THE INFLUENCE OF APPLICATION VOLUME ON THE EFFICACY OF CLOFENTEZINE USED EARLY SEASON FOR THE CONTROL OF PANONYCHUS ULMI (Koch) ON APPLES

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ABSTRACT

This paper describes work carried out in 1985 in France, Italy, the Netherlands and the U.K. Clofentezine was sprayed pre-blossom on apples with overwintering populations of the european fruit tree red spider mite, Panonychus ulmi using commercial sprayers. The dosage rate tested was kept constant at 200g a.i./ha in all nine trials but the application volume, and hence the spray concentration, varied from 100-2500 l/ha. Clofentezine was found to be very effective at all these spray volumes although there was a tendency for the control to be better at volumes in excess of 1000 l/ha. In contrast, more clofentezine was deposited on the trees at lower than at higher volumes. There was also much greater uniformity between trials at the higher volumes. These findings suggest that the nature of clofentezine deposit on the trees is more important than the amount in determining the level of control achieved.

INTRODUCTION

The protection of fruit trees from attack by insects and spider mites usually involves spraying with pesticides. Spray volumes differ from country to country and from crop to crop and vary from 50 l/ha (deciduous fruit in Europe) to 15000 l/ha (large grapefruit trees in the USA). For decades, the question of what is optimal in terms of spray volume, has been discussed but the understanding of the subject remains unsatisfactory.

There is variation in the way in which recommendations for the application of pesticides are expressed. By far the commonest way is to express the recommendation on a basis of concentration. This method is convenient but has serious drawbacks. Since the quantity of pesticide applied is directly proportional to the spray volume, applications made at low and very low volumes may not deposit enough product on the target, and the resulting biological results have sometimes been poor (Cooke et al, 1976). This situation is further complicated by claims that reduction in dosage rates are possible with these reduced volumes (Gunn, 1980). To overcome the problem of dosages per unit area falling below certain minima, modifications to the usage recommendations were introduced. In the USA, for example, a clear distinction is made between 'dilute' and 'concentrate' sprays. 'Dilute spray' recommendations are made on the basis of concentration, those for 'concentrate sprays' on a basis of unit area. This is an attempt to maintain the dosage at or above a minimum level.

Clearly an important factor relating to the efficacy of a product is the amount per unit area of target surface (Herrington et al, 1981). Therefore it follows that quantities of product per unit area need to vary between different crops and within the same crop, because these have different target area indices.

The objective of this work was to investigate the influence of spray volume, concentration and retention on the biological efficacy achieved with one particular product, 'Apollo®', (a 50% suspension concentrate of clofentezine) against Panonychus ulmi on apples.

Clofentezine is recommended as a pre-blossom spray treatment against Panonychus ulmi and other mites attacking deciduous fruit and other crops (Bryan et al, 1981). This compound is particularly interesting in that it is active against the overwintering eggs of the european fruit tree red spider mite. In these trials the target was identified as the twigs (almost leafless) on which these overwintering eggs had been laid the previous autumn.

MATERIALS AND METHODS

Experiment design and site details

The nine trials described were carried out in commercial orchards in France (2 trials), Italy (2 trials), the Netherlands (2 trials) and the UK (3 trials).

Five different spray volumes were used to apply the same dosage of clofentezine to large plots (0.18 to 0.42 ha) (Table 1). Each treatment was unreplicated.

TABLE 1

Spray volume and concentration details

	Treatment	Dosage (g a.i./ha)	Spray volume (l/ha)	Spray concentration (g a.i./hl)
1	Clofentezine 50 SC	200	100	100
2	Clofentezine 50 SC	200	250	80
3	Clofentezine 50 SC	200	500	40
4	Clofentezine 50 SC	200	1250	16
5	Clofentezine 50 SC	200	2500	8

All the applications were made pre-blossom between 2nd April and 1st May 1985.

Sprayer calibration

All the sprayers used in these trials were commercially available tractor mounted, trailed, or self-propelled air assisted sprayers. The sprayers used in Italy, France and the Netherlands were those normally used by the orchard owners. Full details of the sprayers are given in Table 2.

The sprayers were individually calibrated using water for each treatment. This was carried out in one of two ways :-

i) The total output of all the spray nozzles was measured by filling the tank to a datum point and running the sprayer for a known period. The volume of water to refill the tank to the datum point was then measured.

ii) The outputs of one or more nozzles on the sprayer were measured by placing tubes over the nozzles and collecting the spray in a container over a known time. This figure was then multiplied by a factor to give the sprayer's total output.

The effective spray volume per hectare was calculated from these outputs, the orchard row spacing and the tractor's forward speed.

The forward speeds used were kept as close as possible to a range of 4 to 9 km/h, although some of the higher volumes required lower speeds.

The position of the nozzles, and where relevant, airducts, were agreed after discussion with the farmers, from information in the sprayer handbooks, and by assessment of the tree characteristics.

TABLE 2

Details of sprayers used in the trials

	ITALY		FRANCE		NETHERLANDS		U.K.		
	I1	I2	F1	F2	NL1	NL2	UK1	UK2	UK3
Sprayer manuf.	Agro-technica	KWH	Nicolas	Nicolas	Munckhof	Douven	Drake + Fletcher		
Model	Prisma 30/2000	-	Super Etoile	Etoile 277	-	-	Victair		
Sprayer type	Self-propelled	Trailed	Mounted	Mounted	Trailed	Trailed	Mounted		
Number & type of atomiser	2 x 9 Hollow cones	2 x 5 KWH atomiser	2 x 8 Ceramic hollow cones	2 x 8 Ceramic hollow cones	2 x 5 Hollow cones	2 x 4 Hollow cones	2 x 11 Hollow or full cones		
Air duct	360°	2 x 60°	360°	360°	360°	2 x 60°	2 x 60°		
Forward speed (km/h)	4.5-6.0	3.0-7.0	5.1-7.6	4.5-5.0	5.5-7.6	3.5-9.2	3.4-9.2		
Pressure used(kPa)	360	150-360	760-2000	530-3000	500-1500	700-2500	380-500		

Measurement of clofentezine deposits

i) Sampling procedure

Immediately after spraying, twig samples were taken from each plot. From each treatment, fifty terminal twigs, each approximately 10 cm long were cut from the trees and placed in a sealable plastic bag. The twigs were taken from various heights along the full length of the treated rows.

ii) Extraction of clofentezine

Acetone (100 ml) was placed in the bags containing the twig samples which were shaken vigorously for 30 seconds. The washings were then poured from the bags and stored in screw top jars at 4 °C until analysis. The twig samples were weighed after washing.

iii) Analytical procedure

The concentration of clofentezine present in the twig washings was measured using a high performance liquid chromatograph (HPLC).

Analysis was carried out using a Lichrosorb Si-60-5 column of 25 cm length fitted with a guard column filled with HC Pellosil. A Pye Unicam PU 4020 UV detector, set at 268 nm was used to measure the clofentezine present in the twig washings. N-2-(2-propyl)phenylbenzamide (NPPBA) was used as a marker compound.

Spider mite sampling

Several weeks after the treatments, numbers of spider mite motiles on the leaves (20-25 per treatment) were recorded. These assessments (2-7 in number) continued throughout the season.

Two methods were used for assessing the spider mite infestations. The first method involved brushing the mites (all stages) from the leaves onto glass slides coated with Shellac. These were then counted. The second method made use of imprints of the various stages after passing leaves wrapped in blotting paper through a domestic pasta-making machine.

RESULTS

Data on clofentezine deposits can be found in Table 3.

TABLE 3

Corrected clofentezine deposits (ug/unit area), recovered from 50 twigs collected from each treatment

Spray volume l/ha	ITALY		FRANCE		NETHERLANDS		U.K.		
	I 1	I 2	F 1	F 2	NL 1	NL 2	UK 1	UK 2	UK 3
100	6.0(a)	15.9	20.5	14.1	12.6	16.4	8.7	20.0	24.8
250	5.0	14.9	-	15.7	16.9	29.9	8.6	13.4	24.0
500	3.9	14.2	11.5	18.7	16.4	25.6	9.2	13.5	27.2
1250	7.5	16.4	9.6	15.9	12.6	12.7	3.9	12.3	22.8
2500	6.5	11.6(b)	8.7(c)	9.6	8.3(d)	-	4.1	7.4	14.2

Notes :

1. (a) Actual volume 150 l/ha. (b) Actual volume 2000 l/ha. (c) Actual volume 2400 l/ha. (d) Actual volume 2200 l/ha.

2. The clofentezine deposit data obtained from the HPLC was corrected using the twig sample weight. This was to take account of the differing surface areas of the samples.

Figure. 2 shows the logarithmic relationship between applied spray volume and retained spray volume (calculated from data above).

The level of clofentezine measured for each treatment was found to vary greatly between sites. This variation was clearly less at higher than at lower volumes (Fig. 1).

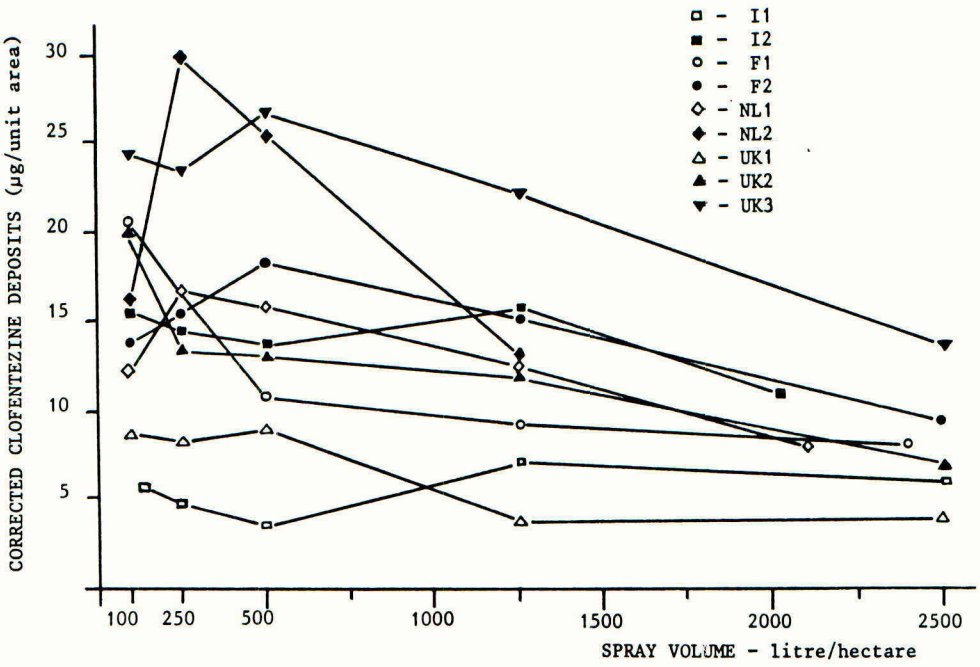

Fig.1 - Corrected deposits of clofentezine.

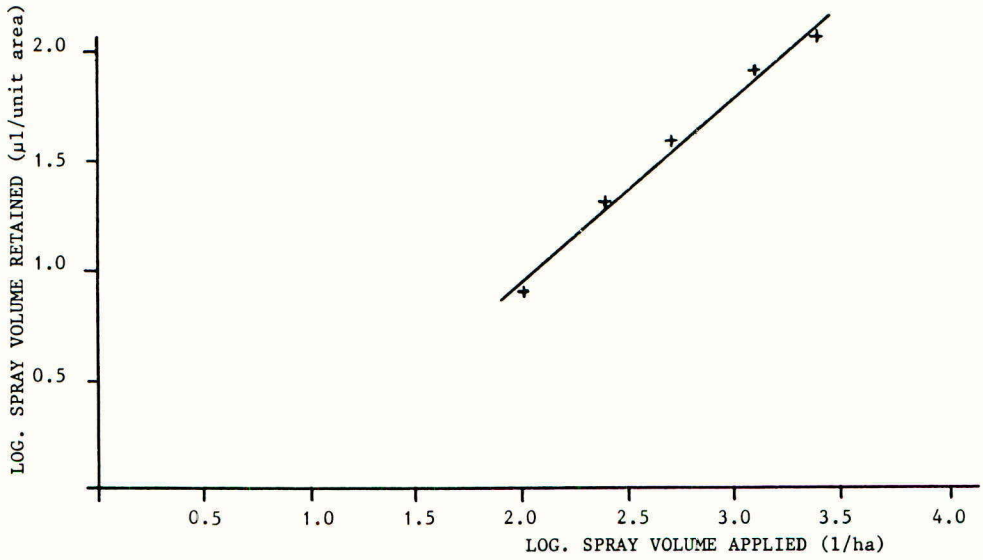

Fig.2 - The effect of applied spray volume on spray volume retained.
Mean of all trials.

TABLE 4

Mean number of Panonychus ulmi motile stages per leaf throughout the season (sampled on 2-7 occasions).

Spray volume l/ha	ITALY		FRANCE		NETHERLANDS		U.K.			
	I 1	I 2	F 1	F 2	NL 1	NL 2	UK 1	UK 2	UK 3	Mean
100	2.9	0.2	1.8	3.9	0.4	1.5	0.1	8.9	1.0	2.3
250	1.5	0.1	-	4.1	0.3	5.5	0	4.6	0.6	2.1
500	2.5	0.3	1.5	2.7	0.2	5.2	0	3.1	0.3	1.8
1250	1.0	0.2	1.0	2.3	0.3	0.8	0	0.6	0.6	0.8
2500	0.5	0.2	1.5	1.9	0.8	-	0	0.8	0.6	0.8

The P. ulmi population varied between sites. It can be seen from the data that in general, better control was achieved with higher spray volumes (Table 4).

DISCUSSION

There were clear indications that as the volume applied increased, the proportion retained decreased. Figure 2 shows that the relationship between volume applied and volume retained can be represented by a straight line. Herrington et al (1981) found a similar relationship.

More variability in clofentezine deposit was found at the lower (< 500 l/ha) than at the higher volumes applied. Visual examination of the sprayed trees confirmed a greater degree of "shadowing" at lower volumes. The improved uniformity of the deposit at higher volumes is not surprising as spray coverage was better and a certain amount of deposit redistribution on the bark is likely.

Somewhat surprising was the considerable variability seen between sites even when the same equipment was used. This was particularly evident in the three UK sites where a six fold difference in deposit was observed. These sites differed in tree layout and the weather, particularly wind speed, was certainly different when the applications were made.

Spider mite control was better and more consistent at volumes above 1250 l/ha. Again, this is not unexpected and supports the general experience of growers and researchers obtained over many years. The data presented in this paper indicate that better mite control was achieved at higher volumes even when the clofentezine deposit was decreasing. This must mean that the form and distribution of the product on the trees is more important than its absolute level in determining the level of Panonychus ulmi control achieved.

These results show that early season sprays of clofentezine at 200g a.i./ha can be applied in a wide range of volumes and will give commercially acceptable control. However, the question of reliability should not be overlooked and in those situations of heavy pest pressure, application volumes less than approximately 1000 l/ha should not be encouraged.

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THE EVALUATION OF A NOVEL ACYLUREA (FLUFENOXURON) ON TOP FRUIT AND CITRUS IN ITALY

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ABSTRACT

Flufenoxuron is an acylurea compound being evaluated against insects and mites attacking a range of important crops. Results of efficacy trials in Italy show that flufenoxuron gives good control of the fruit tree red spider mite (Panonychus ulmi) and the leaf blister moth (Leucoptera scitella) on apples, and the citrus red mite (Panonychus citri) on oranges and clementines. The high level of acaricidal activity of flufenoxuron represents a significant extension of the spectrum of activity of acylureas.

The results of studies on predatory mites, Amblyseius andersoni on apple and Amblyseius stipulatus on citrus, show that the effects of flufenoxuron are comparable with those standard products that are regarded as relatively harmless to these important predators.

Flufenoxuron will be an important addition to the range of products available for control of pests on top fruit and citrus and is very promising for use in integrated pest management programmes.

INTRODUCTION

Flufenoxuron (WL 115110), 1-[4-(2-chloro-α,α,α-trifluoro-p-tolyloxy)-2-fluorophenyl]-3-(2,6-difluorobenzoyl)urea is an acylurea with insecticidal and acaricidal properties (Anderson et al, 1986). Flufenoxuron kills by interfering with the formation of chitin.

The product is currently being developed for use in a wide range of crops. As part of this programme, trials were undertaken during 1985 and 1986 to evaluate its activity against pests of top fruit and citrus in Italy. The effects of this compound on predatory mites have also been investigated.

Studies in 1985 included trials in apples against the leaf blister moth, Leucoptera scitella, the fruit tree red spider mite, Panonychus ulmi and the predatory mite, Amblyseius andersoni. During 1986, the programme was extended to include the citrus red mite, P. citri, and its predator, Amblyseius stipulatus, on citrus.

MATERIALS AND METHODS

Flufenoxuron is available as a 5% water dispersible concentrate (WDC) and a 5% emulsifiable concentrate (EC). The WDC formulation was used in the majority of the trials described here. During 1985, the product was evaluated at doses ranging from 10-40 g ai/hl; during 1986, this dose range was narrowed to 10-30 g ai/hl. All trials were based on randomised block designs with four or five replicates. Treatments were applied using hand held lances and spraying to run off (1000-3000 l/ha, depending on tree size).

Top fruit

Applications against pest species on apples were made at the end of the flowering period. Adults of L. scitella were active in the crop and treatments were applied at the peak of egg laying. A small number of adult P. ulmi were present on the leaves but the majority of mites were still present as winter eggs or immature stages.

Trials were assessed by counting the number of living L. scitella larvae present on the central tree of each plot. P. ulmi was assessed at regular intervals throughout the season by brushing the mites from 32 leaves per plot on to a glass plate coated with a thin layer of petroleum jelly. Motiles (adults and nymphs) were then counted using a binocular microscope. Acaricide treatments were reapplied when the population exceeded a threshold of five motiles per leaf.

A. andersoni was present on the site of one of the acaricide trials and the population of predatory mites was sampled 44 days after treatment. 25 leaves were collected from each plot and inspected under a binocular microscope. The counts of A. andersoni were transformed to $\log_{10}(n + 1)$ values and treatment means calculated.

The effects of flufenoxuron on predatory mites were further investigated in an apple orchard where A. andersoni was present in significant numbers, but the population of P. ulmi was very low. It is assumed that the A. andersoni were feeding on organic matter and detritus on the leaves. Treatments were applied in early July 1985. Populations of A. andersoni were sampled by collecting 15 leaves from each plot and counting motiles using a binocular microscope. Data were transformed to $\log_{10}(n + 1)$ values and analysed using analysis of variance followed by Duncan's multiple range test.

Citrus

Two trials were conducted on oranges in Sicily and one on clementines in southern Italy. Treatments against P. citri were applied at the end of the flowering period in May 1986. The different stages of the mite's life cycle are all present on citrus over the winter period and all stages were present when the treatments were applied. There is a natural decline in the population of P. citri during the hot, dry summer months.

Populations of P.citri were assessed by collecting 25 leaves per plot and counting the number of mites under a binocular microscope.

The effects of flufenoxuron on A. stipulatus, a phytoseiid predator of P. citri, were investigated in two trials on oranges in Sicily. Both the WDC and EC formulations were included in these trials at 10 and 20 g

ai/hl. Fenbutatin oxide and an organophosphorus insecticide, known to be toxic to Amblyseius, were used as reference compounds. Treatments were applied in early May and the population assessed by visual inspection of 20 leaves per plot. The numbers of motiles were transformed to $\log_{10}$ (n + 1) values and analysed by analysis of variance followed by Student - Newman - Keuls multiple range test. P. citri was not present at either site. It is assumed that the A. stipulatus were feeding on organic matter and detritus on the leaves.

