressure is applied to <u>kdr</u> with pyrethrins or pyrethroids, rapid increases in resistance are likely to both types of toxicant (Farnham, 1977; Keiding, 1981). Although low pyrethrin resistance may have been present in housefly populations for some years, pyrethrin mists or aerosols have generally maintained their effectiveness when used intermittently. However, 7 of the 8 farms with strains categorised as highly or very highly resistant to pyrethrins + PB (Table 2), have histories of surface spraying with the residual pyrethroid permethrin. Kunast (1979) has shown that continuous selection pressure by surface treatments with permethrin can result in rapid loss of fly control in intensive animal houses. The application of residual pyrethroids in such premises has been prevented in Denmark (Skovmand and Keiding, 1979) because it jeopardises the future use of pyrethrins and the readily degraded pyrethroids, as mist applications. Space-mists are one of the best methods of rapidly gaining control of fly infestations. In the light of these reports and the observations

[b] 2,2,2-trifluoro-1,1-<u>bis</u>(4-chlorophenyl) ethanol

in our trials, this Ministry does not recommend treatment with persistent pyrethroids in intensive animal houses.

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[d]Sandwich students from the University of Bath and Liverpool Polytechnic respectively.

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INSENSITIVITY OF ERYSIPHE GRAMINIS F.SP. HORDEI TO TRIADIMEFON, TRIADIMENOL AND OTHER FUNGICIDES

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Summary Populations of *Erysiphe graminis* on barley and wheat were surveyed for insensitivity to triadimenol in England, Wales and Scotland in 1981 using mobile nurseries in fields and a wind impaction spore trap (WIST) mounted on a car.

Of the 460 populations on mobile nurseries exposed in 76 spring barley crops, 24% had FD_{50} values of 0.25 g a.i. triadimenol per kg seed, or more, and were classified as insensitive. Of the 83 populations obtained from 19 winter barley crops, 53% were classified as insensitive. These results indicate an increase in the incidence of insensitivity from the value of 3% determined in 1980.

The distribution of insensitive populations was not uniform between cultivars. The most susceptible, cv. Golden Promise, which sustained a large pathogen population, also had the highest incidence of insensitivity. The highly resistant cultivar Triumph, on the other hand, showed a low incidence of insensitivity. Evidence from cv. Koru (mildew susceptible; low incidence of insensitivity) and Mazurka (mildew resistant; high incidence of insensitivity) indicated that interactions may occur between specific pathogenicity characters and insensitivity to the fungicide.

The WIST survey confirmed the widespread occurrence of insensitivity in both barley and wheat mildew populations. It also revealed that the highest incidence in barley mildew occurred in eastern Scotland, presumably correlated with the high frequency of fungicide-treated crops of cv. Golden Promise. The highest incidence of insensitivity in wheat mildew occurred in Yorkshire.

The WIST survey in East Anglia showed that the incidence of insensitivity in barley mildew increased rapidly at the end of May, and remained at a high level in mid-July when the last observation was made.

There was an indication from the survey data and laboratory tests that barley mildew populations selected on crops treated with triadimenol, triadimefon, and some other ergosterol biosynthesis inhibitors, were similar in their insensitivity to triadimenol.

INTRODUCTION

Powdery mildew, *Erysiphe graminis* f. sp. *hordei*, is the most common disease of the barley crop in the UK. During the past ten years, fungicides have been used for its control, the most common being ethirimol, tridemorph and, more recently, triadimefon and triadimenol. There have been reports of insensitivity of the pathogen to ethirimol (Wolfe & Dinoor, 1973), and to tridemorph (Walmsley-Woodward *et al*. 1979). Despite this, there have been few, if any, total failures of disease control due to insensitivity. However, the recent increase in the culture of winter barley and the almost total dependence of cereal growers on fungicides with a similar mode of action (ergosterol biosynthesis inhibition) prompted a survey of the sensitivity of populations of *E. graminis* to this new group of fungicides. In preliminary surveys in 1979 and 1980, triadimefon was used as the test fungicide but for the national survey in 1981 it was replaced by triadimenol.

One form of survey involved the use of fungicide-treated test plants grown in trays for field exposure (mobile nurseries: Wolfe & Minchin, 1976), and a second utilised a wind impaction spore trap (WIST) fitted on a car roof. This paper is a preliminary report of the surveys and some of the implications from the results.

METHODS AND MATERIALS

Mobile nurseries

Seeds of cv. Golden Promise were treated with triadimenol by Bayer UK, to give rates of 0.04, 0.08, 0.125, 0.25, 0.375 and 0.625 g a.i. per kg of seed. Ten to 12 treated seeds of each rate were sown in lines in peat compost (Levington Universal) in seed trays (365mm x 220mm x 55mm) and arranged with a line of untreated seeds at one end and with increasing fungicide rate in each successive line. Ten to 14 days after sowing, two trays of seedlings were exposed in each crop for 4 to 7 days, and then grown on in a glasshouse for a further 4 to 16 days before mildew assessments were made. Plants were assessed by estimating the percentage leaf area affected for leaves 1 (the first formed), 2 and 3. The results were expressed as an FD_{50} value, which was the treatment rate at which the mildew level on a defined leaf (generally leaf 2) was half that on the comparable leaf of the untreated control.

At the time the mobile nurseries were exposed, records were made of mildew levels in the crop and, where possible, of the fungicide programme used and the cultivar grown.

Wind Impaction Spore Trap (WIST)

To survey a larger area, and to observe changes with time, a wind impaction spore trap (WIST) was used. This consisted of a box containing protected seedlings, fitted on a car roof, through which air is rammed during the forward motion of the car.

Barley and wheat seedlings (respectively, cvs. Golden Promise and Cerco, both highly susceptible to mildew) were exposed in batches of about 60-80 over distances of 50-100 km, depending on conditions. The batches usually consisted of one each of untreated barley and wheat seedlings, and one of each species treated with triadimenol (0.025 g a.i. per kg seed). From previous experiments, this rate appeared to give the best discrimination between sensitive and insensitive fractions of the pathogen population.

The first set of exposures was on a standard route of 200 km to the east of Cambridge, covered at more or less regular intervals from late March to mid-July. The second set was made on a transect through the main barley and wheat-growing areas of eastern England and south-east Scotland in July. Assessments of exposed seedlings were made by counting the numbers of colonies that developed.

Laboratory tests

Preliminary investigations of the isolates collected were made on detached leaf segments of the first leaves of seedlings grown from the cv. Golden Promise seed treated by Bayer UK. The leaf segments were maintained under controlled conditions on ½% agar containing 150 ppm benzimidazole.

Standard insensitive isolates grew less well on distal than on proximal leaf segments, indicating acropetal movement of the fungicide in the leaf. They also grew less well on detached compared with intact seedling leaves, indicating that the former retained more fungicide. For preliminary tests of cross-insensitivity, leaf segments were inoculated and maintained in the same way from plants grown from seed treated with triforine at 1, 3 and 7.5 ml product per kg seed.

RESULTS

1. Geographical distribution

a) Mobile Nurseries

The total of 543 mobile nurseries was exposed in 95 crops on 71 different farms in England and Wales. Of the 95 crops, 76 were spring, and the remainder winter barley. Mildew levels were generally high except in some parts of the south-east. The FD_{50} values of the 1981 populations are shown in Table 1.

A distinction was made between populations with FD_{50} values less than the 0.25 g rate (76%), and those with 0.25 or more (24%). Among the spring barley populations, the distribution of these fractions was similar for Aberystwyth, Bristol, Cardiff, Evesham, Shardlow and Wye, with about 11% of the populations having high FD_{50} values. From the remaining sites, the proportion of populations with high FD_{50} values was significantly greater than 11%. The most northerly site, Newcastle, produced one of the highest proportions, 46%. Other nurseries exposed in south-east Scotland all gave high FD_{50} values (J. Gilmour, pers. comm.).

There were more populations with high FD_{50} values among the winter barley sites (53%), though this was largely due to the high frequency among those exposed in the Cambridge area.

b) WIST Transect

The WIST counts for barley fitted the overall pattern of the mobile nursery results in that the proportion of colonies with low sensitivity increased towards the north. From Cambridge to Durham, the proportion of colonies on the treated seedlings was 10% of those on the untreated, from Durham to the Borders region it increased to 43%, and in eastern Scotland it reached a maximum of 62%. An overall comparison of data obtained in England and Scotland for barley and wheat reflected the importance of barley relative to wheat in Scotland and of the relatively high frequency of fungicide insensitivity in Scotland coming from treated crops of the common cultivar Golden Promise (Table 2). Among the wheat exposures, the highest levels recorded were in Yorkshire, where the colony numbers on untreated and treated seedlings were approximately equal.