RESULTS

Top fruit

L. scitella

The percentage reduction in the number of living larvae, relative to the untreated control, is shown in Table 1.

The trials covered a range of infestation levels with 300-2000 larvae on untreated trees. Flufenoxuron consistently gave good control at the doses tested. Diflubenzuron, which has been the standard product in Italy for a number of years, gave satisfactory control in three of the four trials.

TABLE 1

Control of L.scitella on apples. Percentage reduction of living larvae relative to untreated.

		1985		1986	
Treatment	g ai/hl	RAVENNA	VERONA	PADUA	VERONA
		27 DAT	34 DAT	34 DAT	29 DAT
flufenoxuron	10	99.4	93.0	96.8	99.8
flufenoxuron	20	99.5	96.1	96.3	100.0
flufenoxuron	30	-	-	96.5	99.9
flufenoxuron	40	99.9	99.3	-	-
diflubenzuron	12.5	99.9	99.8	34.8	97.3
No. on untreated	-	2035.5	434.1	1057.8	294.0

P. ulmi

The results of one of the 1985 trials and one of the 1986 trials are given in Table 2. The dates of application were 15.5.85 and 8.5.86. The results are expressed as number of motiles on 32 leaves and are representative of results obtained in other trials. Pest pressure was higher in the 1986 trial and the untreated control had to be oversprayed in mid-June.

Flufenoxuron was slower acting than cyhexatin in the 1985 trial but in both years control with flufenoxuron was superior to cyhexatin 3 weeks after application. Flufenoxuron at 10 g ai/hl gave longer protection than the standard acaricidal treatment.

TABLE 2

Control of P. ulmi on apples. No. of motiles on 32 leaves.

1985 - VERONA		DAYS AFTER TREATMENT						
Treatment	g ai/hl	6	21	34	43	49	64	98
flufenoxuron	10	71	35	85	99	266*	77	154
flufenoxuron	20	41	30	60	126	198*	48	31
flufenoxuron	40	21	20	30	54	116*	27	20
cyhexatin	37.5	6	44	295	427*	14	82	780
untreated	-	113	794	1547	936	991	732	1431

1986 - VERONA		DAYS AFTER TREATMENT						
Treatment	g ai/hl	5	19	39	47	56	69	98
flufenoxuron	10	347	80	67	99	629*	106	173
flufenoxuron	20	251	30	33	24	421*	47	96
flufenoxuron	30	197	22	34	7	193*	23	78
cyhexatin	37.5	285	454	1577	2202'	99	6	242
untreated	-	592	3336	8624 +	-	-	-	-

* Retreated
' Retreated with cyhexatin + clofentezine + Treated with standard acaricide

A. andersoni
Data for A. andersoni from the P. ulmi trial are summarised in Table 3.

Numbers of predatory mites were significantly lower in plots treated with flufenoxuron and cyhexatin than in the controls. It is, however, impossible to determine the extent to which this can be attributed to the toxicity of the treatments to A. andersoni rather than indirect effects resulting from reduced prey availability (because of the impact of the treatments on P.ulmi). Under these circumstances, it is most meaningful to interpret the effects of the treatments in terms of their impact on the ratio of phytophagous to predatory mites. It can be seen that A. andersoni was relatively more abundant in plots treated with flufenoxuron than in those treated with cyhexatin. Moreover, comparison of data from treated plots with the control indicates that the flufenoxuron treatments had only a limited impact on the balance between predator and prey.

TABLE 3

Effects of flufenoxuron on A. andersoni on apples. Verona, 1985.

Treatment	g ai/hl	No. of A. andersoni/plot 44 DAT	Ratio of P.ulmi to A. andersoni
flufenoxuron	10	9.5	8:1
flufenoxuron	20	2.3	44:1
flufenoxuron	40	1.0	42:1
cyhexatin	37.5	0.5	667:1
untreated	-	65	11:1

Data from the A. andersoni trial are summarised in Table 4. The results indicate that both flufenoxuron and cyhexatin had some effect on A. andersoni. The numbers on the cyhexatin plots were lower 2 DAT than on the flufenoxuron treated plots, but recovered to the level of the untreated control sooner than on the flufenoxuron plots.

TABLE 4

Effects of flufenoxuron on A. andersoni in the absence of prey. No. of A. andersoni per leaf. Trento, 1985.

		DAYS AFTER TREATMENT						
Treatment	g ai/hl	-2	2	9	21	34	48	59
flufenoxuron	10	2.4a*	0.45bc	2.0abc	0.82b	1.0bc	1.2ab	0.53a
flufenoxuron	20	2.2a	0.94bc	0.92bc	0.54b	0.60c	0.80b	0.35a
cyhexatin	35	2.0a	0.19b	0.10c	0.52b	1.8ab	1.8a	0.82a
untreated	-	2.8a	1.8a	3.7ab	2.7a	1.9a	1.9a	0.83a

* Different letter subscripts denote significant differences between treatments with P <0.05.

Citrus

P.citri

The results of one trial on oranges and one on clementines are given in Table 5. The numbers are lower than for P. ulmi on apples but the population on clementines was a severe infestation. The population on the untreated plots decreased rapidly during the hot weather in mid-June and the trials were then terminated.

All treatments with flufenoxuron and the standard acaricide gave excellent control of P. citri.

TABLE 5

Control of P. citri. No. of mites on 25 leaves.

		ORANGE - SICILY				CLEMENTINE - S. ITALY			
Treatment	g ai/hl	7	14	22	29	8	18	25	DAT
flufenoxuron	10	3	3	12	2	26	3	1	
flufenoxuron	20	7	4	2	1	29	3	1	
flufenoxuron	30	6	5	6	1	16	1	0	
fenbutatin oxide	60	26	2	4	0	5	0	0	
untreated	-	207	200	267	33	376	346	33	

A. stipulatus

Data for A. stipulatus are given in Table 6. The toxic reference compound had a significant impact on the numbers at both sites and at site 1 the effect persisted for 30 days after spraying. At the second site, the numbers of A. stipulatus on the plot treated with the toxic reference recovered to control levels within 20 days of spraying, indicating migration from neighbouring plots.

Flufenoxuron and fenbutatin oxide had a very limited impact on the populations of A. stipulatus at both sites. Numbers in the treated plots were generally not significantly different to those in the controls. The results from site 1 indicate a slight dose response for the EC formulation of flufenoxuron but this was not confirmed at site 2.

TABLE 6

Effect of flufenoxuron on A. stipulatus on citrus. No. of A. stipulatus per leaf. Sicily, 1986.

Treatment		g ai/hl	DAYS AFTER TREATMENT -1	7	10	20	32	60
Site 1								
flufenoxuron	EC	10	3.9a+	3.2a	2.4ac	2.3a	1.9a	0.03
flufenoxuron	EC	20	3.0a	2.0a	1.6c	1.6a	1.4a	0.04
flufenoxuron	WDC	10	4.0a	3.0a	2.5a	2.3a	1.3a	0.09
flufenoxuron	WDC	20	3.2a	3.2a	2.1ac	2.2a	1.0a	0.03
fenbutatin oxide	SC	44	3.3a	2.0a	3.3a	2.5a	0.9a	0.0
toxic reference	-	-	3.4a	0.02b	0.0b	0.0b	0.05b	0.03
untreated	-	-	3.6a	3.3a	2.8a	2.8a	1.9a	0.1
Site 2			-2	7	10	20	32	60
flufenoxuron	EC	10	1.7a	1.8a	1.3a	1.5ab	0.5a	0.1
flufenoxuron	EC	20	2.3a	2.0a	1.4a	0.7b	0.3a	0.2
flufenoxuron	WDC	10	1.9a	2.2a	1.3a	1.0ab	0.8a	0.1
flufenoxuron	WDC	20	2.0a	2.3a	1.3a	1.0ab	0.5a	0.1
fenbutatin oxide	SC	44	2.9a	1.9a	1.2a	0.8b	0.5a	0.3
toxic reference	-	-	3.0a	0.3b	0.5b	1.0ab	0.7a	0.9
untreated	-	-	2.9a	3.1a	2.2a	1.8ab	1.0a	0.4

+ Different letter subscripts denote significant differences between treatments with $P<0.05$. Numbers on the final sampling date were too small to justify analysis.

DISCUSSION

Flufenoxuron is an acylurea compound and controls pests by interfering with the production of chitin. Flufenoxuron is principally active against immature stages that are undergoing moults between the instars. However, it has been demonstrated (Anderson et al, 1986) that adults treated with flufenoxuron may lay sterile eggs.

The results of trials carried out in Italy against P. ulmi on apples, P. citri on citrus and L. scitella on apples demonstrate that flufenoxuron has good activity against these important pest species. Further work is in progress to optimise the doses and timing of application to capitalise on the growth regulant action of the product.

The results of the studies on predatory mites indicate that the effects of flufenoxuron on A. andersoni and A. stipulatus are broadly comparable with those resulting from the application of cyhexatin and fenbutatin oxide. Cyhexatin is generally considered to be relatively harmless to predatory mites under field conditions and has been successfully used for many years in integrated pest management programmes in top fruit (e.g. Collyer, 1980, Croft, 1981) Similarly, extensive laboratory and field studies have demonstrated that fenbutatin oxide is relatively non-toxic to a range of predatory mites (Angerilli and Logan, 1982; Hislop and Prokopy, 1981; Jeppson et al, 1975; Overmeer and van Zon, 1981; Samsoe-Petersen, 1983).

It can be concluded that flufenoxuron will be an important addition to the range of products available for control of pests on top fruit and citrus and has good potential for use in integrated pest management.

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PP321 : CONTROL OF THE MAJOR PESTS IN UK HORTICULTURAL CROPS

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ABSTRACT

PP321 a new ICI pyrethroid with broad spectrum insecticidal and acaracidal activity has been evaluated for pest control on vegetables, top fruit and hops in the UK during the period 1983-86. Results show excellent control of winter moth (Operophtera brumata), leaf midge (Dasineura mali), apple-grass aphid (Rhopalosiphum insertum), apple sucker (Psylla mali), rosy apple aphid (Dysaphis plantaginea), codling moth (Cydia pomonella), fruit tree tortrix (Archips podana) and pear sucker (Psylla pyricola) on apples and pears. Moderate control of woolly aphid (Eriosoma lanigerum), fruit tree red spider mite (Panonychus ulmi) and apple rust mite (Aculus schlectendali) was also achieved. Control of damson hop aphid (Phorodon humuli) and two spotted mite (Tetranychus urticae) on hops was superior to standard products. PP321 showed very high activity against small cabbage white butterfly (Pieris rapae), garden pebble moth (Evergestis forficalis), diamond-back moth (Plutella xylostella) and whitefly (Aleyrodes proletella) on brassicae and against pea moth (Cydia nigricana) on combining peas. There was no phytotoxity by PP321 alone or in tank mixtures with a range of pesticides on any of the crops treated, and all tank mixtures were physically compatible. PP321 has not caused taint to any crop tested.

INTRODUCTION

Pyrethroids are used extensively in the UK for broad spectrum pest control on many vegetable and fruit crops. Although highly active on many chewing and sucking species, their lack of systemic and persistent activity often results in only moderate control of some important pests such as whitefly and certain aphids. In addition, their use can increase the incidence of spider and rust mites, due to undesirable effects on predators and parasites.

PP321, a novel pyrethroid discovered by ICI (Jutsum *etal* 1984), has shown both broad spectrum insect control and acaricidal activity.

Since 1983 over 70 field trials with PP321 have been conducted on vegetables, fruit crops and hops by ICI. The trials have been situated in the important production areas for each crop and included 30 trials on apples and pears, 17 on hops, 10 on brassicae and 6 on peas. A few representative results for each crop and/or pest will be used to illustrate the level of broad insecticidal and acaricidal activity obtainable by a range of application rates.

TABLE 1
Details of field trials 1984-86

Trial No	Variety	Application Dates	Replicates	Pest
APPLES				
85-SE-16	Cox, Worcester, Egremont R.	1/5, 15/7	4	Apple sucker, winter moth
85-SE-16A	Bramley	28/6, 24/7	1	Codling moth, Fruit Tree Tortrix
85-SE-17	Cox	3/5, 27/6	4	Apple sucker, woolly aphid
85-EH-25	Cox	9/5, 13/6,	4	Red spider mite
85-EH-29	Cox Discovery	8/5, 3/6, 9/7, 8/8	4	Red spider mite, Rust mite
86-52-27	Bramley Worcester Grenadier	25/4	1	Apple grass aphid
86-52-29	Cox	4/6	1	Winter moth, apple grass aphid, apple sucker, leaf midge
86-53-2	Tremletts Bitter (cider)	28/4, 13/5 18/6, 7/7	1	Apple grass aphid, rosy apple aphid, apple sucker
PEARS				
85-EH-5	Conference	19/3	4	Pear sucker
85-SE-60	Conference	15/10	3	Pear sucker
86-52-32	Conference	2/4	4	Pear sucker
HOPS				
85-SE-20	Yeoman	17/6, 9/7, 27/7 9/8, 18/8, 26/8	1	Damson hop aphid
86-52-35	Target	1/7, 15/7, 29/7	1	Two spotted mite
86-52-36	Whitbread Golding	20/6, 3/7, 15/7 30/7	2	Two spotted mite
86-52-37	Northdown	2/7, 14/7, 30/7	2	Two spotted mite
BRASSICAE (Brussel Sprouts)				
84-NA-28	Rampart	6/8	6	Caterpillar
84-EM-32	Rasmundar	19/7	4	Caterpillar
85-EH-101	Titurel	24/8, 19/9	4	Whitefly
85-EH-102	Titurel	11/9	4	Whitefly
86-55-17	Oliver	26/6	5	Caterpillar
PEAS				
84-1	Progreta	5/7, 19/7	3	Pea Moth
84-2	Vedette	26/6, 6/7	3	Pea Moth
84-4	Progreta	19/6, 27/7	3	Pea Moth
85-1	Progreta	8/7	3	Pea Moth
85-2	Progreta	13/7	3	Pea Moth

MATERIALS AND METHODS

Replicated and single plot grower applied trials were conducted in the UK from 1983-86 on top fruits, hops, brassicae and peas. Details of crop, dates of application, replication and pests for the results presented in this paper are shown in Table 1.

Replicated fruit trials had plots of 3-9 trees, depending on tree size. Treatments were applied in 400-900 l/ha of water using a motorised knapsack mist-blower. Plot size on replicated brassica and pea trials was 10-35m^2 and application was made by 'AZO' propane or CO_2 gas sprayers regulated at 200-300 kPa giving a water volume of 220-600 l/ha. Single plot trials on fruit and hops had plots of 0.4-1.0 ha, treatments being applied by commercial mist-blowers in water volumes of 500 l/ha on fruit and 550 l (early season), increasing to 1500-2200 l/ha (late season) on hops as bine growth developed through the season.

PP321 was applied to all trials as a 50 g ai/l emulsifiable concentrate formulation. Cypermethrin 10% EC as 'Ambush' C or deltamethrin 2.5% EC as 'Decis' were used as comparative standards. The treatments and rates of use are shown in the tables of results.

Efficacy was assessed by either counting the numbers of live insects/mites or damaged fruits on randomly selected plant samples in each plot. Damaged peas were weighed after combining.

RESULTS

a) Apples

Control of apple pests is presented in Tables 2-6. PP321 at 6g ai/ha gave complete or a very high level of control of winter moth, leaf midge, apple-grass and rosy apple aphids, sucker and codling moth. Control was equal or superior to that obtained by 28 g ai/ha cypermethrin. When applied pre-blossom at 4.5 g ai/ha, PP321 provided excellent control of apple sucker and apple-grass aphid, superior to 14 g ai/ha cypermethrin (trial 86-52-27) Control of fruit tree tortrix by PP321 was similar to that by cypermethrin. PP321 at 6 g ai/ha also gave a useful suppression of apple rust mite and fruit tree red spider, especially when four applications had been applied during season. Red spider infestation on the untreated plots in trial 85-EH-25 was reduced by natural predation. Control of woolly aphid was variable (46-69% when treatment was applied at 400 l/ha, but improved to 77% control by 6 gai/ha PP321 in 1000 l/ha ofwater (results not presented).

TABLE 2
Control of Winter Moth (Operophtera brumata) and Leaf Midge (Dasineura mali) on apples

			No of Live Caterpillars/plot		No of Live Apple Leaf Midge/25 buds
Treatment	Rate g ai/ha	Assess : Trial :	6 DAT 1 85-SE-16	5 DAT 86-52-29	5 DAT 86-52-29
PP321	3		0	-	-
PP321	6		0	0	0
PP321	9		0.5	0	0
PP321	12		0.5	-	-
Cypermethrin	28		0	0	0
Untreated			8.1	12.3	49

DAT = days after treatment, DAT 1 = days after treatment one.

TABLE 3
Control of Apple-grass Aphid (Rhopalosiphum insertum) on apples

			% Apple Grass Aphid Control			
Treatment(1)	Rate g ai/ha	Assess : Trial :	3 DAT 86-52-27	5 DAT 86-52-29	4 DAT 86/53/2	20 DAT 86/53/2
PP321	3.0		78	-	92	100
PP321	4.5		91	-	98	100
PP321	6.0		-	100	-	-
PP321	9.0		-	100	-	-
Cypermethrin	14.0		43	-	-	-
Cypermethrin	28.0		-	100	-	-
Untreated	(No/25 buds)		-	(15)	(100)(2)	(70)(2)

(1) All treatments applied pre-blossom except trial 86-52-29 which was post-blossom.
(2) Percentage of clusters infested.

TABLE 4
Control of Apple Sucker (Psylla mali) on apples

			Mean no. of Live Apple Sucker per 20 florets			
Treatment	Rate g ai/ha	Assess : Trial :	23 DAT 1 85-SE-16	18 DAT 1 85-SE-17	5 DAT 86-52-29	20 DAT 86-53-2
PP321	3.0		10.3 A	4.8 B	-	1
PP321	4.5		-	-	-	0
PP321	6.0		1.5 B	1.1 B	0	-
PP321	9.0		2.0 B	2.5 B	0	-
Cypermethrin	28.0		3.0 B	2.1 B	0	-
Untreated			13.0 A	38.4 A	61	12

Note: different letters within columns indicate significant differences at P=0.05 in this and all subsequent Tables.

TABLE 5
Control of Codling (Cydia pomonella), Fruit Tree Tortrix (Archips podana), Woolly Aphid (Eriosoma lanigerum) and Rosy Apple Aphid (Dysaphis plantaginea) on apples

Treatment	Rate g ai/ha	% damaged fruit at harvest (85-SE-16A) Codling	Tortrix	% Woolly Aphid Control (85-SE-17) 4 DAT	2	% Shoots infested with Rosy Apple Aphid (86-53-2) 20 DAT
PP321	3	0	1.3	64		-
PP321	6	0	1.0	46		0
PP321	9	0	0.8	69		0
Cypermethrin	28	0	1.1	69		-
Untreated		1.5	2.6	0		60

TABLE 6
Control of Fruit Tree Red Spider Mite (Panonychus ulmi) and Rust Mite (Aculus schlectendali) on apples

Treatment	Rate g ai/ha	Trial Assess Stage	No of Spider Mites/10 leaves 85-EH-25 7 DAT 2 Eggs	85-EH-29 15 DAT 2 Eggs	85-EH-29 7 DAT 4 Eggs	85-EH-29 7 DAT 4 Motiles	No of Rust Mites 40 leaves 85-EH-29 7 DAT 4 Motiles
PP321	3		193 A	32	18 A	5.7 AB	21 B
PP321	6		98 AB	14	6 B	2.1 BC	8 B
PP321	9		98 AB	4	3 B	0.5 D	8 B
PP321	12		59 B	11	6 B	0.9 CD	12 B
Cypermethrin	28		206 A	13	21 A	4.7 AB	9 B
Untreated			114 AB	27	46 A	9.9 A	143 A
				NS			

b) Pears

6 g ai/ha PP321 provided similar control of pear sucker to 35 g ai/ha cypermethrin on all trials except 85-EH-5, where 6 g ai/ha gave exceptionally poor results (Table 7). Although not significant, results suggest that control was improved by PP321 at 9 g ai/ha.