Table 1

FD_{50} values for 543 populations of *Erysiphe graminis* surveyed in 1981

Centre	Number of populations in each FD_{50} category*													
	Winter Barley							Spring Barley						
	0	0.04	0.08	0.125	0.25	0.375†	0.625	0	0.04	0.08	0.125	0.25	0.375†	0.625
Aberystwyth	0	0	0	0	0	0	0	6	14	3	0	0	1	0
Bristol	1	0	0	1	1	1	2	13	30	15	8	5	0	1
Cambridge	0	0	0	3	28	3	1	0	0	0	0	0	0	0
Cardiff	0	0	0	0	0	0	0	1	3	2	5	1	0	0
Evesham	0	0	0	0	0	0	0	2	4	4	3	1	0	0
Leeds	0	0	0	0	0	0	0	0	10	20	20	11	2	0
Newcastle	2	3	4	7	2	0	0	6	17	16	22	33	14	5
Reading	0	0	1	1	2	0	0	26	5	4	11	6	9	3
Shardlow	0	0	4	1	1	0	0	3	15	10	5	7	0	0
Wolverhampton	0	7	2	2	1	2	0	0	6	2	3	5	1	1
Wye	0	0	0	0	0	0	0	15	7	9	5	4	0	0
Total	3	10	11	15	35	6	3	72	111	85	82	73	27	10

*g of triadimenol per kg of barley seeds

† equivalent to field rate

Table 2

Colony numbers of barley and wheat mildew on untreated and treated (0.025 g a.i. triadimenol per kg seed) seedlings per 100 km exposure in the WIST in 1981

		untreated seedlings	treated seedlings	% treated/untreated
barley	England	1.6	0.6	38
	Scotland	4.9	3.1	63
wheat	England	1.3	0.5	38
	Scotland	0.5	<0.1	11

Laboratory tests of some bulk samples of the pathogen trapped in England and Scotland confirmed the same pattern (Table 3). Seedlings grown from seed treated at a rate (0.125 g a.i. per kg seed) higher than the standard, were exposed in some of the southern journeys. They revealed the occurrence of high levels of insensitivity within the populations which were, overall, more sensitive than those trapped in Scotland.

Table 3

WIST samples of barley mildew trapped on triadimenol-treated seedlings and tested on leaf segments from seedlings treated with different rates of triadimenol. The values are relative numbers of colonies

		test dose rate (g a.i. triadimenol per kg seed)				
Source		0	0.04	0.08	0.125	0.25
E. England	0.025	100	39	14	3	0
	0.125	100	100	70	2	0
Scotland	0.025	100	91	38	11	3

2. Time sequence: WIST

In the East Anglian region, the proportion of colonies on treated compared with untreated seedlings averaged 9.0% over four separate occasions between 26 March and 19 May, with little variation. At 28 May, however, there was a marked increase to an average of 29%, which was maintained over eight occasions up to 15 July. There was a considerable variation between occasions, but no indication of a decline in the fraction of colonies on treated seedlings. Indeed, in preliminary laboratory tests on the trapped samples, the highest insensitivity score was obtained from the last exposure, on 15 July.

There was a similar pattern of time sequence in the development of insensitivity among the mobile nurseries. From nursery exposures in heavily infected fields (5% mildew infection or more) only four insensitive populations were obtained within five weeks of fungicide application, but 10 were observed six or more weeks after application, implying, again, a late build-up of insensitivity.

3. Cultivar interactions

Analysis of the distribution of insensitive populations among the range of spring barley cultivars sampled was again based on the division of nurseries into those with low and high FD_{50} values. The majority of cultivars (8) gave a similar response with 26% of the populations at the higher level. This was closely correlated with the overall proportion of populations with high FD_{50} values (24%) and was therefore used as a standard to test the distribution among the remaining cultivars (Table 4).

Table 4

Numbers of barley mildew populations in 1981, with low and high FD_{50} values from different cultivars compared with the proportions obtained from a group of eight standard cultivars

Source cultivar	observed low FD_{50}	observed high FD_{50}	expected low FD_{50}	expected high FD_{50}	χ^2	P
a) Golden Promise	18	31	36	13	33.9	<0.001
Mazurka	18	14	24	8	6.0	<0.02
b) Koru	59	5	47	17	11.5	<0.01
Triumph	85	16	75	26	5.2	<0.05

From Table 4, significantly more high FD_{50} populations than expected were obtained from fields, particularly, of cv. Golden Promise, but also of cv. Mazurka. Significantly fewer than expected high FD_{50} populations were obtained from fields of cvs. Koru and Triumph. In addition only one such population was obtained from eight nurseries exposed in a field of highly resistant cv. Atem, and none from ten nurseries exposed in a field of a cultivar mixture (see Wolfe, 1981a, b).

4. Cross-insensitivity

An indication of cross-insensitivity was obtained from the mobile nursery data. The fields that were sampled were again divided into those that gave low and high FD_{50} values, and then classified according to the spray programmes that they had received (Table 5).

Table 5

Numbers of barley mildew populations in 1981, with low and high FD_{50} values obtained from fields with different fungicide programmes

FD_{50}	Fungicide treatment: None	Triadimefon	Triadimenol	Other
low	46	131	116	35
high	4	56	37	11

For row difference, $\chi^2 = 12.1$, $P < .01$

As expected, considerably fewer unsprayed fields contributed to nurseries with high, compared with low FD_{50} values. However, the remaining portion of the χ^2

deviation was due to the triadimefon-treated fields which contributed more than expected to the high FD_{50} nurseries. From 'other' programmes, mainly using other sterol inhibitors the proportion was the same as for triadimenol-treated fields, indicating that they were just as likely as each other to result in populations with high FD_{50} values.

Initial laboratory tests of this relationship, using triadimenol-sensitive and insensitive strains inoculated on seedling leaf segments treated with triforine (sterol inhibitor), showed that pathogen colonies on triforine-treated seedlings could only be obtained from triadimenol-insensitive isolates. More extensive information on the occurrence of cross-insensitivity to a number of sterol inhibitors has been provided by Hollomon (1981).

DISCUSSION

The crucial question arising from the observations in 1981 is whether or not they represent a change from previous years. This may be answered by comparing results from a preliminary survey made in the Newcastle region in 1980 (Fletcher & Griffin, 1981), with those from the same area in 1981, and from the remainder of England and Wales (Table 6). The mildew populations occurring on the mobile nurseries have been grouped into three categories of FD_{50} values because of the differences in dose rates used in 1980 and 1981. As a test fungicide, triadimefon was used in 1980 as opposed to triadimenol in 1981, but tests indicate that they both behave similarly. The proportion of crops sampled in both years that received sterol inhibiting treatment was about the same (92% in 1980; 88% in 1981).

Table 6

Numbers of mobile nurseries in three categories of FD_{50} values in the Newcastle region in 1980 and 1981, and elsewhere in 1981

Origin	FD_{50} values 0-0.025	0.04-0.125	0.25-0.625	Total
a) Newcastle, 1980	115	46	3	164
b) Newcastle, 1981	6	55	52	113
c) England & Wales* 1981	65	223	58	356

*excluding Newcastle Rows b) and c) differ significantly from a) ($P < 0.001$)

It should be stressed that there were no confirmed reports of failure or partial failure of disease control caused by insensitivity to sterol inhibiting fungicides, although there was some anecdotal evidence of shorter than expected duration of control in occasional crops in 1981. Pathogen strains insensitive to sterol inhibiting fungicides are currently less fit than sensitive strains, because they do not predominate. With the continued and extensive use of these fungicides, however, they could become prevalent within a short time. This does not necessarily mean that there will be a large, or even a noticeable, loss in fungicide effectiveness, but the possibility of failure exists, and the situation needs constant monitoring.

Insensitivity to sterol inhibiting fungicides in 1981 increased with time, as revealed by the WIST survey in East Anglia, and as implied by the difficulty of finding insensitive populations soon after fungicide treatment of the crop.

However, the insensitive populations appeared to contain variants with different levels of insensitivity, the highest being the least common. It is possible therefore that selection will favour the increase of the more insensitive forms that will cause infection of treated crops to begin increasingly soon after treatment.

The high frequency of insensitive populations on the highly susceptible cv. Golden Promise, and the low level on the highly resistant cvs. Triumph and Atem, suggest that, since the frequency of insensitivity is low, its occurrence was largely a function of the size of the pathogen population. However, cv. Koru is highly susceptible but generated an unusually low level of insensitivity, and, conversely, cv. Mazurka is relatively resistant and generated an unusually high level of insensitivity. Thus, there may also be more specific interactions between particular pathogen populations and fungicide insensitivity. A similar conclusion could be drawn from observations made by E. Limpert (pers. comm.) on barley mildew populations in northern Germany in 1980. Such effects could be of considerable value in strategies for cultivar and fungicide use aimed at preserving the effectiveness of both (Wolfe, 1981a, b).

The observations made so far on cross-insensitivity indicate that, for practical purposes, all of the major sterol inhibiting fungicides used so far can be considered as a single fungicide in relation to the way that they select for insensitivity, with the exception of the morpholines.

Our major conclusion is that, although there has not yet been any obvious loss in effectiveness of these fungicides due to insensitivity, the trends observed give rise to concern and emphasise the need for deploying all possible strategies to reduce further selection on the pathogen for insensitivity to this important and valuable group of fungicides.

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RESISTANCE TO METALAXYL IN PHYTOPHTHORA INFESTANS IN NORTHERN IRELAND

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Summary Isolates of Phytophthora infestans from blighted potato tubers grown on thirteen Northern Ireland farms in 1980 were tested for their ability to infect detached potato leaflets dipped in 100 mg/l metalaxyl, and where sporulating growth occurred were designated as resistant. Six out of nine metalaxyl/mancozeb-treated crops, both of two metalaxyl-treated crops but neither of two mancozeb-treated crops yielded metalaxyl-resistant strains of P. infestans.

Isolates, maintained on detached leaflets, retained resistance after 16 weekly transfers without metalaxyl, and grew as well as the wild-type. There were no differences in sensitivity to cymoxanil or mancozeb between metalaxyl-resistant and metalaxyl-sensitive isolates. Growth of a resistant isolate was no more inhibited by a metalaxyl/mancozeb mixture than by mancozeb alone.

In 1981 no metalaxyl-based product was marketed in N. Ireland. A survey of foliage blight in 73 crops showed that metalaxyl-resistant strains of P. infestans were present in 5 out of 32 crops on farms where metalaxyl/mancozeb was used in 1980, but in only one of 27 crops on farms where protectant fungicides were used in 1980.

Résumé

On a examiné des isolats de P. infestans prélevés des tubercules mildiousés qu'on avait cultivés dans 13 fermes en 1980 pour mesurer leur capacité d'infecter des feuillettes qu'on avait détachées et trempées dans 100 mg/l de métalaxyle. On a désigné comme "résistants" tous les isolats où la sporulation s'est produite. Six sur neuf groupes de pommes de terre traités à un mélange de métalaxyle/mancozèbe et deux groupes traités au métalaxyle ont produit du mildiou (P. infestans) résistant au métalaxyle, mais ni l'un ni l'autre de deux groupes traités au mancozèbe n'a produit ce mildiou résistant au métalaxyle.

Des isolats qu'on a maintenus sur des feuillettes détachées ont gardé cette résistance après qu'on les eut transférés tous les huit jours pendant seize semaines sans métalaxyle, et ils ont crû aussi bien que le type sauvage. En ce qui concerne la sensibilité au cymoxanil ou au mancozèbe, il n'y avait pas de différences entre les isolats qui étaient résistants au métalaxyle et ceux qui y étaient sensibles. Un mélange de métalaxyle/mancozèbe n'a pas empêché la culture d'un isolat résistant plus que du mancozèbe seul.

En 1981, aucun produit à base de métalaxyle a été mis en vente en Irlande du Nord. Une enquête sur la maladie du feuillage dans 73 cultures a montré que des souches de P. infestans résistantes au métalaxyle se trouvaient dans 5 sur 32 cultures dans des fermes où on avait utilisé un mélange de métalaxyle/mancozèbe en 1980. Cependant, une

seule souche se trouvait dans les 27 cultures des fermes ou on avait utilise des fongicides protecteurs en 1980.

INTRODUCTION

No systemic fungicide with good activity against Oomycetes was available commercially until 1977 when a number of compounds were introduced, of which metalaxyl (Urech et al, 1977) was one of the most promising for control of diseases of agricultural crops (Schwinn, 1979). In 1978, a formulation of metalaxyl (Ridomil 25 WP) was marketed in Europe, including the Republic of Ireland, for the control of downy mildews on several crops and of late blight (Phytophthora infestans) on potatoes. By 1980, metalaxyl was the major late blight fungicide used in the Republic of Ireland. During that summer, conditions were exceptionally favourable for blight and late in the season considerable amounts of disease were observed in some metalaxyl-sprayed crops resulting in yield losses. Subsequent isolation and testing revealed that the break-down in control was due to the development of strains of P. infestans resistant to metalaxyl (Dowley and O'Sullivan, 1981).

In the United Kingdom, although metalaxyl alone was used for control of downy mildews, a mixed formulation (Fubol 58 WP) containing metalaxyl and the protectant fungicide mancozeb, was introduced for potato blight control, since the addition of a protectant improved late-season disease control slightly (Smith, 1979). During 1980, metalaxyl/mancozeb gave excellent control of foliage and tuber blight throughout the U.K., including Northern Ireland, despite climatic conditions favouring the disease. Tests of isolates of P. infestans obtained from the foliage of ten metalaxyl/mancozeb sprayed crops in S. W. England revealed that all were sensitive to metalaxyl (Carter, G.A., pers. comm.), probably because the mancozeb prevented or delayed the build-up of resistant strains. However, it seemed possible that metalaxyl-resistant strains of the pathogen might be present in N. Ireland, since although the mancozeb component of the formulation appeared sufficient to prevent or delay them from emerging de novo, it might well not be capable of combating an influx from the Republic of Ireland where such strains had become established on metalaxyl-sprayed crops. A preliminary survey of samples of blighted tubers, mainly from border areas, was therefore initiated. This paper reports the results of that survey, of some investigations with the isolates obtained and of a survey to determine the prevalence of resistant strains of blight in 1981 potato crops.

MATERIALS AND METHODS

Isolation of P. infestans

Blighted potato tubers were washed, surface-sterilised by flaming in ethanol and slices (0.5 mm thick) cut with a sterile knife. The slices were incubated in humid containers (15^{o}C, in darkness) until sporulating mycelium developed on their surfaces (2-7 d) when the sporangia were washed off with distilled water. After chilling (5^{o}C, 1.5-3 h) to stimulate zoospore release, the resultant suspensions were used to inoculate detached potato leaflets.

Isolates were maintained on detached leaflets incubated in humid containers (15^{o}C, 24 h illumination) and transferred to fresh leaflets at weekly intervals. Glasshouse-grown potato plants, cv. King Edward, provided the leaflets used throughout this investigation.

Test for metalaxyl resistance

Metalaxyl (94.1% w/w technical product) was dissolved in acetone and diluted with distilled water to produce test solutions containing 2 or 100 mg/l metalaxyl with 1% v/v acetone. For each isolate, six potato leaflets (3-5 cm long) were dipped (15 s) in each metalaxyl solution or in 1% v/v acetone, allowed to dry, abaxial surface up, on paper towelling (c. 30 min), then transferred to Petri dishes lined with moist filter paper. The abaxial surface of each leaflet was inoculated (2 x 20 µl) with a sporangia/zoospore suspension (1-5 x 10^5 sporangia/ml) of the appropriate isolate prepared from 5-7 days' growth on detached leaflets. A standard metalaxyl-sensitive isolate was included in each test. After five and seven days' incubation (15°C, 24 h illumination), leaflets were examined and the presence and area of sporulating mycelium recorded. Isolates were designated as resistant if they had the capacity to sporulate on leaflets dipped in 100 mg/l metalaxyl. All resistant isolates were tested at least twice, and after the second test sporangia from metalaxyl-dipped leaflets (100 mg/l) were used to inoculate untreated leaflets, to exclude the possibility in further investigations of isolates containing a mixture of resistant and sensitive strains of the pathogen.

The above method, designed in collaboration with Ciba-Geigy, was also used to test the sensitivity of isolates to mancozeb (50 mg/l) and cymoxanil (100 mg/l), of selected isolates to combinations of metalaxyl and mancozeb and to investigate the effect of sporangial concentration on the infectivity of metalaxyl resistant strains. Mancozeb was used as a suspension of an 80% w/w w.p. formulation (Dithane 945) due to its insolubility in water and organic solvents. Cymoxanil, supplied as a 50% w/w w.p., was extracted with acetone and the recrystallised product (m.p. 159-164°C) used in 1% v/v acetone for tests.

RESULTS

Tests on isolates from blighted tubers

P. infestans was isolated from tuber samples from only thirteen farms in the counties of Londonderry, Tyrone and Antrim, the incidence of tuber blight having been low throughout the province. Resistant isolates were obtained from six out of nine farms on which metalaxyl/mancozeb was used in 1980, from two farms on which metalaxyl alone was used, but not from two farms where mancozeb alone was used (Fig. 1). Tests carried out by Ciba-Geigy on tuber samples from the same sources gave similar results (Marks, T.G., pers. comm.). When the first isolate from a tuber sample proved to be resistant, isolations were made from further tubers wherever possible and in all but one case these too were found to be resistant. Two isolates (where possible) selected from each sample were maintained on detached leaflets for up to 16 weeks before retesting their capacity to grow on metalaxyl-dipped leaflets (100 mg/l). Although eight out of thirteen resistant isolates grew less well in the second test, none had lost the ability to grow and sporulate.