TABLE 7
Control of Pear Sucker (Psylla pyricola) on pears

Treatment	Rate g ai/ha	Trial Assess Stage	No of Adults/beat (4-10 beats/plot) and Nymphs/50 leaves 85-EH-5 2 DAT Adults	85-EH-5 60 DAT Nymphs	85-SE-60 2 DAT Adults	86-52-32 9 DAT Adults	86-52-32 50 DAT Nymphs
PP321	3		0.8 B	0.6 B	1.6 B	0.5	3.3 B
PP321	6		1.0 B	2.8 A	1.5 B	1.5	2.6 B
PP321	9		0.6 B	1.2 B	0.7 B	0.7	1.2 B
PP321	12		0.3 B	1.4 B	0.9 B	0.7	1.7 B
Cypermethrin	35		1.4 B	0.7 B	1.8 B	0.2	3.8 B
Untreated			3.5 A	6.0 A	32.3 A	4.0	12.7 A

c) Hops

Seventeen trials have been performed on hops and results from a typical experiment are shown in Table 8. In general PP321 has consistently given equal or superior control of damson hop aphid compared to either cypermethrin or deltamethrin programmes. In the trial presented here the improved aphid control obtained by PP321 during the migratory period, resulted in a marked reduction in aphid infested cones at harvest. PP321 also gave excellent suppression of two spotted mites (Table 9), especially at the higher rate.

TABLE 8
Control of Damson Hop Aphid (Phorodon humuli) on hops Trial 85-SE-20

Treatment(1) Rate g ai/ha	Pre 1st Spray	Aphids/leaf (20 leaves/plot) 3 DAT 1	18 DAT 1	1 DAT 3	15 DAT 3	% clean cones (100 cones/plot) 18 DAT 6
A PP321 7.5-15.0		0.4	53.7	1.4	0.1	81.0
B PP321 12.5-25.0		2.0	33.7	1.2	0.0	96.8
C Standard		5.8	28.8	14.6	>100	33.7
Control	61.1	-	-	-	-	-

(1) Rates of use and water volume progressively increased as bine growth developed through the season.

A total of 6 sprays were applied as follows :-

Treatment A: Sprays 1 and 2, PP321 at 7.5 g; sprays 3-6, PP321 at 15.0 g ai/ha
Treatment B: Sprays 1 and 2, PP321 at 12.5 g; sprays 3-6, PP321 at 25.0 g ai/ha
Treatment C: Spray 1, cypermethrin at 52.5 g ai/ha; spray 2, deltamethrin at 15.75 g; sprays 3-6, deltamethrin at 21.0 g ai/ha.

TABLE 9
Control of Two Spotted Mite (Tetranychus urticae) on hops

Treatment	Rate g ai/ha	Trial : Assess :	No of Motiles/50 leaves 86-52-35 14 DAT 2	86-52-36 2 DAT 4	86-52-37 2 DAT 3
PP321	7.5-15.0		320	55	112
PP321	12.5-25.0		105	2	48
Deltamethrin	10.5-21.0		1840	91	-
Cypermethrin	35.0-70.0		-	-	188

d) Brassicae

Caterpillars (Table 10) were controlled by PP321 at rates as low as 2.5 g ai/ha and this was superior to 25 g ai/ha cypermethrin for both initial and persistant control. Control of whitefly (Table 11) by 5 g ai/ha of PP321 was equal or superior to 25 g ai/ha cypermethrin. The level of control was significantly improved when the rate was increased.

TABLE 10
Control of Small Cabbage White Butterfly (Pieris rapae), Garden Pebble Moth (Evergestis forficalis) and Diamond-back Moth (Plutella xylostella) on brassicae

Treatment[1]	Rate	% Control				
		84-NA-28[2]		84-EM-32[2]	86-55-17[3]	
	g ai/ha	22 DAT	30 DAT	26 DAT	7 DAT	21 Dat
PP321	2.5	-	-	-	83	100
PP321	5.0	-	-	92 C	80	100
PP321	7.5	-	-	-	83	94
PP321	10.0	97 B	52 A	98 C	-	-
Cypermethrin	25.0	94 A	-15 A	65 B	67	88
Untreated (larvae/plant)		(0.5)A	(0.3)A	(0.6)A	(6.0)	(3.4)

(1) Wetting agent 'Agral' added to all treatments at 300 ml/1000 l water.
(2) Small Cabbage White Butterfly and Garden Pebble Moth.
(3) Small Cabbage White Butterfly and Diamond-back Moth.

TABLE 11
Control of Whitefly (Aleyrodes proletella) on brassicae

Treatment[1]	Rate	Whitefly/plant (3-5 plants/plot)				
		85-EH-101			85-EH-102	
	g ai/ha	5 DAT 1	19 DAT 1	8 DAT 2	6 DAT	29 DAT
PP321	5.0	10 AB	45 B	15 C	85 AB	95 C
PP321	7.5	7 BC	24 C	7 CD	53 BC	51 CD
PP321	10.0	5 C	24 C	6 D	36 C	41 D
Cypermethrin	25.0	12 AB	40 B	53 B	140 A	256 B
Untreated		16 A	82 A	158 A	191 A	624 A

(1) See note 1 above (Table 10).

e) Peas

Trials conducted by the PGRO have shown that 5 g ai/ha PP321 has given similar control of pea moth to that by the standard pyrethroids. All treatments gave 93-100% control of an infestation of pea aphid (Acyrthosiphon pisum) on one trial (result not presented).

TABLE 12
Pea Moth (Cydia nigricana)

Treatment	Rate	% damaged peas by weight at harvest				
	g ai/ha	84-1	84-2	84-4	85-1	85-2
PP321	2.5	0.26 B	0.13 B	0.79 B	0.98 B	1.91 AB
PP321	5.0	0.15 B	0.04 B	0.59 B	0.68 B	0.25 B
PP321	10.0	0.10 B	0.03 B	0.48 B	0.25 B	0.38 B
Cypermethrin	25.0	0.09 B	0.04 B	0.41 B	1.86 B	0.19 B
Deltamethrin	7.5	-	-	-	0.88 B	0.05 B
Untreated		1.57 A	2.02 A	3.04 A	7.12 A	4.00 A

f) Crop Tolerance

No crop damage was evident with PP321 at any rate on the many varieties of vegetables, fruits or hops treated, when applied alone or in tank mixture with a range of other key chemicals. Results of 44 taint tests on fruit and vegetable crops have shown that PP321 does not taint crops grown for processing.

DISCUSSION

The results of trials conducted over the period 1983-86 demonstrate that PP321 provides a high level of control of the major insect pests found in the UK which reduce the crop quality and yield of top fruit, hops and vegetables.

PP321 at 5-6 g ai/ha gave equal or superior control of many Aphididae, Lepidoptera and Psyllidae pests of apples, pears, brassicas and peas to that by 25-35 g ai/ha of cypermethrin. At 6 g ai/ha, PP321 applied as an insecticidal programme on apples has provided a useful level of fruit tree red spider mite suppression after two applications. This level of suppression was increased after four sprays, which also controlled apple rust mites. On brassicas, 5 or 7.5 g ai/ha of PP321 has given superior control of whitefly compared to cypermethrin at 25 g ai/ha.

On hops, spray programmes of PP321 starting at 12.5 g and increasing to 25 g ai/ha as bine height increased achieved excellent control of both damson hop aphid and two spotted mites, superior to cypermethrin at 35-70 g ai/ha and to deltamethrin at 10.5-21.0 g ai/ha.

PP321 showed excellent crop safety on all crops treated, when applied alone or in tank mixtures with other pesticides, and has not tainted treated crops grown for processing.

The development of PP321 provides growers with a new highly effective broad spectrum chemical which will combat most major horticultural pests.

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DEVELOPMENTS IN THE USE OF PROCHLORAZ FOR TROPICAL FRUIT DISEASE CONTROL

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ABSTRACT

Trial results are presented which demonstrate the efficacy of prochloraz as a post-harvest treatment for the control of storage diseases of tropical fruit. Prochloraz, formulated as an emulsifiable concentrate, was evaluated as a dip treatment to freshly harvested bananas, avocados, mangoes, papayas and citrus and a spray treatment to avocados. As a dip treatment over the rate range 25-100 g a.i./hl., good control was observed against all the important fungi constituting the complex of storage rots of these tropical fruit. At 500 g a.i./hl. as a spray treatment, good protection was also afforded against anthracnose of avocados.

INTRODUCTION

Much attention has been focused on the use of the fungicide prochloraz, for the control of diseases of cereals and oilseed rape (e.g. Wakerley & Russell 1985). However, in contrast, there is relatively little published information on the use of prochloraz in other crop areas. The broad-spectrum nature of prochloraz activity has created much interest over recent years in its potential for the control of diseases of tropical fruit.

The post-harvest treatment of tropical fruit, such as avocados, bananas, citrus and mangoes, presents an interesting area of development for fungicide usage. A wide range of pathogens possess the ability to cause serious losses of fruit during storage and shipment. Such storage rots are often a manifestation of infection by a complex of fungi. As an example, harvested bananas suffer from the attention of various species of Colletotrichum, Fusarium, Verticillium and Ceratocystis causing rots of the crowns, necks and fingers (Slabaugh & Grove 1982). Effective fungicides must, therefore, demonstrate good control of these disease complexes.

The main aim of this paper will be to review the results of recent trials demonstrating the efficacy and versatility of the use of prochloraz against storage diseases of tropical fruit.

MATERIALS AND METHODS

Trials were carried out in Australia, the Republic of South Africa and Spain. The following general treatment methods were employed with only minor local trials variations between countries.

The efficacy of prochloraz as a post-harvest treatment for storage disease control was assessed on mature, unripe avocados, bananas, citrus, mangoes and papayas. Most trials relied on natural infections of storage rots. The most commonly used treatment was a 1-5 min. dip in a suspension of prochloraz formulated as a 450 g/l emulsifiable concentrate (OMEGA®). Testing was generally carried out over the range 10-100 g a.i./hl. alongside a cold water dip and local standard fungicide treatment. Following air drying, the fruit was stored under normal commercial conditions and later examined for disease development. Assessments were generally made by calculating the percentage of fruit showing signs of disease.

In addition to treatment by fruit dipping, prochloraz was also applied to avocados as an ultra low volume spray on a moving conveyor belt (1.6 l spray volume/tonne fruit).

Some citrus trials were carried out with fruit inoculated with Penicillium digitatum. Infection was achieved by puncturing the fruit with needles previously dipped in a conidial suspension of the fungus.

RESULTS AND DISCUSSION

The results presented below were selected from representative trials reflecting overall features of prochloraz activity as a post-harvest treatment.

Bananas

The crown rot disease complex of bananas is recognised as being the most serious post-harvest problem in commercial banana production. The procedure of severing the hands from the stems prior to shipment in boxes, exposes a large area of crown tissue which may be rapidly colonised by a variety of wound pathogens, as listed in Table 1. This table also shows that treatment with prochloraz as a post-harvest dip shortly after harvesting is an effective way of protecting the banana fruit from infection. Furthermore, prochloraz is shown to possess a high degree of protectant action, comparable to existing standard treatments, which will persist over the period encompassing shipment and storage. An additional feature of the trials, has been the observation that all those fungi associated with the collar rot disease complex appear to be controlled by prochloraz.

Avocados, mangoes and papayas

Anthracnose (Colletotrichum gloeosporioides) and stem end rots (Botryodiplodia theobromae, Dothiorella dominicana) cause the greatest losses to harvested avocados, mangoes and papayas. It is recognised that infection usually arises in the field and that the fungi often remain inactive until after harvest (Muirhead et al. 1982); hence the rationalé for a post-harvest treatment to eradicate latent infection and prevent the spread of disease in store. Table 2 provides a summary of the level of control of anthracnose offered by post-harvest prochloraz dip treatments.

In trials with mangoes and papayas, prochloraz has consistently demonstrated outstanding control at rates down to 12.5 g a.i./hl. Good protection of avocados from anthracnose and stem end rots for up to 6 weeks after treatment is also offered by prochloraz when used at a dip rate of 50 g a.i./hl. (Figure 1).

In addition to dip treatments, prochloraz has also been evaluated as an ultra low volume spray treatment to avocados. The fruit were passed on a conveyor belt under a hand-held ultra-low volume applicator. As expected, much higher concentrations of prochloraz were required to give good disease control. However, when the fruit were adequately wetted (effected by a spray volume of 1.6 l/tonne fruit), trials showed commercially acceptable control at a rate of 500 g a.i./hl. (Table 3).

Citrus

The blue and green moulds, Penicillium italicum and P.digitatum respectively, are considered to be the most serious causal agents of post-harvest losses to citrus fruit (Eckert et al. 1981). The features of prochloraz activity against these storage rots are illustrated in the results presented in Tables 4-7. In uninoculated fruit dipping trials designed to reflect normal commercial practice, good persistent activity against Penicillium spp. has been demonstrated over the range 50-100 g a.i./hl. (Table 4). Prochloraz showed greater control of P. digitatum than P. italicum. As shown in Table 5, in inoculated fruit trials, it was found that treatment must be effected within 24 hours of infection in order to maximise the benefits of prochloraz usage. As prochloraz has been shown to inhibit sporulation and surface mycelial growth of P. digitatum, the inference is that whilst prochloraz may not have an effect on well-established infections on individual fruit, subsequent sporulation and disease spread to adjacent fruit in store is prevented. An additional feature of prochloraz activity, illustrated in Table 5, is the control of benomyl-sensitive strains of P. digitatum, thus confirming the results of other workers (Eckert et al. 1981).

With reference to prochloraz control of other fungi commonly found causing citrus storage rots, good activity has been recorded against Alternaria citri, Diplodia natalensis and Colletotrichum gloeosporioides but only moderate activity against Geotrichum candidum (sour rot) at dip rates up to 100 g a.i./hl. Commercially acceptable control of sour rot is achieved at higher rates. No activity has been recorded against Phytophthora spp..

CONCLUSIONS

Prochloraz offers good control of a range of economically important storage diseases of tropical fruit as a post-harvest treatment. The effective dose range is from 25-100 g a.i./hl., the optimum rate varying country-by-country according to the composition of the prevalent pathogen complex.

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TABLE 1

Control of banana collar rot disease* complex by post-harvest applications of prochloraz (Republic of South Africa)

Treatment	Rate g ai/hl.	Mean % bananas infected with collar rot Trial 1 T + 18**	Trial 2 T + 21	Trial 3 T + 14	Trial 3 T + 28
Prochloraz	12.5	67	–	–	–
Prochloraz	25	49	36	25	51
Prochloraz	50	29	33	23	41
Thiabendazole	135-250	76	69	54	79
Control (cold water dip)		99	84	79	99

** T + 18 = Assessed 18 days after treatment

* Common fungi associated with the banana collar rot disease complex were:

Colletotrichum musae
Verticillium theobromae
Fusarium roseum
Fusarium moniliforme
Botryodiplodia theobromae
Ceratocystis paradoxa

TABLE 2

Control of anthracnose of tropical fruit by post-harvest applications of prochloraz (Republic of South Africa)

Treatment	Rate g ai/hl.	% Fruit infected with anthracnose Avocados 1*	2	Mangoes 3	4	Papayas 5	6
Prochloraz	12.5	–	–	1	–	0	0
Prochloraz	25	–	–	0	–	0	0
Prochloraz	50	7	15	0	0	–	18
Prochloraz	100	10	21	–	0	–	–
Local standard		–	–	5	2	5	55
Control (cold water dip)		39	65	72	55	32	60

Trial* 1,2,3,4,5 & 6 assessed 42, 39, 14, 21, 18 and 17 days after treatment respectively.

FIG. 1

Control of storage disease of avocados by post-harvest prochloraz dip treatments (Republic of South Africa)

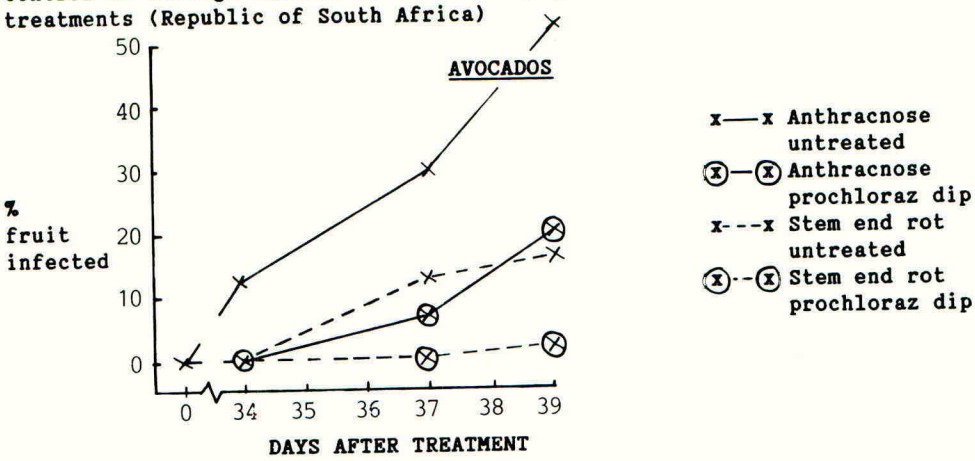

TABLE 3

Control of storage diseases of avocados by ultra low volume post-harvest spray applications (Republic of South Africa)

Treatment	Rate g ai/hl.	% infected fruit: Anthracnose Trial 1	Anthracnose Trial 2	Anthracnose Trial 3	Anthracnose Mean	Stem end rot Trial 1	Stem end rot Trial 2	Stem end rot Trial 3	Stem end rot Mean
Prochloraz	500	17	21	33	24	0	6	7	4
Control		67	65	75	69	2	4	42	16

Assessed 30-38 days after treatment

TABLE 4

Control of *Penicillium* spp. on citrus by fungicide dip treatments (Spain)

Treatment	Rate g ai/hl.	Mandarins	Oranges	% Pathogen incidence: *P. italicum*	*P. digitatum*
Prochloraz	50	2.5	10.3	100	0
Prochloraz	100	4.8	9.9	100	0
Benomyl	100	8.1	20.7	65	35
Imazalil	100	2.0	9.3	100	0
Control		27.0	30.3	70	30

Assessed 60 days after treatment

TABLE 5

Effect of time between inoculation of citrus fruit with Penicillium digitatum and fungicide dip treatments (Australia)

Treatment	Rate g ai/hl.	% fruit infected: Time between inoculation and treatment (h) 0	24	48	0	24	48
		Oranges			Lemons		
Prochloraz	50	3	70	100	0	0	48
Benomyl	50	100	100	100	100	100	100

TABLE 6

Effect of fungicide dip treatments on the sporulation and mycelial growth of Penicillium digitatum on citrus* (Australia)

Treatment	Rate g ai/hl.	% fruit infected: Oranges Sporulation	Oranges Mycelial growth	Lemons Sporulation	Lemons Mycelial growth
Prochloraz	50	0	5	0	0
Guazatine	50	90	0	90	0
Control		75	100	100	100

* Inoculated fruit were stored at 23°C for 66 hours prior to treatment and then assessed 96 hours after treatment.

TABLE 7

Control of citrus post-harvest diseases by prochloraz dip treatments
(Republic of South Africa)

Treatment	Rate g ai/hl.	% fruit infected				
		Penicillium digitatum	Geotrichum candidum	Alternaria citri	Diplodia natalensis	Colletotrichum gloeosporioides
Prochloraz	25	0	2.2	0	0	0
Prochloraz	50	0	2.2	0	0	0.9
Prochloraz	75	0	0.5	0	0	0
Prochloraz	150	0	0	0	0	0
Local standard		0	1.6	0	0	0
Control		45.5	14.0	3.5	3.5	3.5

Assessed 9 wks after treatment

Storage details - 1 wk at 21.5°C, 4 wks at 4°C & 4 wks at 21.5°C.