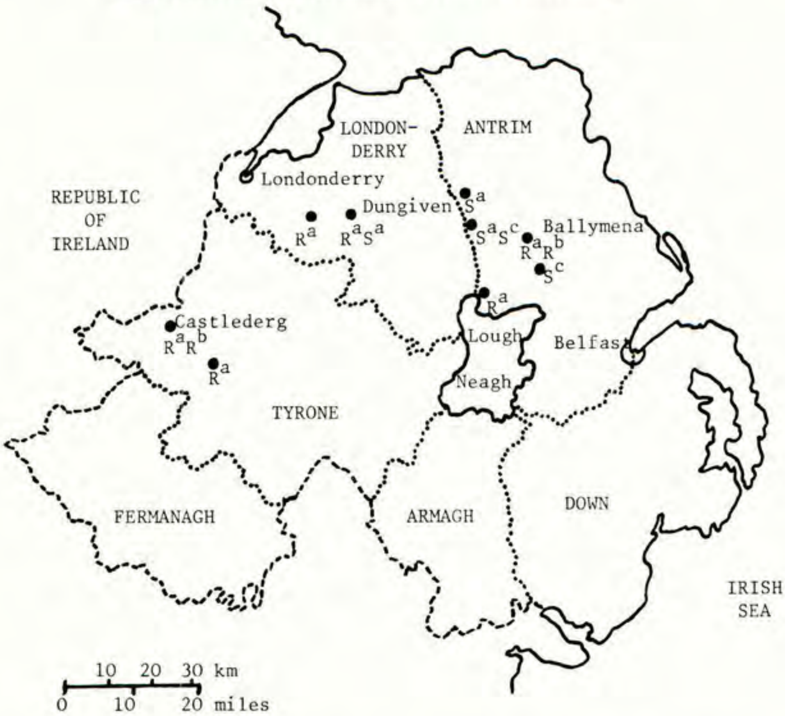
Sensitivity to cymoxanil and mancozeb

Both metalaxyl-resistant and metalaxyl-sensitive isolates failed to grow on cymoxanil-dipped (100 mg/l) leaflets after four days' incubation, although after seven days slight growth had occurred on some leaflets with five out of thirteen resistant isolates, but not with the four sensitive isolates.

The number of inoculated leaflets on which *P. infestans* developed following dipping in a mancozeb suspension (50 mg/l) varied greatly between isolates. The level of disease control achieved by a non-systemic protectant such as mancozeb depends on the area of leaf surface covered. Variations between isolates were probably a reflection of variations in the percentage cover. There

Fig. 1

Sources of isolates of Phytophthora infestans (1980 crops) and results of tests for metalaxyl-resistance



----- border between Northern Ireland and Republic of Ireland

.... Northern Ireland county boundaries

● location of farm/s from which blighted tubers were obtained

R isolates of P. infestans metalaxyl-resistant

S isolates of P. infestans metalaxyl-sensitive

a crop sprayed with metalaxyl/mancozeb, 1980

b crop sprayed with metalaxyl, 1980

c crop sprayed with mancozeb, 1980

was no evidence of any difference in sensitivity to mancozeb between metalaxyl-resistant and metalaxyl-sensitive isolates.

When a resistant isolate (8:2) was exposed to metalaxyl/mancozeb mixtures on detached leaflets, its growth was inhibited no more than by the same concentration of mancozeb alone (Table 1).

Table 1

The effect of mixtures of metalaxyl and mancozeb on growth of metalaxyl-resistant isolate 8.2

Leaflets dipped in (mg/l) mancozeb	metalaxyl	No. of infected leaflets[a]	Mean infection index[a,b]
25	0	3	1.8
0	100	6	7.8
0	5	6	11.1
25	100	3	1.6
25	5	3	2.2

a Based on 6 leaflets/treatment assessed 7 days after inoculation

b Product of the extent of sporulation on a scale 0-3 (where 0 = no sporulation, 3 = normal sporulation) multiplied by the area of leaflet infected on a scale (where 0, 1, 2, 3, 4, 5, refer to 0, < 10, 10-25, 25-50, 50-75, >75% respectively)

The effect of sporangial concentration and the presence of sensitive sporangia on the growth of metalaxyl-resistant isolates

When as few as 100 sporangia/ml (2 sporangia/20 μl drop) of the metalaxyl-resistant isolate were used for inoculation, sporulating mycelium developed on three untreated leaflets after seven days and on one metalaxyl-treated leaflet after ten days (Table 2). The presence of large numbers of sporangia (10^5/ml) of a metalaxyl-sensitive isolate had no effect on growth of the resistant isolate on metalaxyl-treated leaflets when it was present at the same or one tenth the concentration. However, when 10^3 sporangia/ml of the resistant isolate were used, fewer leaflets were infected in the presence of the sensitive isolate than in its absence.

Table 2

The effect of sporangial concentration and presence of a metalaxyl-sensitive isolate on growth of a resistant isolate

No. of sporangia/ml S	No. of sporangia/ml R	No. of untreated leaflets infected[a]	No. of metalaxyl-treated leaflets infected[b]
10^5	0	6	0
0	10^5	6	6
10^5	10^5	n.d.	6
0	10^4	6	5
10^5	10^4	n.d.	6
0	10^3	6	3
10^5	10^3	n.d.	1
0	10^2	3	1
10^5	10^2	n.d.	0

a Based on 6 leaflets assessed 10 days after inoculation

b Based on 6 leaflets dipped in metalaxyl (100 mg/l), assessed 10 days after inoculation

S metalaxyl-sensitive isolate 6.2, R metalaxyl-resistant isolate 6.5

n.d. not determined

1981 RESULTS

Survey of metalaxyl-resistant strains of P. infestans in foliage blight, 1981

No metalaxyl-based formulation was used on any crop sampled during 1981. Results for samples tested up to 31 August (Table 3) indicate that on 16% of farms where metalaxyl/mancozeb had been used in 1980, metalaxyl-resistant strains were present in foliage of 1981 crops. However, the lack of metalaxyl-resistant strains on most farms where protectant fungicides had been used in 1980, indicates that little or no spread of such strains had occurred in the absence of metalaxyl usage, at least during July and early August when most samples were collected.

Table 3

Results for metalaxyl-resistance tests on isolates of Phytophthora infestans from foliage blight in 1981, up to 31 August

Blight fungicide used on farm in 1980	Number of isolates Resistant	Sensitive
non-systemic[a]	1	26
metalaxyl/mancozeb	5	27
metalaxyl	0	1
no potato crop (1980)	1	7
unknown	0	5

a dithiocarbamate- or fentin-based products

DISCUSSION

The finding that blighted tubers from two-thirds of the farms sampled on which metalaxyl/mancozeb was used contained metalaxyl-resistant strains of P. infestans was unexpected since no lack of disease control by this formulation had been reported. However, it is likely that virtually all metalaxyl-sensitive strains were prevented from infecting tubers, even if they were present on foliage, due to the excellent control of tuber blight given by metalaxyl compared with that by mancozeb alone (Fry et al, 1979; Smith, 1979). In contrast, the resistant strain, subject only to control by mancozeb, would have been able to infect tubers. Thus, isolation of blight from tubers probably increased the chances of detecting metalaxyl-resistant strains. This could explain why, when the first isolate from a sample proved to be resistant, all or most subsequent isolates from different tubers were also resistant.

No inference can be drawn from the geographical distribution of resistant samples as to whether metalaxyl-sprayed crops provided the original sites for selection of metalaxyl-resistant strains or whether this also occurred to some extent on metalaxyl/mancozeb-sprayed crops. Although resistance was found in crops from Ballymena and Toomebridge, sites distant from the border with the Republic of Ireland, it was found that some growers had obtained metalaxyl from the Republic of Ireland and had used this in 1979 or 1980. In practice, it seems highly probable that the proximity of metalaxyl-treated crops to metalaxyl/mancozeb-treated ones must have speeded up the selection for resistance in the latter in N. Ireland compared with Great Britain.

Where only mixed formulations (containing two fungicides with differing modes of action) are used, the development of resistant strains is retarded compared with the situation on crops where a single component is applied (Dekker, 1977). However, a mathematical model proposed by Kable and Jeffery (1980) suggests that, even with mixed formulations, resistance will develop in time and that, once the resistant strain constitutes 1% of the total population, the use of mixtures will have little effect on its subsequent build-up. In N. Ireland, the point at which the resistant strain became a detectable proportion of the population may have been reached sooner than in the rest of the U.K., but it is probably over-optimistic to hope that resistance will not develop elsewhere if high levels of usage of metalaxyl/mancozeb are sustained. Indeed, during August 1981 metalaxyl-resistant strains were recovered from blighted foliage of crops sprayed with metalaxyl/mancozeb and with RE 20615 plus a dithiocarbamate (Patafol) in South-west Scotland, North-west England and South Wales (Anon., 1981).

Although cymoxanil did not completely inhibit growth of all thirteen metalaxyl-resistant isolates, whilst none of the four sensitive isolates tested grew at all, this probably represents variation between individual isolates rather than reduced sensitivity to cymoxanil associated with metalaxyl-resistance. A lack of cross-resistance between cymoxanil and metalaxyl was reported in tests on metalaxyl-resistant isolates of P. infestans in Holland (Davidse et al, 1981) and would be expected since the two compounds are unrelated structurally and presumably have different modes of action. Similarly, any reduced sensitivity to mancozeb in resistant isolates would have been surprising but, due to the large usage of the compound in controlling late blight, it was considered desirable to exclude the possibility.

In the field, resistant isolates are likely to encounter metalaxyl/mancozeb mixtures and it seemed possible that the two compounds could exercise a synergistic effect in controlling growth. However, the results show that resistant strains of the pathogen encountering the mixed formulation behave as though they had been treated with mancozeb alone. Since metalaxyl/mancozeb at the rate recommended for blight control produces 0.72 kg mancozeb/ha, compared with the 1.36 kg/ha recommended for mancozeb alone, and is applied less frequently, disease control in crops sprayed with the mixture is likely to become inadequate if metalaxyl-resistance is prevalent. This situation was not reached in N. Ireland in 1980, but, in contrast, in Holland where metalaxyl alone was the most widely used blight fungicide, disease control not only failed in some metalaxyl-treated crops, but also later in the season in some crops treated with metalaxyl/mancozeb (Davidse et al, 1981).

Although some competition between resistant and sensitive sporangia occurred when the proportion of resistant sporangia was below 1%, this could have been due to the inoculation of a small area of leaf surface with very large numbers of sporangia/zoospores. Under these circumstances, the number of possible entry points into the leaf or cells in which to form haustoria may have been limiting; the presence of metalaxyl would not prevent both isolates competing at this initial stage, since its inhibitory effect is exerted after formation of primary haustoria (Staub et al, 1980). In the field, such large numbers of sporangia would be unlikely to be concentrated on a small area of leaf. This experiment also indicated that only one or two sporangia of a resistant strain of P. infestans would be needed to enable it to become established.

It is probable, if large-scale use of metalaxyl/mancozeb in N. Ireland had been continued into 1981, that the proportion of metalaxyl-resistance within the population of P. infestans would have increased rapidly and led to crop losses. The decision by Ciba-Geigy to withdraw metalaxyl/mancozeb from N. Ireland, accompanied by ICI's decision not to introduce their formulation of RE 20615/dithiocarbamate should have prevented further selection for resistance.

Metalaxyl-resistant isolates grow and sporulate as freely as the wild-type and are stable in the laboratory for considerable periods without metalaxyl. Results of the 1981 survey show that, in the field, resistant strains of P. infestans were present in the foliage of crops in July and August, despite the lack of metalaxyl usage during 1981, but seldom appeared to have spread to farms where metalaxyl had never been used. Thus, there is no evidence that resistant strains have any competitive advantage over the wild-type, except in the presence of metalaxyl. Further data are needed before any prediction can be made as to whether the resistant strains will decline to a sufficiently low level within the population to permit their control by mixed formulations or alternating spray programmes using two products.

Acknowledgements

I thank Dr C. Logan for suggesting this study and for his helpful advice throughout its course and Messrs T. Marks and J.M. Smith (Ciba-Geigy Agrochemicals) for useful discussions. Ciba-Geigy Agrochemicals and Du Pont (U.K.) Ltd. donated the metalaxyl and cymoxanil respectively. I am also grateful for the technical assistance given by Miss D. Moore and for the collection of tuber and foliage samples by members of the Northern Ireland Potato Inspectorate.

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NOTES

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IMPACT OF FUNGICIDE TREATMENT OF WINTER BARLEY ON DISEASE CONTROL IN SPRING BARLEY

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Summary Two field experiments examined whether use of the fungicides ethirimol and triadimenol on autumn sown barley influenced their performance on adjacent spring sown crops. Changes in the sensitivity of barley powdery mildew to both fungicides were monitored by laboratory assays, and results compared with effects on mildew development and yield. Autumn use of both fungicides may alter inoculum levels available to infect crops in the following spring, but neither encouraged overwintering of resistant strains in sufficient numbers to influence fungicide performance in the spring.

INTRODUCTION

Re-introduction of ethirimol (Milstem) seed dressing against powdery mildew (*Erysiphe graminis* f.sp. *hordei*) on autumn sown barley renewed concern that overwintering mildew might become resistant and spread to spring sown barley. Since earlier reports of the effects of autumn treatments on ethirimol sensitivity were somewhat conflicting (Shephard *et al*, 1975, Wolfe, 1975), a field experiment was undertaken in 1979/80 to determine if the effectiveness of ethirimol on spring barley was influenced by applications to neighbouring autumn sown crops. A repeat experiment in 1980/81 included the more persistent fungicide triadimenol.

METHODS

Seed of winter (cv. Hoppel) and spring (cv. Wing) barley was treated with 'Milstem' or 'Baytan' (triadimenol formulated with some fuberidazole) at the commercially recommended rates. Cellacol was used to ensure good adhesion to seed of the powdered Baytan and so reduce variation in loadings. This did not appear to affect germination and growth of seedlings in the field. Levels of ethirimol on seed were checked by u.v. spectroscopy of methanol extracts, and of triadimenol by bioautography (Gasztonyi and Josepovits, 1979) of acetone extracts. Plots (9 m^2) of treated or untreated Wing barley were flanked on two sides by similar sized plots of treated or untreated Hoppel. To minimise interaction between treatments, each group of three plots was separated from the next by at least 9m of untreated Wing barley. These surrounds were sprayed with tridemorph (Calixin) when necessary to control mildew.

Mildew was assessed at several growth stages as described in the Ministry of Agricultures' guide for the assessment of cereal disease (Anon, 1976). Assessments of eyespot (*Pseudocercosporella herpotrichoides*) and net blotch (*Pyrenophora teres*), which was especially severe on Hoppel in 1981, were also attempted. Where possible mildew samples were collected for fungicide assays from 25 infected leaves within each plot and assayed the following day. Young mildew conidia were inoculated (2,500 conidia cm^{-2}) on to leaf segments (cv. Proctor) floating on solutions containing a range of either ethirimol or triadimenol concentrations. Synchronous appressoria development was achieved by manipulation of light and humidity, and for ethirimol, effects on appressoria formation assessed after 24h (see Hollomon, 1977 for details). Since triadimenol acts after mildew has entered the host, for this fungicide leaf segments were harvested 72h after inoculation, cleared and stained in 0.05% trypan blue in lactophenol, and examined microscopically. As mildew colonies then consisted of a largely unbranched hypha, sensitivity was assessed on the basis of hyphal length at each dose. ED50 values were calculated from the linear regression of these lengths on the logarithm of the dose. As an example, Fig. 1 shows the dosage response lines for two mildew clones derived from single pustule isolates. JB6 was obtained from the field before widespread use of fungicides which inhibit ergosterol biosynthesis: JB29 was isolated from a mildew population from treated barley kindly supplied by Dr. J.T. Fletcher (ADAS, Newcastle). The response of both clones has not altered after at least 6 months in laboratory culture. That these laboratory observations correspond to behaviour <u>in vivo</u> was confirmed by disease development on triadimenol-treated Proctor seedlings (Table 1).

Yields were determined for a plot area of $3m^2$ after the grain was dried to 15% moisture content.

RESULTS

Effect of fungicides on disease

Both seed treatments controlled mildew during the autumn, but only triadimenol was sufficiently persistent to affect mildew development in the following spring. When spring barley emerged in early May, mildew levels on the lowest green leaf in flanking Hoppel plots were reduced by 60% ($P < 0.001$) where triadimenol had been applied the previous autumn. Control of mildew on the upper leaves was even better. Despite this, treatment did not increase the dry weights (root plus shoot) of Hoppel plants surviving the 1980/81 winter.

On untreated Wing plots mildew was more severe during the spring of 1981 than in the previous year, but in both years disease development was not influenced on these plots by treatment applied to flanking Hoppel plots (Fig. 2). Ethirimol did control mildew in 1980 until GS 52, but its effectiveness was diminished by treatment of neighbouring Hoppel plots (Hollomon, 1981). In 1981, ethirimol was less effective and performance was not influenced by adjacent Hoppel plots. Triadimenol delayed the start of the mildew epidemic by at least a fortnight and provided further control until early July. Treatment of flanking Hoppel plots with triadimenol increased, rather than diminished, its effectiveness when used the following spring. Neither fungicide appeared to control eyespot or net blotch.

Effects on fungicide sensitivity

Sensitivity of mildew populations decreased following ethirimol treatment of Hoppel in the autumn of 1979. These differences did not persist and by the following spring populations on both ethirimol treated and untreated plots were identical. Inoculum from these plots infected emerging spring barley and was reselected, for sensitivity again decreased on all ethirimol treated plots (Table 2a). However, these shifts in ethirimol sensitivity during the spring were not influenced by treatments applied the autumn before. Changes in ethirimol sensitivity on Wing were less pronounced in 1981. Increases in ED50 values were confined to the early stages of the epidemic, and again were not influenced by treatments applied to adjacent autumn sown barley.