BEHAVIOUR MODIFYING CHEMICALS IN INTEGRATED PEST MANAGEMENT PROGRAMMES FOR OLIVE PESTS.

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ABSTRACT

Behaviour Modifying Chemicals (BMCs) have been described for the two most important pests of olives in the Mediterranean basin; Dacus oleae and Prays oleae. Both sex and food attractants are currently being used in monitoring the populations of these pests. Recent advances in trap design and controlled release technology have contributed significantly to the efficiency, consistency and selectivity of olfactory traps as tools for population monitoring. The use of BMCs in direct suppression of both P. oleae and D. oleae populations has progressed along four lines, namely mass trapping, 'lure and kill', mating disruption and the use of repellents, but with differing degrees of success in each case.

INTRODUCTION.

In the Mediterranean basin three major pests of olive groves predominate; the olive fly, Dacus oleae (Gmel.), the olive moth, Prays oleae Bern, and the olive black scale, Saissetia oleae (Oliv.). Significant advances have been made over the last two decades into understanding the Chemical Ecology of the first two species and a number of highly active Behaviour Modifying Chemicals (BMCs) including pheromones and allomones have been elucidated. Although the integration of such compounds into pest management strategies has not progressed as quickly as was initially expected, significant progress has been made with a number of BMCs in selected uses and examples will be given in this paper.

BMCs DESCRIBED FOR OLIVE PESTS.

The BMCs described to date for olive pests have been well reviewed recently (Delrio, 1985) and will not be repeated here. The most important compounds described to date include sex pheromones, food attractants, and plant-derived repellents. Table 1 shows that studies to characterize olive pest pheromones seem most complete while others on oviposition attractants and repellents are still in their infancy.

CONTROLLED RELEASE OF BMCs.

In most cases, insect BMCs cannot be used by themselves as pure chemicals in the field. Their high degree of volatility and their tendency to degrade chemically at high temperatures and/or direct sunlight have to be overcome. In the first case, this can be done through the use of suitable controlled release devices (CRDs) and in the second case, with antioxidants. The CRDs used with olive pest BMCs vary according to the way those compounds are to be used in the field. To lure insects into traps or to a particular point within the olive grove, a single-point source is

TABLE 1. The Behaviour Modifying Chemicals of Olive Pests.

	Pheromones		Other Attractants		Repellents
Species	Sex	Oviposition Deterrent	Food	Oviposition	Plant-derived
Dacus oleae	+++	-	+++	+	++
Prays oleae	+++	-	+	+	+
Saissetia oleae	No BMCs described to date.				

\- None described to date. + BMCs shown to exist.
++ Compounds partly elucidated. +++ Compounds fully elucidated.

used while BMCs which are to be dispersed over a large surface area are formulated in multi-point source CRDs.

Single-point sources

The most commonly used CRD for both D. oleae and P. oleae sex pheromones is the polyethylene vial. This has been shown to perform consistently well under field conditions for monitoring both D. oleae (Jones et al 1983 Jardak et al 1985). The release rate curve from this device does however follow first order Kinetics, i.e. the rate at which the pheromone is dispensed diminishes with time so that more pheromone is released at the beginning than at the end of a dispenser's life (Fig. 1). Recent advances in the controlled release of pharmaceuticals, however, have produced a series of polymers which give zero order release Kinetics over periods in excess of 120 days (Smith 1985). One such system, Biolure^{R} (Smith et al 1983) is currently being developed for use with BMCs in insect pest monitoring and control. It has already been shown to improve the effective lifespan of ammonium acetate in the field (Economopoulos & Papadopoulos 1985) and is currently being developed by the present authors for use with both D. oleae and P. oleae pheromones.

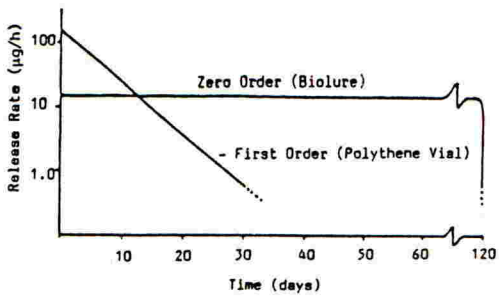

Fig. 1. Release rates of D.oleae pheromone from different dispensers.

Multi-point sources

The most commonly used multi-point source pheromone dispensers include Conrel^{R} hollow fibres, Hercon^{R} plastic laminates and microcapsules. Whereas the first two devices require specialist equipment for large scale mechanised dispersal, the latter can be applied using conventional spray equipment. All three devices, however, show first order release Kinetics so that the persistence of a volatile pheromone such as that of D. oleae in the field is limited to a few weeks at most.

CURRENT USES OF OLIVE PEST BMCs

Population Monitoring

Dacus oleae

The greatest use of olive pest BMCs to date has undoubtedly been in the field of population monitoring. Traps which rely on the fly's attraction to yellow colour have been used for a number of years to monitor D. oleae. The attraction range of such traps does not, however, exceed the limits of the tree upon which it is hung and capture efficiency is low (Delrio, 1985). However, if an attractant capsule containing the sex pheromone of D. oleae is suspended on or near such a trap then the efficiency (Jones et al 1983) and range of attraction of the trap is increased several fold (Delrio et al 1983). Yellow traps whether baited or unbaited do suffer from the disadvantage, however, of attracting non-target species which can sometimes be important parasites or predators (Neuenschwander 1982).

Non-specific olfactory attractants such as ammonium salts and protein hydrolysates have also been used as attractants in McPhail traps. Such traps have a higher capture efficiency than the unbaited yellow traps (Economopoulos 1979; Katsoyannos 1983) but can vary during the season or with humidity changes (Delrio 1985). Although the McPhail traps capture insects other than Dacus oleae they are more selective than yellow traps and less detrimental to beneficial species (Katsoyannos 1983).

Improvements in trap design can help reduce the problem of non selectivity and lack of consistency to some extent. Sticky traps can be used which do not have colours or shades which are attractive to beneficial insects (Haniotakis et al 1982) or, alternatively, the sticky surface can be oriented in such a way that it selectively attracts D. oleae. (Jones et al 1983). Similarly, McPhail traps which incorporate a sticky coating on the outside (Zervas 1982) or a yellow coloured base (A. Montiel Bueno, unpublished data) attracts more consistently during the whole year round.

Successful use of such monitoring systems can give the following information:

1. presence or absence of the pest.

2. sex pheromone traps demonstrate the exact period of renewed sexual activity in D. oleae in early summer when the olives reach sufficient size for oviposition. This is the optimal period for commencement of spray treatments. (Delrio, 1985).

3. correlations can be obtained between trap catches and infestations (Ballatori et al 1980; Crovetti et al 1983) so that spray thresholds can be established (Delrio, 1985).

4. the effectiveness of insecticide treatments against adults can be measured directly from pre and post treatment catches.

Prays oleae

Delta traps baited with the female sex pheromone (Z-7-tetradecenal) of P. oleae are very efficient and selective and have become widespread in their use. Several years of study on trap design and placement at Granada, Spain and other locations have shown that the traps take accurate representative samples from the population (Pralavori et al 1981; Ramos et al

1985). Generation peaks can be clearly defined and control measures, where required, can be applied at the optimal time (Jardak et al 1985). Attempts at establishing a correlation between infestation and trap catches during the flight of adults which give rise to the flower and fruit generations of the moth have proved very difficult. Correlations can be obtained between trap catches and numbers of eggs laid in many years (Ramos et al 1981) but one year in five often falls outside the general pattern. This would appear to be the result of late ripening of the fruits and the consequent inability of gravid females to lay their eggs (P. Ramos, unpublished data). Attempts at correlating trap catch with larval infestations have similary been problematic due primarily to the effects of egg predators which can modify the degree of larval infestation to varying extents from year to year (Campos & Ramos, 1985). Means of measuring accurately the effects of egg predators are now being developed at Granada which, coupled with trap catch data, crop development observations and yield estimates, will provide an accurate risk assessment of P. oleae damage which can be used in turn to evaluate the need and cost effectiveness of control measures.

Suppression of Pest Populations

Mass trapping

By employing suitable densities of BMC-baited traps, population suppression can be achieved by male and/or female annihilation. Whereas mass trapping experiments with Prays oleae have not given satisfactory results, those with Dacus oleae have looked more promising. Unbaited yellow sticky traps have been used successfully for D. oleae control in both small and large groves (Economopoulos, 1980). Several traps per tree are needed for this to succeed, however, making the technique both uneconomic and highly detrimental to the beneficial insect population. The density of traps required can be reduced if an olfactory lure is included with it. Experiments carried out in Sardinia have shown that using one Rebell yellow trap per tree baited with protein, ammonium carbonate and pheromone, good control can be achieved in years of high olive yield and small D. oleae populations, but in years of low yields, the results are less satisfactory (Delrio, 1985). In Greece, using a density of one trap, baited as above, per nine trees it was possible to reduce the number of spray applications in a grove of 10,000 trees from 3 to 1 (Broumas et al 1983).

Using yellow traps baited with pheromones only has not, however, proved very effective in controlling D. oleae when compared with experiments combining both pheromones and food attractants (Haniotakis et al 1982). This would imply that a sufficiently high proportion of males is not being removed from the population for females to be left unfertilised. Delrio (1985) found that pheromone baited traps caught 25% of released males within 24 h of release which is a reasonable figure when the natural dispersive tendency of the fly is taken into account. Recent work done in the U.S.A. with Lepidopteran pheromones has shown up the most inefficient facets of pheromone traps (Cardé et al, pers. comm.) It appears that the efficiency of recruitment of moths to a pheromone plume emanating from a trap with subsequent orientation up the plume to within 0.5m of the source is at least 95% efficient, whereas actual entrapment in or on the trap can vary enormously and is usually very low. Very few observational studies have been made in the field on the final approach behaviour and subsequent entrapment of flies responding to olfctory traps. This aspect will require thorough investigation and improvement before mass trapping can be successfully established as a control strategy for D. oleae.

Lure and kill

This technique, sometimes referred to as 'attracticides', overcomes to a great extent the problems of low entrapment efficiencies mentioned above. Again the insects are lured by olfactory attractants towards the odour source but instead of trapping the responding insects using some form of entrapment device, the insects land on surfaces near the odour source which have been treated with insecticides. This concept is not new, of course, in that bait sprays have been used for many years against D.oleae and other tephritid fruit flies (Nadel 1966); protein hydrolysates mixed with insecticides and sprayed in strips can give very effective control of D.oleae in most cases but it can often be very detrimental to beneficial insect populations which also respond to the food bait. For this reason, it has been discontinued in some countries. Experiments carried out in Spain over the last two years (Montiel Bueno & Mata 1985) have shown, however, that when the protein hydrolysate is replaced by a suitably formulated sex pheromone attractant then the problem of cross attraction of beneficial insects is avoided. Moreover, using hand applications of this insecticide and pheromone mixture, the degree of D.oleae control was similar to that obtained with the original bait sprays. Aerial applications of the mixture are currently being carried out to see if comparable results can also be obtained using this application method.

Mating disruption

The possibility of disrupting the mating process of lepidopteran pests using their sex pheromones is now well established and several attempts have been made to apply this technique to Prays oleae. Experiments in Spain, Italy and France have shown, however, that this technique works only when populations are low, i.e. usually during the first flight of adults in any season (Civantos & Simon, unpublished data; Cirio & Menna 1985; Arambourg 1985). It is suggested that since populations are significantly higher during the second flight of adults then random encounters between adults would be sufficient to ensure sufficient fecundity in the females for infestation levels to be maintained. Both laboratory and field experiments are required however to establish the exact reason or reasons why the technique of mating disruption cannot be used with P. oleae.

Attempts have also been made in Spain to apply this technique to D.oleae. Experiments carried out during 1981 and 1982 (Montiel Bueno & Mata 1985) have shown that significant differences can be obtained between treated and control plots but that the quantity of pheromone required to produce the effect could not be maintained sufficiently high with the CRDs used at that time. The novel membrane CRDs now being developed should, however, produce the required release rates indicated from the initial field trials.

Oviposition Deterrence

Ovipositing D. oleae females are known to avoid olives where eggs have already been laid. This would appear to be a response to deterrent chemicals placed on the olives by females who have already oviposited in those fruits. Unlike other tephritid fruit flies, however, the deterrent chemicals do not come from the female herself; it has been shown that the juice which exudes from the oviposition puncture is spread over the fruit by the ovipositing female once oviposition is completed. Chemical components in this exudate would appear, therefore, to produce the deterrent effect. Several compounds have been extracted from this olive fruit exudate (Vita 1978; Orphanidis & Kalmoukos 1970; Girolami et al 1981) and field trials with some of these compounds have produced significant

reductions in oviposition by D. oleae (Fiume & Vita 1977; Girolami et al 1979). Lack of persistence and some phytotoxicity problems have been encountered, however, which will have to be overcome before this technique can be used extensively in the field. There is also a suggestion that the technique might be made more efficient if traps or lure & kill treatments are applied concomitantly so that the repelled insects do not disperse into neighbouring olive groves and aggravate the D. oleae problem there (Delrio 1985).

Although it has been shown that there are factors which control the onset of oviposition by P. oleae onto fruits, none have been isolated to date, but this line of research could also produce good oviposition deterrents for P. oleae.

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METHODS FOR THE ROUTINE SCREENING OF ACARICIDES AGAINST THE CITRUS RUST MITE PHYLLOCOPTRUTA OLEIVORA (ASHMEAD) (ACARI: ERIOPHYIDAE).

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ABSTRACT

This paper describes work carried out at the University of Florida in 1985 and 1986, to develop methods for checking the efficacy of acaricides against Phyllocoptruta oleivora in the laboratory. Methods for culturing and handling these rust mites were developed and results obtained with 2 standard acaricides, amitraz and dicofol, using spray and dip tests. Particular attention has been given to the problems encountered with this technique.

INTRODUCTION

Over 1250 species of mites in the superfamily Eriophyoidea have been described and include the rust, bud, gall, and blister mites (Keifer et al. 1982). Several eriophyids are important pests of various crops throughout the world. Eriophyids tend to have limited host ranges with many restricted to a single host plant species. The citrus rust mite, Phyllocoptruta oleivora (Ashmead) (Acari: Eriophyidae) is a particularly important species that attacks citrus in many countries. This mite is the most important arthropod pest occurring on Florida citrus. The citrus rust mite and spider mites on citrus account for approximately 40% of the total acaricide usage in the United States.

The citrus rust mite is approximately 150 to 165 microns in length (Jeppson et al. 1975). The life cycle consists of an egg stage, two motile nymphal stages, two quiescent chrysalis stages, and the adult male or female. Development rate for eggs and immatures is at a maximum at 26-28 °C (J.F. Allen, unpublished data). Females on average lay 10.7 eggs with a maximum of 26 eggs during their lifespan. Egg development is completed in 2 to 4 days at 26 °C (Swirski and Amitai 1958; 1959).

The citrus rust mite is very difficult to rear in the laboratory for extended periods due to cyclic population fluctuations, restrictive environmental requirements, including temperature and water vapour concentration (Hobza and Jeppson 1974; Allen and Syvertsen 1979), availability of a constant food supply (i.e. immature green citrus fruit), the minute size of the mite itself, and the occurrence of a pathogenic fungus, Hirsutella thompsonii Fisher that parasitizes the mite.

The efficacy of chemical acaricides is usually investigated using laboratory cultures of the two-spotted spider mite, Tetranychus urticae Koch or another closely related species. However, it is inadvisable to extrapolate findings between tetranychid and eriophyid mite species. Eriophyid mites have not been used in such screening tests owing to difficulties in rearing and handling these small arthropods, although some researchers have, in the past, developed appropriate techniques (Hobza and Jeppson 1974; Oldfield et al. 1970; Reed et al. 1964).

This paper sets out to describe methods for maintaining citrus rust mites in the laboratory between May and August (the time when they are abundant in Florida groves) and for the routine laboratory testing of acaricides against them during this time period.

MATERIALS AND METHODS

Citrus rust mite culture

Small to medium sized immature citrus fruit (3.5–8 cm diameter) infested with P. oleivora were collected in the field and placed in a 61 x 41 x 30 cm plastic tank in the laboratory. The lid was kept open 5 to 6 cm for air exchange. New fruit were added and older, dehydrated fruit removed once a week. High mite infestations reportedly failed on yellow, maturing fruit or on fruit 2.5 to 3.5 weeks past excision (Hobza and Jeppson 1974).

Preparation of test fruit

Fruit, 3.5 to 7.0 cm in diameter (immature 'Hamlin' orange) and free from rust mite attack, were collected by cutting the stem of each fruit with pruning shears. These fruit should be used the following day for pesticide evaluations of the citrus rust mite to ensure consistent fruit quality. Hobza and Jeppson (1974) reported that maturity and age of fruit after excision are important considerations.

In 1985, the fruit were dipped in 0.15% copper sulphate solution for 60 seconds to inhibit the growth of the fungus Hirsutella thompsonii. Clear plastic drinking straws (6 mm diameter) were cut into 0.5 to 1 mm lengths and a single such section placed on the upper part of the fruit. Each fruit was then dipped in molten paraffin wax leaving a small area free of wax within the drinking straw area. This method sometimes failed to confine the motile mite stages and was very time-consuming.

In 1986, copper sulphate was replaced with 95% ethanol due to accelerated breakdown of copper treated immature fruit due to stem end rots (E.F. Hopkins, unpublished data). Larger areas of fruit (approximately 2 to 3 cm^2) containing the desired numbers of eggs were circled with India ink, before dipping in the paraffin wax. Squares were then drawn with India ink within this test area to facilitate locating eggs or other mite stages (Swirski and Amitai 1957). Fruit to be used in dip tests were not waxed until after drying following the pesticide treatment. Fruit to be sprayed were waxed before pesticide treatment. The wax-free arenas in both sets of fruit were lightly ringed with a Canada balsam-castor oil mixture (ratio 1.5:1). The mixture was applied on the edge of the wax surface to prevent escape of the mites immediately following waxing (Swirski et al. 1967).

Individual test fruit were held in glass covered deep Petri dishes (100 x 80 mm). Each fruit was placed on a 34 mm (i.d.) PVC pipe section 1.5 cm in length. Water was added to each Petri dish to an approximate depth of 1 cm. Care was taken to ensure that the water level in each dish did not contact the fruit.

The mite culture and individual experiments were held in the laboratory on bench tops at 26 °C ± 1 °C with a 14:10 (l:d) photoperiod.

Infesting the test fruit

Citrus rust mites were brushed from the surface of a culture fruit into the test area on each fruit. The test fruit were then checked under a stereomicroscope to ensure that sufficient healthy motiles (20-60) had been transferred. These fruit were then ready for treatment or left for 1 or 2 days to allow egg numbers to increase.

Dipping all test fruit in 95% ethanol for 30 - 60 seconds results in mortality of all motile stages of the citrus rust mite while the eggs remain viable (Reed et al. 1964; McCoy 1978). This practice was initiated in 1986, and was found to be particularly useful in establishing a population of known age and structure. In previous tests, motile stages were removed by means of a microbrush made from a single human hair. This process was too laborious.