Figure 1

Dosage response lines for triadimenol sensitivity for two mildew clones

	ED_{50} µg/ml	95% Confidence limits	Slope
JB6	0.001	0.0007-0.004	- 4.06±0.6
JB29	0.030	0.025 -0.036	-12.34±0.8

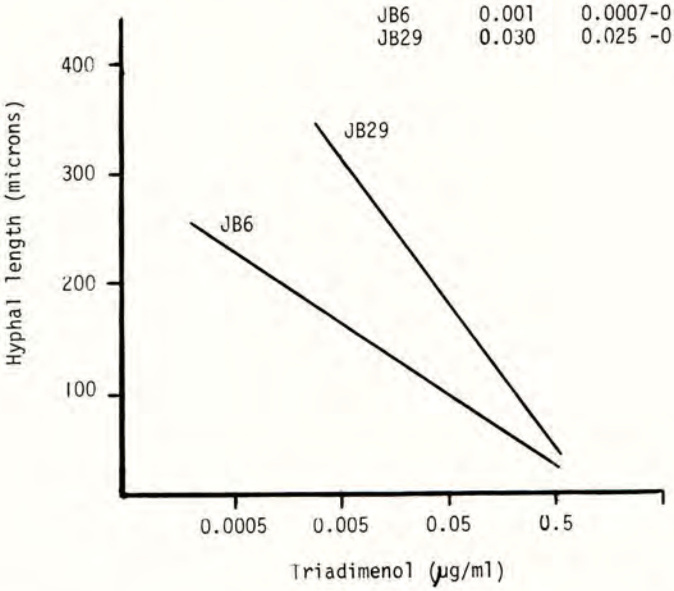


Table 1

Triadimenol sensitivity of two mildew clones on barley (cv. Proctor) seedlings

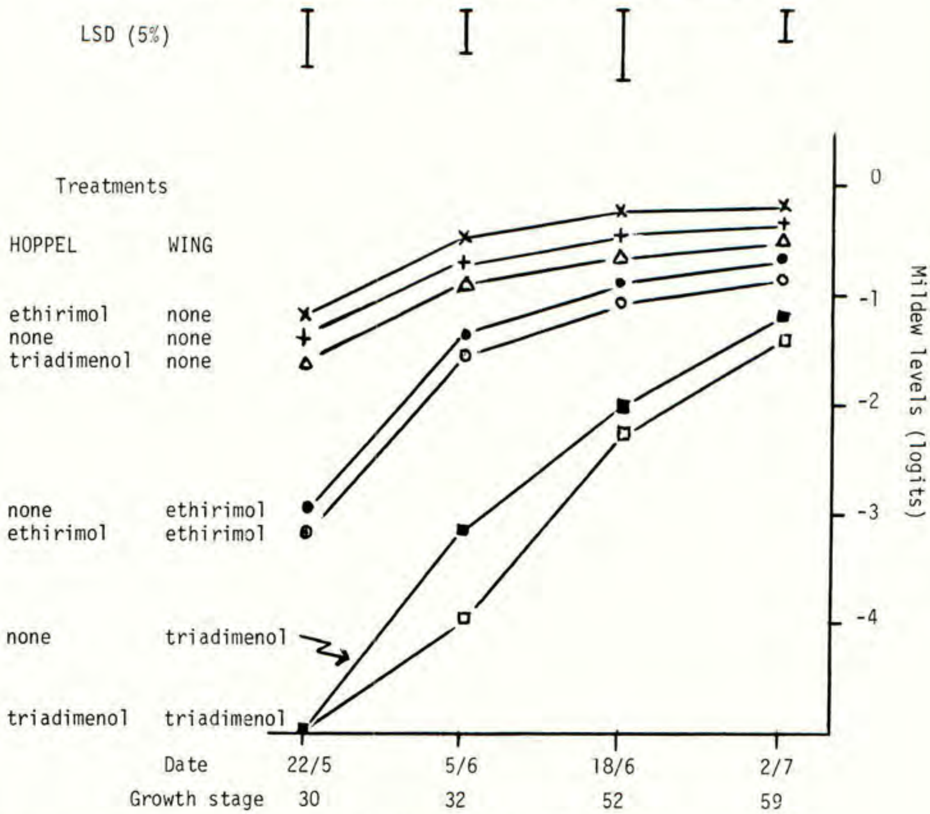
BAYTAN (g/100 Kg seed)[1]	% leaf area infected[2]	
	JB6	JB29
none	38.5	74.0
2.34	26.3	74.0
4.68	4.9	67.0
9.36	1.4	64.0
18.75	0.2	45.0
LSD (5%)	14.0	

1 Commercially recommended rate 150g/100 Kg seed.

2 Ten-day old seedlings inoculated (1000 conidia cm^{-2}) and disease assessed seven days later. Data were transformed to logits (logit p = ½ ln p/(100-p) for statistical analysis.

Figure 2

Barley powdery mildew development on Wing in 1981



Disease levels are expressed as logits ($= \frac{1}{2} \log_e(p/q)$)

Although effects of triadimenol on mildew control persisted throughout the winter, assays failed to detect any decrease in triadimenol sensitivity of the inoculum available from these plots in the spring. Monitoring for triadimenol sensitivity in mildew populations from Wing was restricted by the low levels of disease on treated plots. When sufficient mildew was available by growth stage 32, decreased sensitivity was observed on all triadimenol treated plots (Table 2b). Although sensitivity increased somewhat during the following month, at growth stage 59 mildew on treated plots remained less sensitive than on untreated plots. Treatments applied to adjacent autumn sown plots did not influence triadimenol sensitivity.

Table 2

Fungicide sensitivity of mildew from plots of Wing

a) Ethirimol : spring 1980

Treatments		Ethirimol sensitivity (ED_{50} µg/ml)	
HOPPEL	WING	GS 30	GS 52
none	none	0.94	0.84
ethirimol	none	0.79	0.88
none	ethirimol	3.11	2.67
ethirimol	ethirimol	2.99	2.54
LSD	(5%)	0.34	0.26

b) Triadimenol: spring 1981

Treatments		Triadimenol sensitivity (ED_{50} µg/ml)	
HOPPEL	WING	GS 32	GS 59
none	none	0.005	0.007
triadimenol	none	0.007	0.006
none	triadimenol	0.028^{+}	0.018
triadimenol	triadimenol	0.026^{+}	0.020
LSD	(5%)	0.002	0.003

$^{+}$ Inoculum level 500 conidia cm^{-2}

Table 3

Effects of fungicides on yields of spring barley

Treatments		Yield of Wing (t/ha)	
HOPPEL	WING	1980	1981
none	none	4.78	5.78
ethirimol	none	4.83	6.07
none	ethirimol	5.41	6.10
ethirimol	ethirimol	5.02	6.00
none	triadimenol	-	6.13
triadimenol	none	-	5.78
triadimenol	triadimenol	-	6.16
LSD	(5%)	0.41	0.35

Effects on yields

Ethirimol and triadimenol seed dressings applied to Hoppel barley did not increase yields. In 1980 ethirimol increased yields of spring barley by 8.8% ($p < 0.05$), but its effectiveness was influenced by treatments applied the previous autumn to Hoppel (Table 3). Where these flanking plots were untreated, ethirimol increased yields of Wing barley by 13.2% compared with only 3.9% where neighbouring Hoppel plots were treated. Yield increases in 1981 were smaller. Only triadimenol significantly increased yields of Wing (6.2%, $p < 0.05$), but this was unaffected by treatments applied to adjacent Hoppel plots.

DISCUSSION

Although the effectiveness of triadimenol and ethirimol on spring sown crops may be influenced by treatments applied to autumn sown crops, this could not be attributed to increases in resistance in overwintering mildew populations. Ethirimol resistance generally increases within mildew populations on treated crops (Shephard et al, 1975), but ethirimol resistant strains are poor competitors (Hollomon, 1978) and their frequency soon declines as effects of the fungicide diminish. Nevertheless, protection of foliage from disease in the autumn by ethirimol may ensure that larger plants survive the winter. Infection of these plants the following spring might provide a larger inoculum source than might exist on untreated plants. This, rather than resistance, may perhaps explain why autumn use of ethirimol influenced its performance the following spring, although other factors must be involved for similar effects were not observed in 1981. Autumn use of triadimenol, however, increased its effectiveness on adjacent spring sown plots, delaying still further the mildew epidemic that eventually developed on treated plots. Smaller inoculum levels within treated Hoppel plots during the spring may account for this. Mildew spreads rapidly and differences in inoculum levels are likely to be short-lived on untreated barley, thus accounting for the absence of any effect of neighbouring Hoppel plots on mildew development on untreated Wing.

These results were obtained during 1980 and 1981 when disease levels differed considerably. During this period use on barley of fungicides that inhibit ergosterol biosynthesis (triadimenol, triadimefon, prochloraz, propiconazole, nuarimol) increased greatly. Consequently, the mildew population may yet to reach equilibrium with regard to its sensitivity to these fungicides (Fletcher and Wolfe, 1981), and shifts in sensitivity may still occur. Further shifts in the natural population might enable enough less sensitive strains to overwinter on triadimenol treated crops to effect its performance the following spring. Monitoring of mildew populations for triadimenol sensitivity will continue, and we plan further experiments of the type reported here.

Acknowledgements

Thanks are due to Dr. G.L. Bateman for eyespot assessments, to ICI, Plant Protection Division for Milstem, and to Bayer (UK) for Baytan.