Chemical treatment of fruit

Fruit were either dipped into or sprayed with the test solutions. Fruit that were dipped in pesticides for evaluating effects on motile citrus rust mite stages were not infested until after treatment to avoid washing off mites from the treated surface. Pesticide dip tests of eggs and all spray tests were infested prior to treatment. The numbers of eggs, nymphal stages or adults within each arena were recorded prior to treatment to give the precount in these tests. The individual test fruit were left uncovered in individual glass, deep Petri dishes for 24 hours and then covered. With this method unwanted spider mites got onto the test fruit. The latter procedure should be amended by placing a fine screen cloth over the dishes to prevent possible airborne contamination by mites other than the citrus rust mites. Water pH was 7.4 in all tests conducted in 1986.

Assessments

Numbers of eggs and living motile stages were recorded in the different tests. A chrysalis stage which appeared turgid and shiny was classified as 'living'. Adult and active nymphal stages were considered alive if movement of body or appendages was observed following prodding with a single-hair brush. It was not feasible to record dead motiles as these could not be distinguished from general debris on the fruit surface.

RESULTS AND DISCUSSION

Population growth of citrus rust mite in the laboratory

A mixture of adult and nymphal stages were brushed into the wax-free areas on each of 8 fruit in total. Regular counts were then made of the living motile stages present. The results obtained show that citrus rust mite populations can establish and grow on immature green citrus fruit maintained under these conditions. An estimated population growth rate, K (K = N/No, where No is the initial number of mites and N is the number of mites at the end of one generation, egg to egg) was calculated (Hobza and Jeppson 1974). In this particular test study a K value of 2.4 was determined. In a series of tests in 1986 a range of K values (1.56 - 5.65) were determined for untreated rust mite colonies. Hobza and Jeppson (1974) recorded K values of less than 1 to greater than 9.0, dependent on temperature and humidity.

1985 test results with amitraz

Adults were transferred to test fruit and left for 2 days to oviposit. After this period, the adults were removed and the number of eggs recorded before treatment. Some of the fruit were dipped in 100 ppm amitraz, others were sprayed.

Table 1 illustrates the efficacy of the treatment as well as the validity of the test. The results show the effectiveness of amitraz in killing citrus rust mite. Whether the compound kills the eggs or larvae emerging from eggs cannot be determined with this type of test.

TABLE 1

Ovicidal/larvicidal activity when the eggs of the citrus rust mite are treated with amitraz.

Treatment	Dosage (ppm)	Number of* eggs per fruit before treatment	Number of living* larvae per fruit 3 days after treatment
Amitraz (dipping)	100	71	0
Amitraz (spraying)	100	71	0
Water check (dipping)	0	54	41
Water check (spraying)	0	32	27

* Mean of three replicates.

Fruit treated with amitraz were infested with a mixed population (20-60 per fruit) of adult and immature stages. Regular counts of all live stages were made (Table 2). Amitraz killed all the citrus rust mites in the test in less than 24 hours.

TABLE 2

Residual activity of amitraz against motile stages of the citrus rust mite.

Treatment	Dosage (ppm)	Mean* number of living motiles per fruit 1 DAI**	3 DAI	7 DAI	9 DAI	12 DAI
Amitraz	100	0	0	0	0	0
Water check	0	19.6	19.8	42.4	31.4	14.4

* Mean of five replicates
** DAI, Days after infestation

1986 test results with dicofol

Dicofol 4MF was selected for the further development of the test procedures for determining acaricidal activity against the citrus rust mite. This product is widely used within the citrus industry of Florida for eriophyid and tetranychid mite control.

Table 3 shows that dicofol has no ovicidal activity at dosage rates up to 400 ppm. One test at 1000 ppm did show some such activity. Another feature of the acaricidal action of dicofol in its slow activity. Very little dose response was evident two days after treatment, but this became more evident after 6 days.

TABLE 3

Activity of dicofol applied as a 30 second dip against the eggs of citrus rust mite, (2 tests pooled)

Dosage (ppm)	Mean number of eggs per five fruit before treatment	% Hatch 2 DAT**	% motile mortality* 2 DAT	6 DAT
0	69	38	-	-
10	65.5	27	33	64
40	78	26	32	45
80	78	30	24	44
200	80	27	33	72
400	63.5	25	43	93

* Mortality values calculated with the Tilton-Henderson equation
** DAT, Days after treatment

Sprays of dicofol onto motile stages showed slightly better activity after two days (Table 4).

TABLE 4

Activity of dicofol applied as a spray against motile stages of citrus rust mite (4 tests pooled)

Dosage (ppm)	% motile mortality*			
	2 DAT	5 DAT	6 DAT	8 DAT
0	-	-	-	-
10	39	48	54	53
40	68	60	74	99
80	81	67	55	95
200	87	87	91	100

* Mortality values calculated with the Tilton-Henderson equation

One or more higher concentrations of dicofol should have been evaluated in the spray test to obtain a more conclusive mortality approaching complete kill. Most of the remaining living motiles in the 80 and 200 ppm rates consisted of recently emerged first stage nymphs. This supports the lack of ovicidal activity of dicofol at the rates tested. Unfortunately, this same situation was responsible for much of the variability within a given test.

A dosage response was evident with both dip and spray procedures using dicofol. The toxic effects of dicofol to the citrus rust mite were more conclusively shown at 5 or 6 days after spraying versus the 2 to 3 day interval. More acaricides must be evaluated to further refine the procedure.

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FURTHER EVIDENCE FOR A FEMALE SEX PHEROMONE IN THE BLACK CURRANT LEAF MIDGE *DASINEURA TETENSI*

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ABSTRACT

A field experiment was done to demonstrate the presence of a pheromone in the blackcurrant leaf midge, (*Dasineura tetensi*) (Diptera : Cecidomyiidae). The experiment showed that traps containing virgin females caught large numbers of males, but traps containing virgin males were unattractive to males or females.

INTRODUCTION

The blackcurrant leaf midge (*Dasineura tetensi*) is a serious pest of blackcurrants in most areas of England in which they are grown (Alford, 1984). It also occurs in Germany and Finland (Barnes, 1948). Adult females lay their eggs on the growing tips and lateral buds and as the larvae feed the leaves become twisted and rolled. When fully developed, larvae drop to the ground and, depending on the time of year, either pupate or spin a silken cocoon in which they diapause. In this country there can be three, possibly four generations a year and there do not appear to be any alternative hosts (Barnes, 1939. Alford, 1984).

Present control measures are aimed at the larvae but, because of the phenology of the plant insecticidal protection is only complete for one week. Spray timing is currently based on the examination of plant material for developing larvae. Local detection of emerging adults would ensure that cover could be applied before oviposition occurs.

Early work showed that the presence of a female elicited pre-copulatory behaviour in the male resulting in copulation (Barnes, 1939). Following the success of preliminary investigations into the sex pheromone of the female pea midge, *Contarinia pisi* (Wall *et al.*, 1985), an attempt was made to trap blackcurrant midge using live virgin adults. The aim of the experiment was to evaluate the possibility of using traps as a species-specific monitoring system for adults. A successful monitoring system could be used in a similar way to the sex-attractant monitoring system for the pea moth, (*Cydia nigricana*) (Biddle *et al.*, 1983; Lewis *et al.*, 1975; Macaulay, 1977; Wall & Greenway, 1981). The following account indicates the presence of a female sex pheromone.

MATERIALS AND METHODS

Insects used as lures for field experiments were reared from diapausing cocoons collected in Kent during February 1985. Soil containing cocoons was stored in the dark, at 5°C. Prior to collection it had been subjected to normal field conditions. After six weeks the soil was washed, sieved and the cocoons were floated out in a saturated solution of magnesium sulphate. The cocoons were then rinsed with distilled water and placed on 3 cm of damp silver sand in glass tubes 3 cm in diameter and 7.5 cm high. The tubes were stoppered with cotton wool and placed at 23°C in a L16 : D8 regime.

The field experiment was set out in a blackcurrant field in Kent, in which adult midges were emerging. Traps were of the delta water type used for *C. nigricana* (Wall and Perry 1980) and were initially used at mid crop height (50 cm), although following behavioural observations the traps were placed on the ground.

Virgin male and female lures consisted of 5 adults caged in open ended glass tubes (Batiste, 1970; Lewis *et al.*, 1975) supplied with water. A control delta water trap was also included in each replicate. There were five replicates spaced 5 m apart. The three treatments were randomised within each replicate and spaced 5 m apart. Traps were placed within the rows of blackcurrant bushes by 21.30 hrs and collected at 15.15 hrs the next day.

RESULTS

Adult emergence from the collected cocoons started after six days at 23°C and continued for a further seven days. A total of 506 adults emerged of which 52% were females.

Traps containing virgin females caught substantially more adult males than did the control traps or traps containing virgin males (Table 1); only one adult female was caught. When the virgin female traps were at mid-crop height, they attracted males to the immediate area and these could be seen walking and flying above the soil surface. At no time did any of the males fly to the traps, even in the sheltered area between bushes, until the traps were placed at ground level.

TABLE 1 CATCHES OF *D. TETENSI* IN TRAPS CONTAINING VIRGIN ADULTS 9/5/85

REPLICATE	TREATMENT					
	CONTROL		VIRGIN MALES		VIRGIN FEMALES	
	F	M	F	M	F	M
1	0	4	0	2	0	19
2	1	7	0	6	0	32
3	0	4	0	1	0	93
4	0	4	0	1	0	25
5	0	0	0	5	0	7
x̄	0.2	3.8	0	3	0	35.2

DISCUSSION

Although the experiment was done on only one day at a single site the results strongly indicate the presence of a female sex pheromone. It is interesting to note that it was only when the traps were placed on the ground that males were caught in the traps. Catches of adult male midges would probably have been higher if the traps had been placed at ground level throughout the experiment.

The use of a female pheromone to monitor populations of adult male blackcurrant midge would be an invaluable aid to growers and advisory bodies. However, this would involve a commitment to the isolation, identification and synthesis of a pheromone and the development of a more convenient design of sticky trap.

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CHEMICAL CONTROL OF BLACKCURRANT LEAF MIDGE USING FENPROPATHRIN

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ABSTRACT

Fenpropathrin, at 100 g ai/ha in 1000 litres of water which is likely to control blackcurrant gall mite also controlled blackcurrant leaf midge. At 50 g ai/ha fenpropathrin also worked well against leaf midge. The insecticide protected blackcurrant plants against egg-laying and in addition seemed capable of killing D. tetensi larvae inside small convoluted leaves.

INTRODUCTION

Blackcurrant leaf midge (Dasineura tetensi, Rübsaamen) has become more widespread and serious in Kent since the withdrawal of DDT in 1981 (Harris and Wardlow, 1984). Adult midges emerge from their overwintered cocoons during April/May. It may take 6-7 weeks for most of the first generation to emerge, resulting in prolonged infestation pressure, which frequently runs on through to subsequent generations. The crop is therefore likely to be under continuous attack from April to July. The recommended treatments are HV sprays of a mixture of azinphos-methyl and demeton-S-methyl or demeton-S-methyl alone. The most commonly used insecticide is fenitrothion although it has no label recommendation. Chemical treatments are applied when the first "mature" white larvae are seen in distorted or convoluted leaves, usually seen about 10-14 days after egg-laying.

During 1985, observations on the effect of fenpropathrin (Meothrin) on blackcurrant pests (L R Wardlow, unpublished data) indicated that this insecticide might be effective against leaf midge and the work reported here was designed to test the efficacy of fenpropathrin and to attempt to ascertain how it worked.

MATERIALS AND METHODS

Observations were made in 1986 in a 5 year old blackcurrant plantation (Cultivar Baldwin) in Kent. The crop was grown in 3 m wide rows with 0.6 m between bushes in the rows giving 5445 bushes/ha. Bushes were pruned to the ground in autumn 1985 and the trials were conducted on the regrowth, which is known to be very susceptible to attack by leaf midge. Each plot consisted of ten bushes arranged in four randomised blocks. Two treatments of fenpropathrin were compared with fenitrothion and untreated controls.

Treatments

A. Fenpropathrin as the 10% EC formulation was used at 100 g ai/ha applied at first flower, in a volume of 953 l/ha on 2 May. A second spray was applied at the end of flowering (3 June) at a higher volume (1905 l/ha) and a third spray two weeks later (19 June), also at 1905 l/ha.

B. HV spray of fenpropathrin at half the rate of treatment A applied on 2 May and subsequently whenever the larval infestation justified treatment.

C. Fenitrothion (50% EC) HV spray at 460 g ai/ha applied whenever larval infestation justified treatment ie., 19 May, 19 June, 6 July, all at 1905 l/ha.

D. Untreated controls. All timings were based on adjacent unpruned crops.

Observations on larvae treated with fenpropathrin

On 27 June when plots of other experimental treatments were abandoned the infestation of larvae of leaf midge was allowed to develop and treatments A and B were applied to each of four plots. Five days later larval mortality was assessed by looking at 25 damaged leaves from each plot (including the untreated controls) at X50 magnification with a binocular microscope.

Assessment of larval damage

On 22 July the lowest 15 leaves on five shoots from the central five branches of each plot were scored for larval damage using the categories in Table 1.

TABLE 1

Categories of leaf damage by blackcurrant leaf midge larvae.

Category	Score	Description of damage
Nil	0	No leaf distortion
Slight	1	Slight distortion but leaf shape or colour not affected
	2	Slight distortion, leaf shape affected but colour still green.
Moderate	3	Considerable distortion and leaf mishappen but still green.
	4	Considerable distortion, leaf mishapen and curled, some necrosis.
High to severe	5	Considerable distortion, partial leaf death
	6	Total leaf death.

The percentages of leaves in each damage category were calculated and the data were subjected to logit transformation for analyses; logit = 0.5 log (% ÷ (100-%)).

RESULTS

Leaf damage

Assessments showed that fenpropathrin (at both rates tested) protected foliage against leaf midge. At the higher rate the first signs of damage did not appear until the first week of June (ie., four weeks after treatment). More than 90% of the leaves were undamaged or only slightly damaged throughout the period of the experiment (Table 2).

TABLE 2

Effect of fenpropathrin on Blackcurrant Leaf Midge (logit transformation of percentage of leaves damaged (actual percentage in parenthesis).

Treatment	Damage category			
	Nil	Slight	Moderate	High-Severe
Fenpropathrin 0.1 g ai/l	0.94(87.0)	-1.08(10.1)	-1.87(2.2)	-2.30(0.7)
Fenpropathrin 0.05 g ai/l	0.74(81.4)	-0.95(13.3)	-1.52(4.5)	-2.31(0.8)
Fenitrothion 0.46 g ai/l	0.17(58.7)	-0.61(22.7)	-1.04(10.9)*	-1.32(7.8)*
Untreated	-0.50(27.1)	-0.82(16.2)	-0.95(12.8)	-0.13(43.8)
SED	0.29	0.18	0.41	0.47

* Although this leaf damage was extensive it should be noted that the only commercially available insecticides are larvacidal, and give only a few days protection against adult midges. At this stage the crop may seem to be badly affected, but in fact good control of larvae has been obtained.

Effect of fenpropathrin on larvae

Because fenpropathrin prevented egg-laying few larvae were present at any time, so assessments were conducted to check the effect of the insecticide on larvae (see Materials and Methods). Results are given in Table 3.

TABLE 3

Effect of fenpropathrin on blackcurrant leaf midge larvae inside distorted leaves.

Treatment	Nos. of Larvae per 25 distorted leaves					
	Dead			Live		
	Small	Medium	Large	Small	Medium	Large
Fenpropathrin 0.1 g ai/l	36.0	27.3	14.3	0	0	0
Fenpropathrin 0.05 g ai/l	42.5	17.8	5.0	0.3	1.0	0
Untreated	0.5	0.5	0	44.5	43.0	29.7

Fenpropathrin clearly penetrated foliage and had killed larvae inside the convoluted leaves. The small proportion of medium or large-sized larvae in treated leaves suggested that the treatments may act as a repellent.

DISCUSSION

Fenpropathrin possesses both preventative and curative activity against blackcurrant leaf midge and the spray-programme being developed against gall mite will also protect against leaf midge. The length of control is especially important during the flowering period when other

insecticides would be harmful to bees. Protection by fenpropathrin lasted for four weeks during this experiment but it is not known if this period would be reduced or extended in warmer seasons. The lower rate of fenpropathrin was highly effective against leaf midge and may be applied either before or after the gall mite programme should the midge attack begin early or be unexpectedly prolonged.

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HEXACONAZOLE: A NOVEL FUNGICIDE FOR USE AGAINST DISEASES ON VINES

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ABSTRACT

Hexaconazole, 'Anvil', is a new systemic triazole fungicide with excellent protectant, curative and translaminar activity against vine powdery mildew and black rot. It is applied at very low rates. Its outstanding curative action provides additional flexibility and insurance against sub-optimal applications.

INTRODUCTION

Hexaconazole is a new triazole fungicide for the control of powdery mildew (Uncinula necator) and black rot (Guignardia bidwellii) of vines. The broad-spectrum antifungal activity exhibited by hexaconazole and its physical, chemical and environmental properties are described by Shephard et al. (1986), in this conference.

Uncinula necator is a serious pathogen of vines in all major vine growing countries. In Europe it is particularly prevalent in the South and South-West of France, Italy and Spain. The fungus can attack the vine foliage, stems and flowers and bunches remain susceptible until the ripening process begins. The fungus overwinters as dormant mycelium in infected buds or as ascospores in cleistothecia, resident in crop debris. Early season infections are particularly important and if left unchecked cause considerable reduction in fruit yield and quality. Consequently, control measures are applied prior to secondary infections from an early stage of vegetative growth. Sulphur is still used extensively, but in many parts of Europe it is being superseded by the triazole fungicides. These fungicides offer the advantages of a lower application rate, combined with an extended spray interval, as a result of their re-distribution within the vine and curative action.

Guignardia bidwellii is a pathogen of the vine found in areas of higher rainfall, for example, in the South-West of France. It survives the winter on crop debris, primarily as perithecia. The first contamination of the vine is associated with periods of high rainfall and leaf wetness. Pycnidia, released by rain and splash dispersed, infect early vegetative growth. Pycnidiospores, from these lesions, infect fruits at flowering and may infect berries until ripening, causing rotting and desiccation.

Current control measures utilise preventative applications of phthalimide or dithiocarbamate fungicides. A mixture of triadimefon, propineb and cymoxanil is the commercial standard in France.

MATERIALS AND METHODS

Glasshouse studies

Hexaconazole was tested as a 5% w/v suspension concentrate (SC) formulation for the control of U. necator. Young vine seedlings grown in 4cm diameter pots or potted on to 8cm diameter pots were used in all tests. The 5% SC, appropriately diluted with water, was applied to maximum retention as a foliar spray using a Devilbiss spray gun at 10 psi; as a root drench by syringe to the compost at a volume of 10ml/4 cm pot or as a stem application using a camel hair brush. When chemical was applied prior to inoculation, plants were incubated at 24°C, 60% r.h., 16 h day; 17°C, 95% r.h., 8 h night, until inoculation.

Plants were inoculated by shaking 1 day old spores from infected stock plants onto the adaxial leaf surface. Test conditions are given below (Table 1). Treatments were replicated 3 or 4 times and completely randomised during incubation. Assessments of percentage leaf area infected were made 7 to 10 days after inoculation.

TABLE 1

Glasshouse test conditions

Test type	Point of chemical application	Days between chemical application and inoculation	Incubation temperature (°C)
Protectant	Leaf adaxial	+1	20 - 26
Protectant	Leaf adaxial	+4	20 - 26
Systemic	Soil	+13	20 - 21
Curative	Leaf adaxial	-4	17 - 26
Translaminar	Leaf abaxial	-2	20 - 26

Stem mobility test

Additional wetter (0.05% w/v Tween) was added to the chemical to facilitate application. Chemical was applied to the mid-stem of young vine plants growing in 8cm pots, 2 days after inoculation. The leaf above the point of application was assessed 8 days after application.

Penetration studies

Chemical was applied to the adaxial surface of leaves of young vines 2 days after inoculation. Chemical was washed from the leaves with a high volume water spray 1, 2, 4 or 6 h after treatment. Disease on these treatments was compared with an unwashed control 8 days after application.

Field studies

Vine trials were laid out as randomised blocks with centralised guard rows between blocks. There were 4 replicates per treatment. The first 2 or 3 chemical applications were made with a high volume knapsack sprayer (300-700 l/ha); later applications were made with a low volume, pneumatic, mistblow system (180-210 l/ha). The concentration of low volume applications was increased to provide the same rate/ha as conventional equipment operating at a volume of 1000 l/ha. Plot sizes were sufficient to assess 100 bunches and 100 leaves on 15 different shoots. Assessments of leaf or bunch infection were made as appropriate and the data analysed using a Fisher protected t-test. In crop safety trials 3 to 5 high volume applications were made before and during flowering at rates of 2.0 to 4.0 g a.i./hl. Phytotoxicity assessments were made on bunches and leaves 10 days after each application. In a number of trials bunches were harvested for residue analysis and fermentation studies. These trials received 8 to 9 application per season at rates of 1.5 to 2.0 g a.i./hl.

Powdery mildew trials

Contamination of all trials was natural. Initial sprays were applied at the first 'Avertissement Agricole' warning bulletin or the 3 to 4 leaf stage. Sprays were applied every 14 days until just before ripening. Details of a trial in the USA to test the curative action of hexaconazole are given in Table 6.

Black rot trials

Vines at Barsac, Vendeuvre and Tours were artificially contaminated by suspending infected mummified fruit from the training wires.

Application schedules varied between sites. At Barsac applications commenced at the 4/5 leaf stage and continued every 14 days; 8 applications were made in total. At Vendeuvre and Tours application frequency was related to climatic conditions. After heavy rainfall, with a high risk of infection periods, spray intervals were reduced.

At Tours, 13 treatments were made from the 2 leaf stage at 8-14 day intervals with a mean of 11 days between treatments. At Toulouse, 8 treatments were made from the 4 leaf stage at 12-16 day intervals with a mean of 14 days between treatments. At Vendeuvre, 11 treatments were made with a mean of 10.7 days between treatments.

Different treatment regimes reflect differences in disease pressure between sites. At Toulouse the first application was made 6 days after an infection period, providing an opportunity to assess the curative activity of hexaconazole. In all other trials sprays were applied preventatively.

RESULTS

Glasshouse studies

Hexaconazole was more active in controlling U. necator than one of the leading triazole standards, penconazole, when applied as a 4 day curative (Fig. 1) or as a 2 day curative translaminar treatment (Fig. 2) in the glasshouse. Dose responses for 1 and 4 day protectant tests were similar (Fig. 3), indicating that hexaconazole has excellent persistence over this period and re-distributed effectively in a young expanding leaf. Under glasshouse conditions young leaves are not susceptible to infection for much more than 4 days.

Figs. 1 - 4. Control of Uncinula necator with hexaconazole

Fig. 1. 4 day curative test

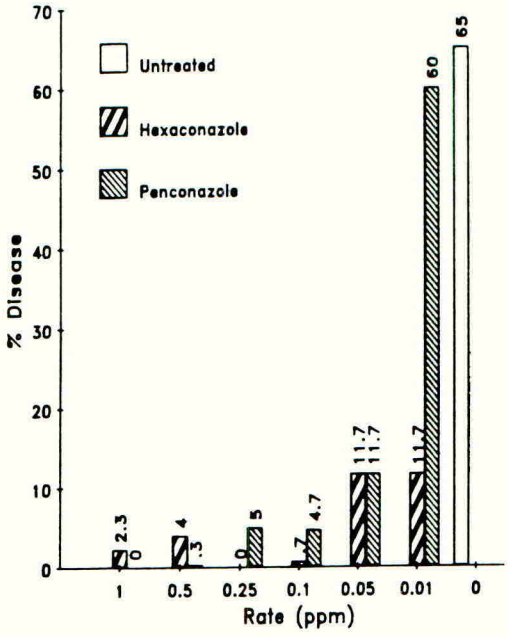


Fig. 2. 2 day curative translaminar test

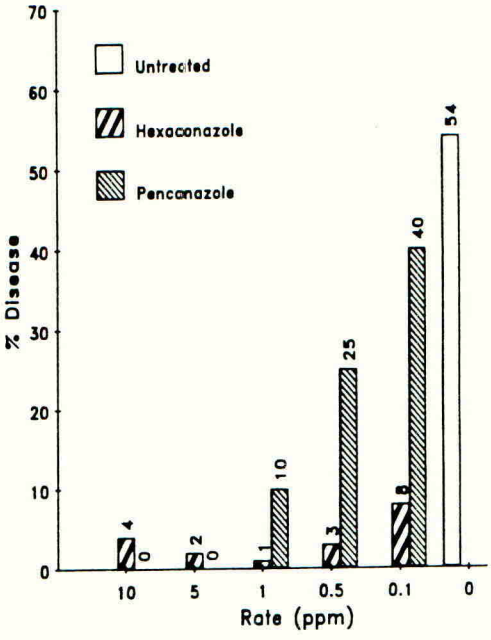


Fig. 3. 1 and 4 day protectant test

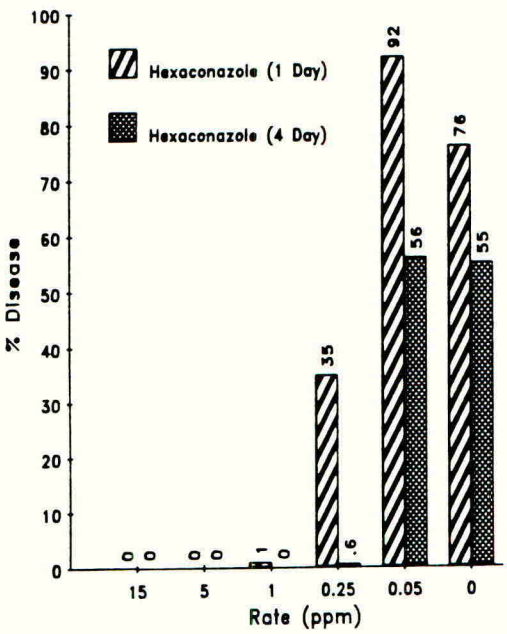
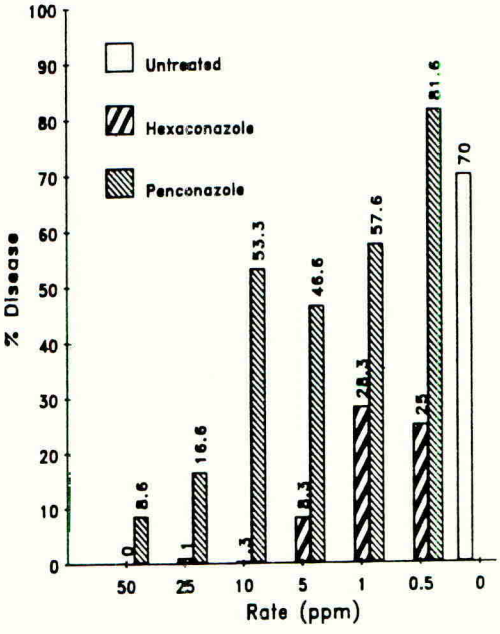


Fig. 4. 13 day systemic test



When applied to the roots, hexaconazole demonstrated excellent systemic activity, effectively protecting new growth (Fig. 4). Application to the stem at 15 ppm significantly decreased the level of disease developing on the leaf above the point of application; similar results were shown by penconazole. In penetration studies, 5 ppm of hexaconazole gave 100% disease control, despite vigorous washing 2 h after application.

Field studies

Black rot

Hexaconazole, applied at a rate of 1.5-2.0 g a.i./hl, gave excellent control of black rot in situations of high disease pressure on either a fixed 14 day interval or a variable schedule in response to infection risk periods (Tables 2 and 3).

Its performance was consistently superior to the phthalimides (folpet and captafol) and dithiocarbamate (mancozeb) protectant standards. The curative action was demonstrated at Toulouse, where the application of the first spray 6 days after an infection period resulted in a significant difference between the results with hexaconazole and those with the protectant treatments (Table 3), when assessed 14 days after the first spray.

TABLE 2

Control of black rot on artificially infected vines 1985: France

Treatment	Rate g a.i./hl	% bunches infected BARSAC[1] (I.N.R.A)[3]	No.leaves infected VENDEUVRE[2] (S.P.V)[4]	% bunches infected
		1DAT8[5]	5DAT5	8DAT10
Hexaconazole	2.0	3.0c[6]	16.0c	4.0c
Triadimefon	5.0	38.1b	-	-
Mancozeb	280.0	16.4bc	285.0b	12.5b
Untreated	-	98.6a	528.0a	98.0a

1 Spray interval, 14 days commencing 4-5 leaf stage
2 " " , 5-14 days " 4-5 " "
3 I.N.R.A. = Institut National de la Recherche Agronomique
4 S.P.V. = Service de la Protection des Vegetaux
5 1DAT8 = 1 day after the eighth spray application
6 Values in the same column followed by the same letter are not significantly different at P = 0.01

Triadimefon also demonstrated useful black rot activity, but was less effective than hexaconazole in trials at Barsac and Toulouse in controlling bunch infection (Tables 2 and 3). Hexaconazole at 2.0 g a.i./hl and the mixture of hexaconazole (1.5 g a.i./hl) with captafol and folpet were equally as effective as the commercial standard, triadimefon + propineb + cymoxanil, in all trials where they were compared (Tables 2 and 3).

TABLE 3

Control of black rot infections on vines 1985: France

Treatment	Rate[1] g a.i./hl	% bunch area infected TOURS[2] A[3]	B	TOULOUSE[2]	% leaves attacked TOURS A 13DAT6	B 13DAT6	TOULOUSE 14DAT1
Hexaconazole[4]	1.5	1.0d[5]	0.2c	16.8cd	8.3c	4.0c	0.9c
Hexaconazole[4]	2.0	0.4d	0.0c	9.0de	2.8c	3.0c	1.8bc
Hexaconazole + folpet + captafol	1.5+ 96+24	0.2d	0.0c	6.3e	4.0c	2.3c	0.6c
Folpet + captafol	160+40	10.1c	6.0b	20.7bc	26.8b	17.8b	16.0a
Triadimefon	5.0	-	-	28.7b	-	-	4.2b
Triadimefon + propineb + cymoxanil	5.0+ 145+12	0.1d	0.0c	7.6e	3.5c	2.0c	5.7b
Mancozeb	280	21.8b	8.0b	30.7b	30.0b	16.3b	17.6a
Untreated	-	74.3a	87.4a	60.0a	82.0a	80.0a	14.0a

1 Sprays commenced at the first Avertissements Agricole warning and thereafter at 8 to 16 day intervals
2 Assessments made prior to harvest
3 A and B represent different trials in the same area.
4 5% w/w soluble grain formulation
5 P = 0.05

Powdery mildew

When used as a preventive treatment on a 14 day interval, hexaconazole demonstrated outstanding control of powdery mildew on vine foliage and fruit (Tables 4 and 5). In all powdery mildew trials hexaconazole compared favourably with leading systemic standards. In Trial D, France 1985 (fruit infection) and Trial B, France 1985 (foliage infection), hexaconazole was significantly more effective than triadimefon and fenarimol respectively. Hexaconazole was consistently superior but not significantly so in all cases to a treatment with sulphur (Tables 4 and 5). In two trials where the rate of hexaconazole was increased by 50% after flowering, almost complete disease control was achieved (Table 4).

Excellent curative activity of hexaconazole against U. necator was demonstrated in the field situation (Table 6). The application rate of hexaconazole in this trial was half that registered for use in France.

Crop safety

In the last 2 years hexaconazole has been tested on 22 different varieties of wine and table grape in France. Generally no phytotoxic symptoms were observed. In a very small number of cases internode length was slightly reduced on young shoots after the first application, particularly under cooler conditions. No differences in internode length were seen later in the season. No differences were observed with respect to bunch quantity or quality.

Residue and fermentation studies

At harvest and 8 days after application the residues of hexaconazole were below the lower limit of residue detection. Fermentation studies demonstrated that hexaconazole had no effect on the fermentation process, or the organoleptic quality of the wine.

TABLE 4

Control of powdery mildew on vine fruit 1984-85: France

Treatment	Rate g a.i./hl	% no bunches infected 1984			% bunch area infected 1985			
		A 27DAT8	B 14DAT8	C 16DAT7	A 2DAT8	B 14DAT6	C 15DAT6	D 6DAT5
Hexaconazole[1]	1.5	0.0c[2]	0.5c	12.5b	0.1b	-	-	0.4c
Penconazole	1.5	0.0c	2.0c	24.0b	0.9b	-	-	0.6c
Sulphur	1000.0	17.3b	36.0b	15.0b	1.4b	-	-	-
Triadimefon	5.0	-	-	-	-	-	-	9.6b
Hexaconazole	1.5-2.25[3]	-	-	-	-	0.0b	0.1b	-
Penconazole	1.5-2.5[3]	-	-	-	-	0.0b	0.1b	-
Fenarimol	1.2-1.8[3]	-	-	-	-	0.2b	2.0b	-
Untreated	-	68.0a	88.0a	98.7a	59.0a	31.0a	64.7a	71.0a

1 5% w/v suspension concentrate formulation
2 $\underline{P}$ = 0.05
3 Lower rate applied every 14 days up to flowering; higher rate applied every 14 days after flowering

TABLE 5

Control of powdery mildew on vine foliage 1984-85: France

Treatment	Rate g a.i./hl	% leaf area infected 1984		1985			
		A 8DAT7	B 13DAT3	A 14DAT4	B 5DAT5	C 5DAT5	D 4DAT4
Hexaconazole[1]	1.5	0.1b[3]	3.6b	0.3d	0.2c	0.2c	0.7b
Hexaconazole[2]	1.5	0.5b	-	0.2d	-	-	0.9b
Penconazole	1.5	0.6b	2.4b	0.4d	0.3c	0.3c	0.9b
Fenarimol	1.2	-	4.0b	3.7c	3.0b	1.0b	-
Sulphur	1000.0	0.4b	-	7.7b	-	-	-
Untreated	-	40.0a	46.5a	42.6a	38.8a	25.8a	29.0a

1 5% w/w soluble grain formulation
2 5% w/v suspension concentrate formulation
3 $\underline{P}$ = 0.05

TABLE 6

Curative action against powdery mildew on vines 1985: USA

Treatment	Rate[1] g a.i./hl	% bunches infected 28 DAT3	% bunch area infected 28 DAT3
Hexaconazole	0.75	25de[2]	1.6bd
Penconazole	0.75	31cde	1.0cd
Penconazole	1.5	19e	0.3d
Flusilazol	0.75	38bd	3.0b
Flusilazol	1.5	20de	0.9cd
Fenarimol	1.2	48bc	2.8bc
Untreated	-	100a	90.4a

1 3 sprays applied at 14 day intervals. First spray application was delayed until approximately 1% bunch area was infected. Berry size at first application was 2-4mm in diameter.

2 $\underline{P} = 0.05$.

CONCLUSIONS

Hexaconazole is a highly active new fungicide with excellent protectant, penetrant, and curative properties. Applied preventatively with a 14 day interval at 1.5 g a.i./hl it provides excellent control of vine powdery mildew. The curative properties of hexaconazole could provide flexibility to the grower who may not always be able to apply treatments optimally, though it would be wise to avoid treating powdery mildew infections curatively whenever possible.

Hexaconazole used alone at 2.0 g a.i./hl or at 1.5 g a.i./hl in combination with folpet and captafol, provides excellent control of black rot if utilised in a programme linked to the probability of disease incidence. These treatments should also prove highly effective with a 14 day interval, except perhaps in situations with very high disease pressure. In these cases, reducing the interval to 10 days would be prudent.

The addition of folpet and captafol to hexaconazole in tank mixture not only provides additional protectant activity against black rot, but also offers the grower, in a single mixture, the opportunity to control vine powdery mildew, vine downy mildew and black rot, whilst also providing a significant level of efficacy against grey mould. These diseases are caused by the four major vine pathogens in Western Europe.

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RAK I-EUPOECILIA AMBIGUELLA PHEROMONE: THE FIRST MATING DISRUPTION PRODUCT FOR COMMERCIAL USE IN GERMAN VINEYARDS

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ABSTRACT

For five years BASF has been carrying out trials on mating disruption in the grape berry moth Eupoecilia ambiguella using the sexual pheromone Z-9-DDA, under conditions as close as possible to those encountered in practice. The experience gained in these trials as regards dosage, number of applications and site differences resulted in commercial recommendations for the control of the second generation of E. ambiguella by the mating disruption technique. The method is now registered for use in the Federal Republic of Germany on the second generation, and the first use on a commercial scale took place this year.

INTRODUCTION

As in many other butterfly and moth species sexual attractants play an important role in the mating behaviour of the Grape Berry Moth Eupoecilia ambiguella. Male moths find females ready to mate by following the pheromone trail left by the female, in the direction of increasing concentration.

Considerations were made relatively early as to how these attractants could be utilized for the control of insect pests. The concept of mating disruption was thus developed, based upon the distribution of a large number of pheromone dispensers (point sources) within a limited vine-growing area. An artificial pheromone cloud is thus formed, which eclipses the natural pheromone trails left by the female moths. As a result the males of E. ambiguella can no longer find the females to mate.

Only occasional random matings occur and the number of fertilized females in the population declines. The use of the mating disruption method helps to make insecticide-free controll of E. ambiguella a viable possibility. This is an important step in the direction of integrated pest management in vines.

MATERIALS AND METHODS

After carrying out initial orientational experiments, trials were laid down on larger areas in 1982, at first in the Palatinate vine-growing area of the Federal Republic of Germany (Vogt et al., 1985). In 1983 vineyards in the Mosel regions were included in the programme (Englert, 1985), and in 1985 the mating disruption technique was tested under varying conditions in all German vine-growing areas.

Generally the trial areas were about 4 ha in size, or larger (one area was even 117 ha). Some were isolated areas not adjacent to other vineyards, and others were situated in the middle of vine-growing areas.

The dispensers employed were Hercon Flakes, three layered plastic discs, the inner surfaces of which were impregnated with the pheromone Z-9-DDA.

The number of pheromone sources (dispensers) varied, usually it was around 150 per ha, but could also increase to 500 per ha.

In 1982 the dispensers were stuck on to the wooden support poles, but in the following years they were affixed by hand to the training canes and wires by means of staples.

The initial doses of pheromone employed in 1982 were, on average, 17 and 20 g a.i./ha; from 1983 onwards 25 g a.i. were used throughout, and in 1985 the dose was increased to 50 g a.i. per ha per generation. In accordance with the Federal Biological Institute's guidelines for registration trials on insect mating disruption in vines, the control plots were at least 100 m^2 in size and at least 100 m away from treated plots.

The effect of the pheromones (which is the disruption of the male insects' orientation system) was determined in various ways:

a) Using pheromone traps the loss of orientation of the males to the traps was checked.
b) Females were trapped and the number which had mated was compared with the number of mated females from control plots. Trapping in baited glass traps was also used to determine the proportions of mated and non-mated females present in the population.
c) Assessing the amount of inflorescences and grapes attacked.

Since the most reliable method of evaluating the success of the mating disruption technique is by monitoring the subsequent level of attack, only the results obtained using this method are presented here.

RESULTS

The following tables show the levels of attack obtained between 1982 and 1985 in the Fed. Republic of Germany. It should be noted that the threshold level for damage on grapes in Germany is 10-12% for the first generation (20-30% in Baden) and 4-6% for the second generation.

In 1982 the average dose of 17-20 g a.i. per hectare per generation produced interesting results. The threshold of damage was not reached in the first generation, but the reduction in infestation was only just over 60%, even though the population density was relatively low. In the second generation 83% control was achieved, but on account of the abundance of insects in this generation the mean infestation level was nevertheless 21.4%, that is far over the level critical for damage (Table 1).