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NOTES

SESSION 10

ROLE OF APPLICATION TECHNOLOGY IN PEST MANAGEMENT

ELECTROSTATIC SPRAYING OF CROPS WITH THE APE 80

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Summary An easily constructed version of the APE 80 has been tested in 1981 field trials. The design permits rapid changing of the liquid flow rates and easy calibration.

Deposition on the crop increases significantly with increasing voltage while crop canopy penetration is unchanged. Successful trials on cotton and soybean using a hand-held unit have shown that the accelerated passage of charged spray drops to the target can overcome the problem of evaporation of ULV water-based formulations in high ambient temperatures. The effect of formulation on charge and particle distribution is also discussed.

INTRODUCTION

With increasing evidence of the values of small drops and low volumes in pesticide application, techniques that improve the transport and impaction of the spray on the target must be considered seriously. Electrostatic spray charging techniques have been developed and shown to improve both transport and impaction of the drops. Several electrostatically charged systems are now being developed and evaluated including the Electrodyne sprayer (Coffee, 1979, 1980), both hand held and tractor mounted and that of Inculet (1980), a charged air assisted system for orchard pests.

The apparatus developed at Rothamsted, the APE 80, Arnold and Pye (1980), was primarily intended for tractor boom mounting and the application of oil and water-based ULV formulations to field crops. Inert tracer techniques were used to study the effect of applied voltage on spray deposition. The application of active chemicals and the subsequent evaluation of biological efficacy, are the subject of a separate paper by Griffiths et al (1981).

APPARATUS

The original APE 80 design (Arnold and Pye 1980) has been modified to permit flow rates to be changed and calibration made, without removing the spinning disc. This modification also gives greater resistance to electrical tracking, important when using low resistivity formulations. A three speed spray head was constructed for the hand-held unit but in present work only the top speed of 4500 RPM was used. The 12v motor operating the spinning disc requires 10 ma (0.12W) when running at this speed while the power requirements of the HV unit on the hand-held model vary inversely with the resistivity of the formulation, but are also small.

METHODS AND MATERIALS

Crops of field beans and barley were sprayed using a tractor mounted boom carrying three or four quickly detachable spray heads one metre apart, with a spray containing an ultraviolet tracer UVITEX. Residual deposits were estimated by analysing extracts of leaf samples or filter paper targets previously attached to the leaf surfaces.

RESULTS

Trials on field beans were at two growth stages. Table 1 shows the results of the application made when the crop was 12 cm high and using a water-based spray with a resistivity of 5.8 kΩ/cm^{-1}.

Table 1

Field beans crop height 12 cm
The effect of voltage level on spray penetration and distribution

Leaf position on plant	Voltage level KV	Deposition ng/cm^{-2}	SE ±
Upper	30	62.44	4.49
Lower	30	41.24	8.71
Upper	15	47.90	9.34
Lower	15	22.51	4.53
Upper	0	30.40	4.22
Lower	0	15.94	2.16

The effect of voltage change on gross deposition is similar to that observed in laboratory work (Arnold & Pye 1980). The previously observed increase in deposition due to charging the spray is largely maintained even when the area of exposed soil greatly exceeds the area of plant foliage and the atomisers are operating at only 30 to 35 cm above the soil surface.

A second spraying was carried out when the crop was 90 cm high and the canopy more dense.

The level of crop penetration remained virtually unchanged (see Table 2) whether application was from an uncharged ULV rotary atomiser used as a placement sprayer or when the drops are charged, while the amount of deposit on the upper leaves increased dramatically.

Table 2

Field beans crop height 90 cm
The effect of voltage level on spray penetration and distribution

Leaf position on plant	Voltage level KV	Deposition ng/cm^{-2}	SE$\pm$
Upper	30	145	14.1
Lower	30	10.98	2.34
Upper	15	67.4	15.2
Lower	15	10.96	1.27
Upper	0	32.13	4.39
Lower	0	13.42	4.71

On barley sprayed with water and oil-based formulations the volume reaching the stems approximately 25 cm below the top of the plants significantly increased with increasing voltage although the penetration remained low. In this case a significantly greater increase in gross deposition was observed with the low resistivity water-based formulation, than with the oil-based spray. (Fig. 1)

Effect of voltage on spray penetration & distribution

Deposition on stems 250 mm below plant tops

Water plus 10% uvitex 5·8k Ω/cm

Oil plus 10% uvitex 10M Ω/cm

Application rate 4l/ha

Spray heads 4 tractor mounted

Barley crop height 600mm

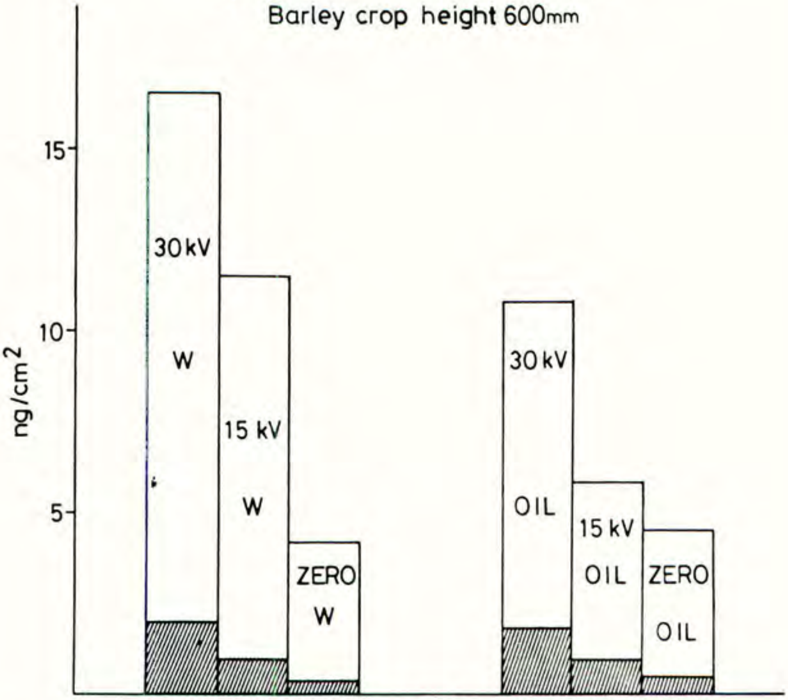

Fig I

A range of both oil and water-based formulations was sprayed on cotton and soybean crops in America by a hand-held version of the APE 80 to test performance at higher temperatures.

The spray penetration was poor throughout the trials (Table 3) but again encouragingly large increases were observed in deposits on both upper and lower leaves when the drops were charged.

Table 3

The effect of charge on spray penetration & deposition
Water based spray on cotton plants

Leaf position on plant	Leaf surface	Deposition ng/cm^{-2} Charged	Uncharged	SED$\pm$
Upper	Adaxial	69.7	6.1	8.3
Upper	Abaxial	50.4	3.9	3.6
Lower	Adaxial	5.2	2.7	0.77
Lower	Abaxial	2.8	1.04	0.46

Table 4 shows that as observed previously, charging the drops increased the proportion reaching the abaxial surface of leaves so that in some cases the concentrations on adaxial and abaxial surfaces are nearly equal. This ratio is maintained on leaves situated 35 cm below the tops of the plants.

Table 4

The influence of charge on spray deposition
Water-based spray on cotton plants

Leaf position on plant	Leaf surface	Deposition ng/cm^{-2} Charged	Uncharged	SED$\pm$
Upper	Adaxial	143	68.9	12.8
Upper	Abaxial	142	2.8	15.9
Lower	Adaxial	13.8	9.0	2.9
Lower	Abaxial	14.5	0.9	3.0

With an oil-based formulation (Table 5) even greater abaxial deposition was observed; very similar results were obtained with a soybean crop.

Table 5

Effect of charge & formulation on spray distribution
Oil-based spray on cotton plants

Leaf position on plant	Leaf surface	Deposition ng/cm^{-2} Charged	Uncharged	SED$\pm$
Upper	Adaxial	5.9	1.8	1.5
Upper	Abaxial	61.5	4.3	4.59
Lower	Adaxial	3.62	2.72	0.6
Lower	Abaxial	8.15	1.3	0.82

DISCUSSION

The trials described here using a UV tracer, were aimed at establishing the optimum parameters for spraying with the APE 80 before complementary biological trials using an active chemical formulation. These field applications by a charged ULV spinning disc system show the general effectiveness and the particular limitations of the technique. Effectiveness in some crops is limited by the growth stage and density of the canopy but in all cases penetration using the spinning disc atomiser (unless used in the drift application model) is improved by charging although only by the overall increase in the gross deposition, while the ratio of top to lower leaf coverage often remains unaltered.

The enhanced total deposition is achieved mainly by increased deposits on the stems and abaxial surfaces of the upper leaves, suggesting that the charged mode may be particularly valuable for the more efficient application of translocated chemicals at lower rates.

The effectiveness of the design for the application of a range of formulations to four different crops and in different climatic conditions has been demonstrated.

Further research is clearly necessary to establish its effectiveness with pesticides and fungicides to examine the influence of design features under a wider range of conditions and using other formulations.

Acknowledgements

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BIOLOGICAL EFFECTIVENESS OF SPINNING DISC ELECTROSTATIC SPRAYERS

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Summary During 1981 apparatus designers, biologists and chemists collaborated to evaluate the performance of tractor-mounted electrostatic sprayers of the spinning disc type in field tests on pea and bean weevils, black bean aphids and barley mildew. Results indicate that systemic materials can be applied electrostatically in open canopy crops at considerably decreased dosages without significant loss of biological effect.

INTRODUCTION

The APE 80 spinning disc electrostatic sprayer has been described by Arnold and Pye (1980). Before the novel method of spraying possible with the APE 80 sprayer can be introduced commercially, many questions need to be answered concerning the physical parameters (voltage, height above crop, etc.) that give greatest depositions of chemical, and the type of crop (open or closed canopy), of pesticide (systemic or non-systemic), of formulation (water or oil) and of the pest or disease for which the electrostatic system is most effective.

METHODS AND MATERIALS

Three situations were studied: (1) pea and bean weevil (*Sitona lineatus*) on field beans (*Vicia faba*) (2) black bean aphid (*Aphis fabae*) on field beans and (3) powdery mildew (*Erysiphe graminis*) on spring barley. Two types of trial were done on each crop: a preliminary study to determine the optimum physical parameters, followed by a biological test of pesticides on larger plots. Both types of trial included detailed chemical analyses of deposits on different parts of the plants and will be reported in more detail later; this paper summarises results of the biological measurements.

All biological tests included (a) different dosages of pesticide applied electrostatically, (b) an oil formulation vs. an emulsifiable concentrate in water, (c) a systemic vs. a non systemic pesticide and (d) a standard application of pesticide via a conventional hydraulic system (110° fan jets). The hydraulic system used volumes of about 400 l/ha in contrast to 4 l/ha for the electrostatically charged spinning discs but pesticide concentrations were adjusted to give equivalent doses of active ingredient per hectare.

Biological effectiveness was judged (1) against *S. lineatus* adults by repeated notch counts on developing leaves and by counts of samples obtained by DVAC suction apparatus, (2) against *A. fabae* by repeated counts of live aphids and (3) against *E. graminis* by a leaf infection score (Anon, 1976) 18 days after spraying.

RESULTS

In the trial on S. lineatus (Table 1) leaf notching was severe at first, but declined later. Some notches found during the first count may have been made before the insecticide had acted so the second and third counts measure treatment effectiveness more reliably. The oil and water formulations of permethrin applied electrostatically gave large decreases in notching even when applied at half rates and were at least as effective as the standard treatment except after four weeks, when the effects of treatments appeared to be wearing off. The suction samples taken during early June (Table 1) contained relatively few adult Sitona but the greatest numbers were obtained from the unsprayed and microcapsule-sprayed plots.

In the aphid trial (Table 2) the non-systemic insecticide permethrin was more effective when sprayed hydraulically than electrostatically, but neither method of treatment with this insecticide had prolonged effects on the aphid populations. Thus after 3-4 weeks, permethrin sprayed plots had at least as many infested plants as controls. Demeton-S-methyl greatly decreased infestations of aphids for 5-6 weeks; even the half rate applied electrostatically was as effective as the hydraulically applied standard, and the quarter rate, although less effective, was considerably superior to the controls.

Examination of the barley mildew trial on 6th June (Table 3) showed that unsprayed plants had up to 30% mildew infection on the third leaf from the top of the plant. The non-systemic fungicide ditalimfos was effective only when applied with the hydraulic sprayer; the water formulation was too viscous to flow freely through the electrostatic spray apparatus, whilst the oil formulation flowed well, yet was not very effective in decreasing the amount of mildew. When applied electrostatically, both water and oil formulations of the systemic fungicide tridemorph significantly decreased mildew to almost the same extent as tridemorph applied by the hydraulic system. Half rates of tridemorph applied electrostatically also decreased mildew significantly.

DISCUSSION

Oil, water and even microcapsule formulations were delivered successfully through the spinning disc electrostatic sprayers that were evaluated in these trials.

In the tests against Sitona, pesticides were applied to a relatively young, open crop harbouring insects able to move about the plant to feed. In these conditions electrostatic sprays of oil and water formulations of both permethrin and dimethoate were as effective, even at half rates, as hydraulic sprays.

When insecticides were applied at a later stage of crop growth against immobile aphids sheltering in the rolled terminal foliage, the non-systemic material permethrin was more effective applied hydraulically than electrostatically, presumably because the larger volume of liquid applied with pressure penetrated better to the pest. The systemic pesticide demeton-S-methyl applied electrostatically was extremely effective even at half dose, possibly because charging helped to increase the amount of insecticide intercepted by the plant and therefore the amount redistributed by the plants' transport system to the tissues where aphids fed.

On barley, lack of penetration of electrostatically applied fungicide through the thick crop canopy may explain the poor performance of the non-systemic material ditalimfos.

The results suggest that the advantages of electrostatic spraying can be exploited most easily in open canopy crops, when the pest is mobile, or when a systemic material is used. In favourable circumstances dosages can be halved and volumes of carrier decreased 100-fold, without loss of biological activity.

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Table 1

Trial on pea and bean weevil (*Sitona lineatus*)

Sprayed 13-14 May 1981

Treatment		Mean no. notches/plot (10 leaflets/plot) 22 May	29 May	5 June	12 June	Mean no. of adult Sitona
Control	(1)	86.0	55.3	20.0	16.3	5.7
	(2)	88.3	65.3	29.3	16.7	6.3
+Non-systemic insecticide						
Oil-electrostatics						
	- 100g a.i./ha	17.0	1.3	3.2	4.7	1.3
	- 50	16.7	1.7	5.8	6.3	4.0
Water-electrostatics						
	- 100g a.i./ha	24.0	1.7	1.5	5.7	1.3
	- 50	30.7	2.3	1.7	8.0	5.0
Water-hydraulics						
	- 100g a.i./ha	33.0	4.0	2.3	3.0	1.7
Microcaps-electrostatics						
	- uncharged	46.3	6.0	8.7	5.3	6.0
	- charged	36.7	5.3	7.5	12.3	4.0
*Systemic insecticide						
Oil-electrostatics						
	- 500g a.i./ha	21.3	3.0	6.3	8.3	1.7
	- 250	15.0	2.7	5.3	4.7	1.3
Water-electrostatics						
	- 500g a.i./ha	22.3	2.3	5.3	4.0	2.7
	- 250	23.3	3.3	3.2	6.0	2.0
Water-hydraulics						
	- 500g a.i./ha	25.3	10.3	7.3	7.0	5.0
S.E.D.		8.90	7.86	4.29	3.35	1.71

+ permethrin
* dimethoate

Table 2

Trial on black bean aphid (Aphis fabae)

Sprayed 12 June 1981

Treatment		Percentage stems infested					
		15 June[a]	25 June	2 July	9 July	16 July	27 July
**Controls	(1)	57.5	41.9	51.3	55.6	83.8	80.0
	(2)	62.5	30.6	38.8	53.8	72.5	74.4
	(3)	45.0	32.5	45.6	56.3	75.6	81.9
	(4)	52.5	37.5	41.3	63.8	83.1	83.1
+Non-systemic insecticide							
Water-electrostatics - 100g a.i./ha		20.0	20.6	34.4	66.2	91.9	90.6
Water-hydraulics - 100g a.i./ha		7.5	2.5	17.5	52.5	62.5	60.0
*Systemic insecticide							
Water-electrostatics - 240g a.i./ha		0	0.6	2.5	7.5	6.9	10.6
- 120		0	0.6	2.5	1.9	6.9	11.2
- 60		5.0	4.4	8.1	13.8	20.6	23.8
Water-hydraulics - 240g a.i./ha		2.5	0	2.5	3.1	10.6	6.9
S.E.D.		8.37	6.31	9.31	9.20	10.25	8.95

\+ permethrin
* demeton-S-methyl

[a] On 15 June ten stems/plot were examined in the laboratory; on the other dates 40 plants/plot were examined in the field.

** Controls (2), (3) and (4) contained the dye UVITEX OB as a marker.

Table 3

Trial on barley mildew (*Erysiphe graminis*)

Sprayed 18 June 1981

Treatment		Mildew score on 6 July Area of third leaf affected (%)
Control	(1)	23.0
	(2)	29.7
+Non-systemic fungicide		
Oil-electrostatics	- 525g a.i./ha	12.7
	- 262	21.0
Water-electrostatics	525g a.i./ha	22.4
	- 262	22.0
Water-hydraulics	- 525g a.i./ha	5.8
*Systemic fungicide		
Oil-electrostatics	- 525g a.i./ha	7.2
	- 262	8.9
Water-electrostatics	525g a.i./ha	5.0
	- 262	7.5
Water-hydraulics	- 525g a.i./ha	4.4
S.E.D..		4.18

+ ditalimfos

* tridemorph