TABLE 1

Control of E. ambiguella by the mating disruption technique, FRG 1982, n = 3

Treatment	Dose (g a.i./ha)	average number of larvae on 100 inflorescences or grapes	
		1st Generation	2nd Generation
Untreated	-	15	118.8
Z-9-DDA	17-20	6 (2-8)	21.4 (14-29)

In 1983 the rate of 25 g a.i. per hectare per generation produced very satisfactory results. In the first generation the threshold of damage was not attained, but the infection pressure was not high. During the second generation a level of attack over the threshold of damage was assessed only in some parts of the trial area (Table 2).

TABLE 2

Control of E. ambiguella by the mating disruption technique, FRG 1983, n = 4

Treatment	Dose (g a.i./ha)	average number of larvae on 100 inflorescences or grapes	
		1st Generation	2nd Generation
Untreated	-	39 (11-90.5)	73 (35-125)
Z-9-DDA	25	5.4 (2.5-12.5)	7.3 (3-13)

The positive picture provided by the 1983 results was clouded somewhat in 1984, when a number of experimental areas were included, which proved to be incompatible with respect to

the mating disruption method. These were terraced vineyards on the Kaiserstuhl in the Rhine valley. It transpired that the terraced areas were too susceptible to wind currents, thus making the maintenance of a homogeneous pheromone atmosphere difficult. The results obtained from such plots in the first generation were unsatisfactory. In the second generation the terraced plots were excluded from the trials and good results were obtained (Table 3).

TABLE 3

Control of E. ambiguella by the mating disruption technique, FRG 1984

Treatment	Dose (g a.i./ha)	average number of larvae on 100 inflorescences or grapes	
		1st Generation n = 5	2nd Generation n = 2
Untreated	-	9.2 (0-52)	25.2 (10.5-49)
Z-9-DDA	25	6.24 (1-62)	2.5 (0-4)

The experience obtained between 1982 and 1984 prompted us to increase the dose to 50 g a.i. per hectare per generation in 1985, in order to obtain satisfactory results with the Hercon dispensers.

Nevertheless the threshold of damage was exceeded in the first generation in 1985, in some cases to a considerable extent, so that a curative insecticide spray had to be applied to prevent further damage.

The trials on the second generation produced satisfactory results. Only in places where unusually high initial populations were present, as a result of lack of insecticide treatment against the first generation, was the critical level of damage exceeded (Table 4).

TABLE 4

Control of E. ambiguella by the mating disruption technique, FRG 1985, n = 12

Treatment	Dose (g a.i./ha)	average number of larvae on 100 inflorescences or grapes	
		1st Generation	2nd Generation
Untreated	-	35.7 (0-115)	28.3 (1-110)
Z-9-DDA	50	11.3 (1-45)	5.5 (1-30)

CONCLUSION

Now that a large number of trials has been carried out on extended areas under very varying conditions (north and south aspect, steep slopes, flat areas), it is clear that not only the dose has to be considered.

The population density is without doubt one of the deciding factors influencing the success of the mating disruption technique.

In conclusion it may be stated that the mating disruption technique can be regarded as a suitable approach to control the second generation of E. ambiguella. This has been confirmed by the first employment of RAK I-Eupoecilia ambiguella Pheromone (50 g a.i./ha) on a commercial scale against the second generation in German vineyards in 1986, after the product had received official recommendation.

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COFFEE LEAF RUST (HEMILEIA VASTATRIX, BERK. AND BR.) IN COLOMBIA
PART I An Integrated Approach to the Development of Machinery for the Application of Fungicides

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INTRODUCTION

In September 1983 coffee rust (Hemileia vastatrix) reached Colombia, one of the last S. American countries to be afflicted with this disease. Although chemical control of coffee rust is widely employed in many countries, its efficiency depends on a thorough knowledge of disease behaviour under the local climatic and agricultural conditions and the use of appropriate spraying machinery. The particular conditions of Colombian coffee areas presents a special challenge to the efficient chemical control of coffee rust.

In November 1984 a development programme was initiated between the National Federation of Colombian Coffee Growers (F.N.C.C.) and The Overseas Development Administration of the British Government (O.D.A.) at the F.N.C.C. central research station, CENICAFE, in Caldas, Colombia. The principal objective was to develop suitable portable spraying equipment and ancillary techniques for coffee leaf rust control on the steep slopes of the Andes. The project concentrates on reducing the volumes of spray liquid applied to provide efficient spraying with good leaf canopy penetration and leaf coverage.

THE DISEASE AND ITS EFFECTS ON COFFEE PRODUCTION

Coffee leaf rust produces characteristic powdery yellow/orange pustules in patches on the undersides of the leaves. Spores dispersed from these pustules by wind and rain serve to infect other leaves on the same or different trees. Thus the disease spreads and increases in severity during favourable conditions.

Coffee rust spores require water and temperatures above 16°C for germination and will only infect the undersides of coffee leaves during darkness or very low light intensities. Therefore, the disease is only active during the rainy season and in areas where night temperatures at that time of the year are generally above 16°C.

The main effect of coffee rust is to reduce the photosynthetic capacity of the tree and hence its vigour, largely by causing premature

defoliation. This affects the productivity of the tree because coffee produces flowers and fruits on branches which have grown during the previous season,so that yield is largely determined by the vigour of previous vegetative growth. Growing coffee berries are a physiological sink for carbohydrates and other nutrients and when the photosynthetic capacity of the tree is limited, the berries will continue to grow at the expense of vegetative growth. Thus coffee rust firstly limits vegetative growth, and consequently the following season's crop; and secondly, if severe defoliation results, the withdrawal of carbohydrates from roots and shoots cause the tree to starve. This results in a condition termed overbearing dieback, which can kill the tree in extreme cases.

The conventional method of controlling coffee rust is by foliar sprays of copper-based fungicides, although systemic compounds such as triadimefon are increasingly used. These are usually applied at 4-6 weekly intervals throughout the rainy season, either by knapsack sprayers or semi-stationary motorised pumps with hand lances using 250-500 l/ha. To be effective, the fungicide has to reach the undersides of the leaves, either directly or by subsequent redistribution in rainwater. The epidemiology and control of coffee rust have been reviewed by Waller (1982).

Coffee rust first appeared in the New World in Brazil (Bahia) in 1970. Since then, it has progressed successively throughout the Continent aided by a secondary focus, which appeared in Central America (Nicaragua) in 1977 (Fig. 1). Coffee rust in Latin America has been reviewed by Scheiber and Zentmyer (1984).

In Colombia the disease spread rapidly throughout the main coffee producing areas during 1984/5. Now it exists in all coffee producing countries of the Continent, recently reaching Cuba and Jamaica in 1986. Although the disease is spread primarily by air-borne spores, vectors such as man, birds, insects etc. which can carry spores and the movement of diseased seedlings have contributed to the widespread dispersal of coffee rust.

BEHAVIOUR OF COFFEE RUST IN COLOMBIA

Being a mountainous equatorial country, Colombia has an extensive rainy season, with June and July being the only months which may be dry in coffee growing areas. Much of the coffee is grown at altitudes below 1600 metres, where night temperatures are adequate for coffee rust infection. There is also little seasonal variation in ambient temperatures. Thus, there are few climatic limitations to coffee rust development and the epidemic pattern (Fig. 2) is mainly controlled by periods of new leaf production and the shedding of old leaves. Intensities and fluctuation in disease incidence are greatest at lower altitudes, where host growth and disease development are fastest and the effect of dry periods greatest (J. Leguizamon C. pers. com.). In common with other areas the incubation period of the disease is longer at higher altitudes than lower altitudes, thus slowing down the rate of disease development. The main cultivar grown is the susceptible semi-dwarf Caturra, often in fairly dense stands. Under these conditions disease spread is rapid, so that 100% of trees are affected after four months from the first appearance in selected blocks of coffee. There is a strong correlation between disease incidence and

Fig. 1. Spread of coffee rust throughout Latin America.

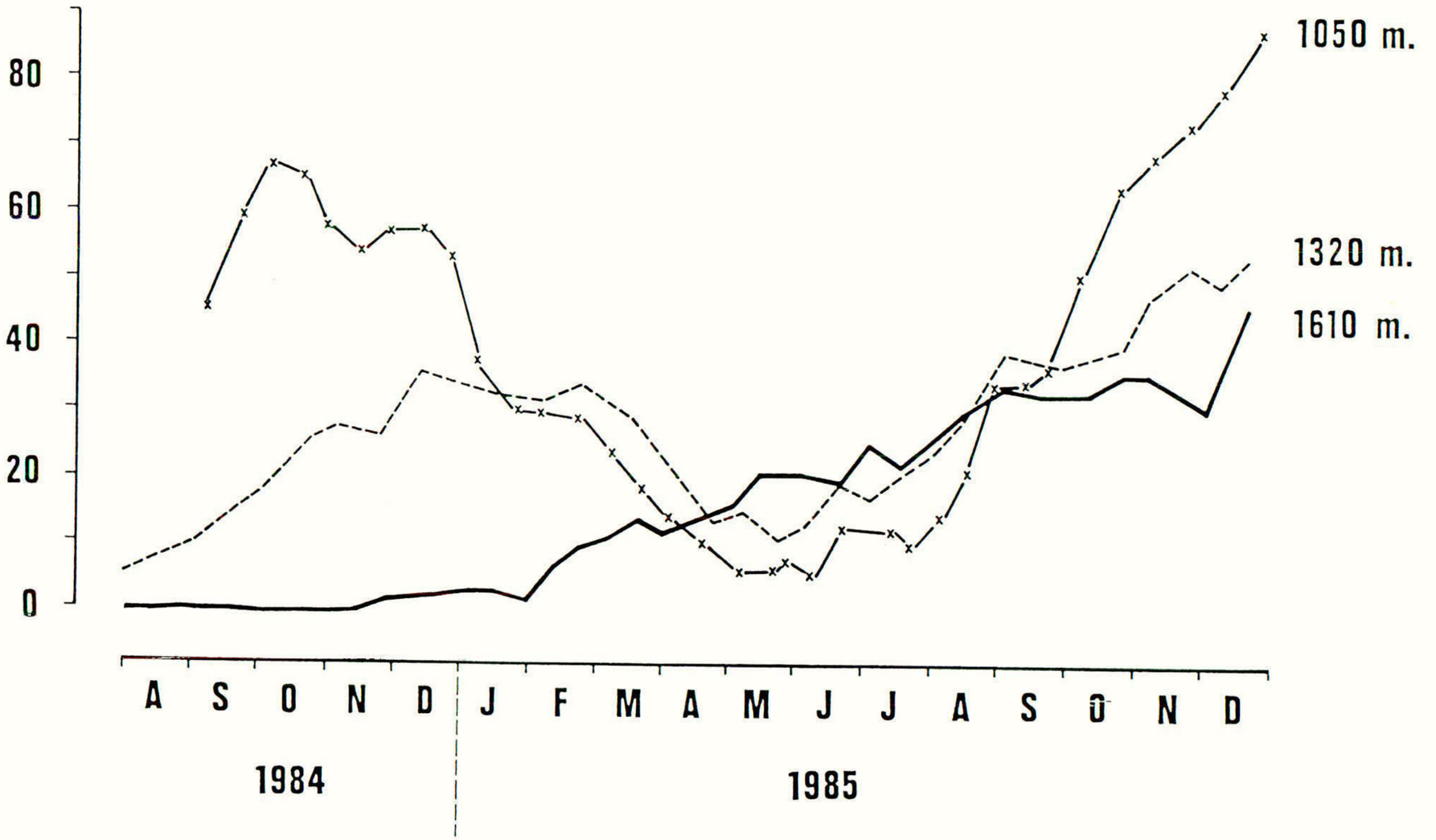

Fig. 2. Annual leaf rust cycle: percentage leaves with rust v. time for various heights above sea level (metres).

defoliation two months later but not with yield during the same year, although during the following year yield reductions of 80% have been recorded (C. Baeza A. pers. com.).

DIFFICULTIES OF CONTROL IN COLOMBIA

The year-round epidemic of coffee rust in Colombia means that an extensive spray programme of up to 6-8 applications is required, making control more expensive both in materials and labour than in other countries with longer dry seasons. The physical limitations to efficient spraying are difficult to overcome. The steep slopes and dense stands of coffee increase the labour of spraying; in some areas it is virtually impossible to operate heavy sprayers with hand-directed lances and pumps. The use of pre-pressurised knapsack sprayers is one solution, but the method is inefficient and the work rate particularly on steep slopes is slow, requiring a day for one man to spray 0.25 ha. With an average size of coffee farm of 3 ha., this makes timely spraying difficult. In addition, the heavy weight of sprayers, high water consumption and poor leaf cover of spray deposits further reduce efficiency.

The use of hand-directed spinning disc sprayers can overcome some of these problems, but they have had mixed results in many countries such as Kenya (Maithia 1983) and Brazil (Hashizume et al, 1973). Work in Honduras suggested that the problem was one of poor and uneven canopy penetration (C. P. Bennett pers. com.). Therefore, work in Colombia is aimed to rectify this deficiency.

APPROACH TO THE DEVELOPMENT PROGRAMME

At the start of the project, a number of assumptions were made based on the experience gained by F.N.C.C. and Micron Sprayers Ltd. These assumptions were as follows:

sprayers would apply either low volume (20-50 l/ha in water), or ultra-low volume (<5 l/ha in oil);

the sprayers would be portable;

work would concentrate initially on the coffee cultivar Caturra grown without shade;

the fungicides used would be based on copper.

Having made these assumptions, a decision was taken on the priorities to be given to the various interacting factors affecting the development of suitable sprayers.

These factors may be divided into two categories - those involved with the action of the spray on the coffee plant, and the characteristics of the machine and its use.

The factors in the first category are listed as follows:

topography - in particular the steepness of the slopes on which coffee is grown;

climate - the considerable variations in the ambient temperature and relative humidity affects the rate of evaporation of spray liquid and hence the rate of reduction in the size of the droplets after they leave the machine. Wind strength and direction will influence the pattern of droplet deposition;

the structure of the coffee plant - including variation in the architecture of the plant (shape, size and leaf area index) and whether the coffee is grown under shade;

the incidence of coffee leaf rust and its distribution within the plant;

the spray - droplet size and density on a given leaf (i.e. evenness of deposition and the relative placement on the upper and lower leaf surfaces) and the distribution on the leaves throughout the plant.

The factors in the second category relating to the performance of the machine are listed as follows:

work rate, i.e. the area of coffee sprayed by one machine in a given time;

reliability of the machine;

safety to the operator;

environmental effects, particularly undesirable consequences of drift away from the target;

efficacy of disease control as a result of the combination of the machine and the chemical applied;

economic considerations.

All these factors are interrelated, and in the establishment of the development programme they would have to be considered in terms of priorities, because the number of ways in which the problem could be tackled is at least equal to the number of factors under consideration.

INITIATION OF THE PROGRAMME

At the start of the programme, the factors listed in the second category were not taken into consideration, other than ensuring that any experimental machine was reliable in the field, reasonably portable and safe to the experimenter.

Given the initial assumptions, the main decision was that the programme of work would begin by concentrating on the way in which the droplets are distributed throughout the coffee bush, as a result of alteration to the droplet characteristics. The characteristics considered were:

droplet size;

droplet number;

nature of the carrier liquid (oil, water, or both);

air/droplet velocity;

degrees of electrostatic charging.

The experimental machines were constructed principally to produce desired droplet characteristics, rather than attempting to fulfil the expected practical requirements.

In order to evaluate these effects in the field, a suitable method of trial design, sampling method and the corresponding statistical treatment was established. This was done by carrying out a large-scale experiment with a thorough analysis of the variability of droplet distribution throughout the coffee plant. This study defined the trial design and sampling requirement, such that a simple design could be used to determine the droplet distribution throughout the plant under different conditions of planting density, architecture and shape.

The establishment of a data base from the experimental results would then be followed by the use of bio-assay techniques to establish the relationship between the size and distribution of droplets and prevention of leaf rust infection.

With the results of the bio-assays, and using the information obtained on droplet distribution, the programme was designed to check the performance of prototype machines in the field in terms of efficiency of disease control under practical conditions.

ACKNOWLEDGEMENTS

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COFFEE LEAF RUST (HEMILEIA VASTATRIX, BERK. AND BR.) IN COLOMBIA
PART II Low Volume Application - Droplet Deposition and the Implications for Machine Design

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INTRODUCTION

In Colombia, current application methods for coffee leaf rust control principally use knapsack sprayers fitted with a vertical boom to which are attached four nozzles or hand lances supplied from long hoses attached to semi-stationary engines. These apply 200-500 l/ha, depending on the age and spacing of the coffee bushes, with a maximum work rate of 0.4 ha/day/operative which can be reduced to below 0.2 ha/day under difficult application conditions. The F.N.C.C./O.D.A. project described in PART I of this paper aims to develop techniques which will offer simpler, easier, more timely and effective spraying using reduced volumes of application. Particular difficulties are created by the presence of steep slopes, with the consequent desire to keep one or both hands free and the high leaf area indices. Volumes of application in the region of 20-50 l/ha, are being considered involving the application of oil, water or mixtures of both, using drop sizes in the range of 20-90μ.

Low volume applications are routine in the commercial control of banana leaf spot (Mycosphaerella musicola). Seakin (1972) and Morgan (1974) demonstrated the possibilities for reduced volumes for disease control in apples and Mabbett and Phelps (1983) in oranges.

Furthermore, when using contact insecticides, it has been shown that small drops are more efficient than large ones (Wyatt et al. 1985) and that charging of small drops can lead to a reduction in a.i. applied in commercial practice.

The Spray Target

Two different views are commonly expressed on the "target" for spray droplets, i.e. the location where the drops are required.

The first is that droplets must be deposited directly where the spores germinate, i.e. in the case of coffee leaf rust, on the undersides of the fully expanded leaves. Since the rust spores require moisture throughout the period of germination, those leaves protected from the evaporative influence of the sun, provide the most favourable conditions. Consequently, the prime "target" is the interior of the bush, at the middle and lower levels.

The second view is that the spores are dispersed essentially by air movement and have a particle size in the range of 20-50μ, depending on the extent of agglomeration of the spores. These particles can be expected to land in a similar manner to spray droplets of a similar size range, i.e. when the velocities are high, by impaction in the tops of the bushes on the stems and small branches, and when velocities are low, by sedimentation on to the top surfaces of the leaves in the middle and bottom of the bushes. This view assumes that redistribution of the a.i. takes place along with the redistribution of the spores to the undersides of the leaves. On this assumption, a greater concentration of the fungicide in the top of the bush could be expected to lead to a more effective use of the a.i. before it reaches the ground and is lost in the soil. A consequence of this view is that deposition of the spray on the underside of the leaf is, in the first instance, not essential.

Droplet Production

For this project the spinning disc system of droplet production was chosen for maximum flexibility. It has the capability of producing relatively even sized droplets of the size desired (20-90μ) over a wide range of flow rates (5-100 ml/min) and can also deal with a variety of formulations based on oil and/or water.

Disc speeds in the range 7,000-25,000 rev/min are used and voltage for droplet charging ranged from 0 to 35 Kv.

Droplet Dispersion

Three methods of droplet dispersion are under investigation:

1. Natural air movement. As evidenced by the weather records at CENICAFE, Chinchina, there would appear to be a consistency in the strength and direction of the air movements throughout the year. Typically, the air moves up the slope from 6.00 a.m. throughout the day and down the slope from 5.00 p.m. and throughout the night. In tall coffee, thermal movement of air up through the crop starts at around 10.00 a.m. Whilst these movements differ between localities, they are predictable for a given locality and could be used to aid droplet dispersion.

2. A broad beam of turbulent medium velocity air, as obtained from axial flow fans. This method of droplet dispersion was included in the investigation:

   (i) to reduce to a minimum the need for the operator to direct the air beam;

   (ii) to accommodate variation in slope;

   (iii) economic and other considerations related to reducing the power requirement.

3. A narrow beam of high velocity air, as obtained with a conventional mistblower. This method was included because the high leaf area indices found in Colombian coffee suggested that penetration of the drops could present a problem.

Droplet Deposition

To obtain underleaf cover two methods are being investigated:

(i) deposition by impaction using the forced air movements provided for droplet dispersion;

(ii) deposition using droplets electrostatically charged at different levels.

Where the droplets have moved away from the sphere of influence of the forced air movement, or where machines are used which do not input an additional velocity to the droplets, deposition will be essentially on the upper surfaces of the leaves due to sedimentation, with the light air movements prevailing within the canopy. The impetus of the very small drops flung from the spinning disc disappears within a few centimetres and can be disregarded.

Equipment and Method of Use

To carry out the programme of work, a range of experimental machines were conceived, designed and fabricated by Micron Sprayers Ltd, some involving modifications to existing commercial designs and some involving radically new concepts. These machines have allowed the droplet production and dispersion methods to be studied in a variety of ways, which can be considered under the following headings:

1. Position of the spray outlet:

   (i) above the coffee;

   (ii) central (within the bushes);

   (iii) base (underneath the bottom branches).

2. Angle of the spray outlet:

   (i) to the horizontal;

   (ii) to the direction of travel.

3. Movement of the outlet:

   (i) in the horizontal plane;

   (ii) in relation to the direction of travel.

EXPERIMENTAL METHODS

The liquids used have either been water with Saturn Yellow or Lumogen in oil, depending on the treatment being investigated. Counts were taken on each surface of the leaf using monocular microscopes under u.v. light.

Since the start of the project, plot size and the number of counts taken for each treatment have have been increased to reduce variability, so that currently for a single treatment a minimum of 12 trees are treated on both sides. Sampling is based on taking leaves from three levels

(bottom, middle and top) and four positions (exterior and interior on both sides of the bush) at each level, in a line at right angles to the direction of travel. Leaves were marked with a rotary hand punch to indicate leaf position in the canopy and placed into separate sampling bags for each level.

RESULTS

Results (droplets/cm^2 and ratios of counts, upper:lower leaf surfaces) are shown for the four positions across the tree. The three levels are separated by double broken lines. The droplet counts for the upper and lower leaf surfaces are separated by a solid line. The directions of spray are shown by single arrows and the natural air movement by a double arrow.

Where the natural air movements are used to achieve deposition, the cover achieved is essentially on the top surface of the leaves. Results from the four trials were very similar in their profiles, little affected by the differences in tree height, leaf density and environmental conditions. Only in the top of the trees is a windward bias observed, otherwise droplet counts appear similar throughout the cross section but with a gradual reduction with depth within the tree (Fig. 1).

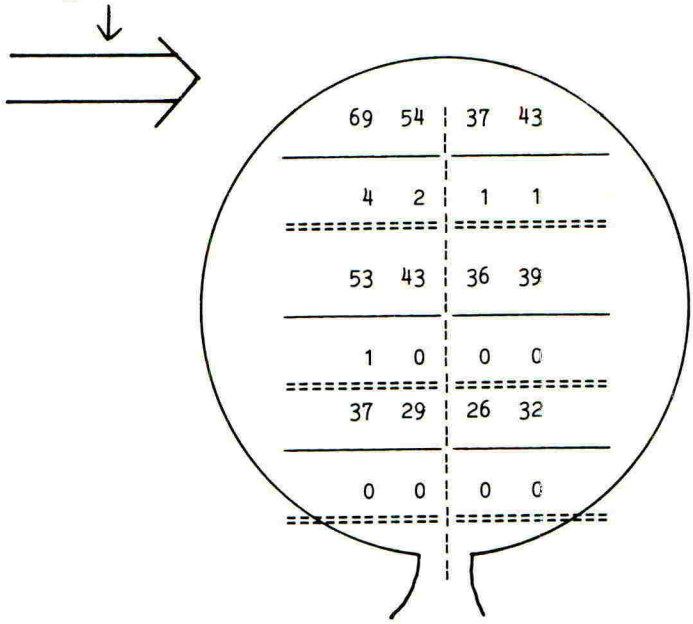

Fig. 1. Deposition of spray (droplets/cm^2) on the upper and lower leaf surfaces; application rate 11 l/ha. Natural air movement.

Where forced air movement is used, good cover has been achieved on both sides of the leaves close to the spray outlet. The higher the air velocity used, the further from the outlet this occurs. Nevertheless, the underleaf cover obtained in the inside position at the bottom level is

consistently less than elsewhere in the canopy.

The results suggest that as the droplets move away from the influence of the forced air movement, so the deposition of the droplets is dominated more by sedimentation than impaction and as a result they are found essentially on the top surface of the leaf. This feature is illustrated in Figure 2 which shows the influence of the position of the spray outlet on the distribution pattern.

Charge improves the deposition on the underleaf surface as shown by the lower ratios of the droplets on the upper to lower leaf surfaces (Fig. 3), though at the expense of penetration. It has been shown, however, that the application of charge to the droplets can lead to a reduction in the variability of the cover on both surfaces of the leaves. The overall variance (when expressing the droplet density in log units) was reduced from 0.16 to 0.12 by the addition of a 35 kV charge.

Machines producing fine droplets (30-50μ) with air assistance were capable of achieving good coverage with water, provided that the spray outlet was in the central bottom position. When water was used, examination of the droplets on the leaf under the microscope showed that evaporation was influencing the droplet size, with the largest droplets found in the middle of the bush and smallest droplets found in the top of the bush.

DISCUSSION

A central idea of the project has been that the cover obtained depends not only on the spray equipment used, but also the way in which it is used.

The patterns of cover obtained should be regarded only as a useful starting point. Their effectiveness will depend not just on the characteristics of the disease, but also on the mode of action of the a.i. used, its formulation and consequent influence on the spread of droplets and the uptake, persistence and redistribution of the active ingredients.

A feature of electrostatic charging is that, given a high charge to mass ratio, penetration is impeded, resulting in uneven cover with heavy deposits on the outside of the bush and on the margins, particularly on the underside of the leaf. This raises the question whether it is possible to overcome these characteristics by a reduction of the charge without losing the benefits of increased deposition and improved under leaf cover. The results show that charging of the drops can lead to a reduction in the variability of cover on the leaf and this indicates that there could be an optimum charge in terms of the quality of the cover obtained. For disease control evenness of cover would seem to be of importance, particularly when dealing with oil formulations where copper will be less soluble and redistribution is less of a factor than with water formulations. Charging can be expected to lead to improved deposition of the spray, particularly with fine droplets. Present methods of assessment are not suitable for assessing this, or the extent to which charge can be reduced without losing this benefit.

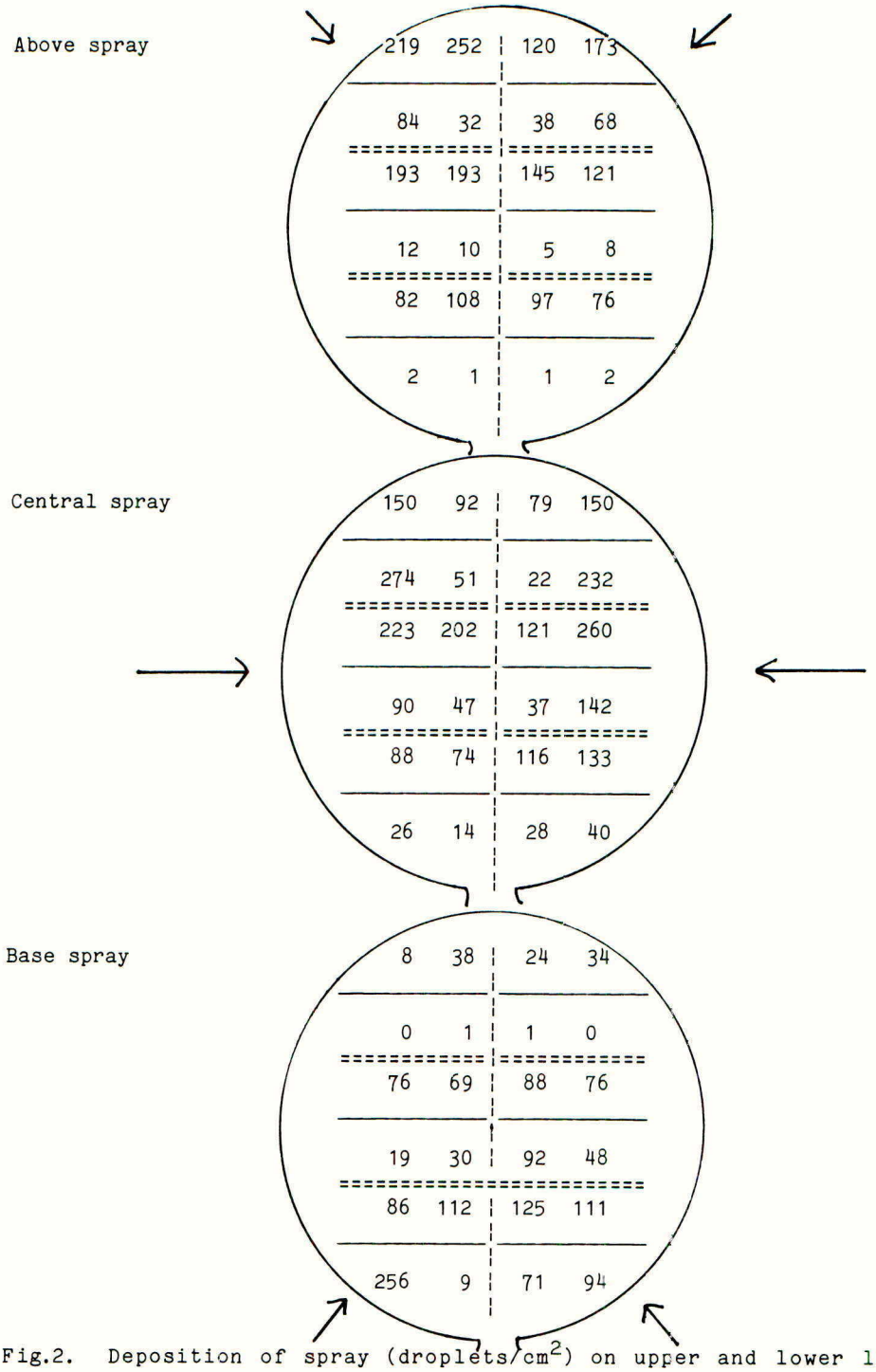

Fig.2. Deposition of spray (droplets/cm^2) on upper and lower leaf surfaces; application rates between 2.5 and 5 l/ha. High velocity forced air movement.

Considering forced air movement, the higher the velocity of the air at the spray outlet, the further the spray can travel through whatever barriers are present and still have energy to produce sufficient leaf movement for coverage by impaction on both sides of the leaf. This is particularly relevant to the taller coffee and coffee planted at wider spacings. Considering natural air movement, there is also the possibility that, in the tropics, the day-to-day weather is sufficiently predictable that a technique can be developed using natural air movements only.

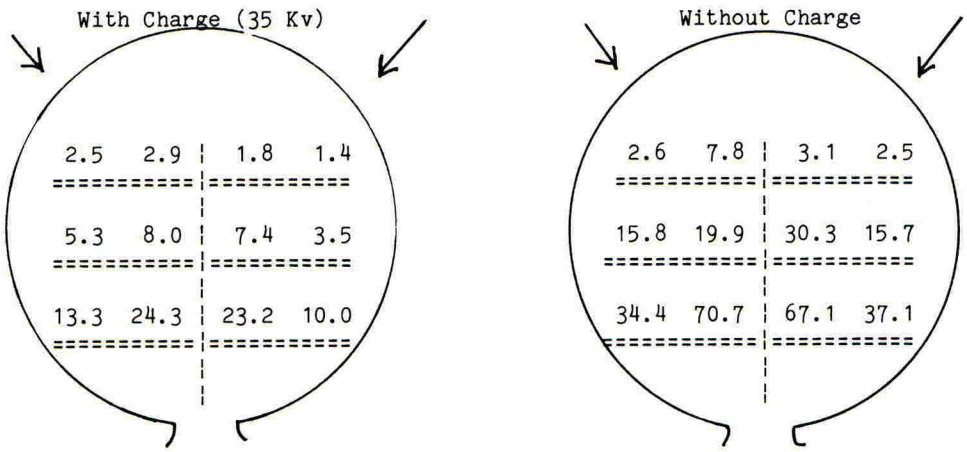

Fig. 3. The effect of charge on the ratio of cover on upper and lower leaf surfaces. High velocity forced air movement.

In the work done so far, the evenness of cover obtained has been very encouraging, but the questions which remain to be answered are :

(i) is a deposit solely on the tops of the leaves sufficient to provide good control of rust?

(ii) can a non-evaporating liquid be formulated economically to provide sufficient active ingredient on the top of the leaves?

In terms of the "target" for the spray droplets, it would seem that if it were possible to meet the requirements of both the views originally presented, the more complete would be the control achieved. The method of application which most nearly meets these requirements is the high velocity charged spray, operating from a central position behind the operator. However, in practice this may be difficult to achieve, certainly in economic terms. For underleaf cover in the bottom half of the tree, an outlet placed underneath the foliage and pointing upwards presents the best coverage, but is unlikely to be a practical solution.

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FACTORS INFLUENCING THE EFFICACY OF A BIOFUNGICIDE FOR CONTROL OF GREY SNOW MOULD ON TURFGRASS

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ABSTRACT

Field studies were conducted on creeping bentgrass in 1985 to determine the effects of cellulose, inoculum concentration, and time on the potential of isolates T011 and T016 of Typhula phacorrhiza to suppress grey snow mould (T. ishikariensis). Suppression of grey snow mould induced by grain inoculum of isolate T011 at 50 g/m^2 and 200 g/m^2 was not significantly different from the suppression induced by quintozene (30 kg a.i./ha). After snow-melt, redevelopment of the turfgrass canopy was more rapid in plots treated with 200 g/m^2 of inoculum than in plots treated with 50 g/m^2. No residual disease suppression was observed in plots treated with 200 g/m^2 of isolate T011 one year earlier. Equal concentrations of isolate T011 and T016 did not differ in their disease suppression potential. An increase in the concentration of isolate T016 significantly reduced the time required for redevelopment of the turf canopy but it had no effect on disease suppression. Cellulose amendments did not enhance disease suppression potential of isolate T011. No sclerotia of T. ishikariensis were observed in plots treated with quintozene or grain inoculum of isolate T011 or T016. The number of sclerotia of T. phacorrhiza recovered increased significantly with increasing concentrations of grain inoculum of T016.

INTRODUCTION

Fungicides containing inorganic mercury or quintozene are used extensively for management of snow mould diseases of turfgrass in Canada. The cost of applying these fungicides, coupled with concerns about contamination of soil and water, have prompted investigations into the use of microbial antagonism as an alternative approach to managing winter diseases.

Results of recent studies (Burpee et al. 1986) indicate that isolate T011 of Typhula phacorrhiza, a low-temperature-tolerant saprotroph, can be utilised on creeping bentgrass as an effective biological control agent for grey snow mould caused by T. ishikariensis var. ishikariensis. When applied as wheat-grain inoculum at 100 g/m^2 in 1983 and 200 g/m^2 in 1984, isolate T011 suppressed 44% and 70% of grey snow mould in plots of creeping bentgrass naturally infested with T. ishikariensis.

The present study was designed to determine the effects of cellulose, inoculum concentration and time on the disease suppression potential of isolates T011 and T016 of T. phacorrhiza.

MATERIALS AND METHODS

Isolates of Typhula phacorrhiza used in the experiments included isolate

T011, collected from the thatch layer of Kentucky bluegrass near Cambridge, Ontario in 1982 and isolate T016, collected from foliage of wheat near Arkell, Ontario in 1982. Cultures of both isolates were derived from single sclerotia and maintained on BASM agar (Smith 1981) at 10°C.

Experiments were conducted from December 1985 to May 1986 on a 8-year old stand of creeping bentgrass cv. Penncross maintained at the Ontario Ministry of Agriculture and Food Horticultural Research Station, Cambridge, Ontario. Mowing, fertilisation and irrigation schemes were similar to those prescribed for bentgrass golf putting greens (Beard 1982).

The disease suppression potential of isolates T011 and T016 of T. phacorrhiza was evaluated on two 4 x 9 m swards of creeping bentgrass with a history of severe infection by T. ishikariensis. Inoculum of both isolates was prepared by transferring mycelial plugs from agar cultures to 1-l Mason canning jars containing moist autoclaved wheat grain (100 cm^3 grain, 20 ml H_2O). Cultures were incubated for 12 weeks at 10°C.

Within each sward, plots (1 x 1 m) were infested by dispersing grain inoculum over the turf surface by hand on 4 December 1985. Snow covered both swards on 6 December 1985 and remained until 28 March 1986.

On one of the swards, treatments included the application of 50 and 200 g/m^2 of grain inoculum of isolate T011. Untreated plots and plots treated with heat-killed (autoclaved) grain inoculum served as controls. A 5% w/v suspension of Avicel Micro Crystalline cellulose (Brinkmann Instruments Limited, Toronto, Ontario) was applied with a hand-pump sprayer to additional untreated plots and to plots treated with 50 g/m^2 of inoculum. The intensity of grey snow mould in the plots treated with T. phacorrhiza was compared with disease intensity in plots treated with quintozene (14W, O.M. Scott, Marysville, Ohio) at a rate of 30 kg a.i./ha.

Applications of 50, 100, 200, and 400 g of grain inoculum and 100, 200, and 400 g of heat-killed grain inoculum of isolate T016 were made to the second sward. Additional treatments included quintozene (30 kg a.i./ha) and an untreated control. Treatments in both swards were arranged in a randomised complete block design with four replicates.

The Horsfall-Baratt rating system (Horsfall & Cowling 1978) was used to estimate disease intensity (% necrotic foliage per plot) on 30 March 1986. Recovery (i.e. time required for the turfgrass canopy to redevelop after snow mould damage) in both swards was estimated at weekly intervals from 30 March until 26 May 1986. Calculations of the disease suppression that resulted from each treatment were based on disease intensity in the untreated plot in each block. Data were subjected to analysis of variance and means were statistically separated by Cluster analysis (Scott & Knott 1974). Simple linear regressions were used to detect significant changes in disease suppression, sward recovery, and numbers of sclerotia formed per plot with increasing concentration of isolate T016.

Sclerotia of T. phacorrhiza and T. ishikariensis in each sward were collected by hand and counted from five cores of soil (5 cm diameter) removed from each plot on 31 March 1986.

A measure of the residual disease suppression induced by isolate T011 was made by estimating the intensity of grey snow mould on 30 March 1986 in plots of creeping bentgrass (1 x 1 m) treated with 200 g of grain inoculum of isolate T011 on 21 November 1984. No supplemental treatments were made to these plots in 1985. Values were statistically analysed as described previously.

RESULTS

The intensity of disease suppression induced by isolate T011 (50 and 200 g/m^2 of inoculum) was not significantly different ($P = 0.05$) from the suppression induced by quintozene (30 kg a.i./ha) (Table 1). The application of cellulose (5% w/v) did not significantly enhance the disease suppression potential of isolate T011. Applications of heat-killed inoculum, heat-killed inoculum plus cellulose and cellulose alone resulted in an increase in disease intensity.

TABLE 1

Suppression of grey snow mould on creeping bentgrass by isolate T011 of *Typhula phacorrhiza*

Treatment	Rate	Disease Suppression (%)*	
Heat-killed inoculum	200 g/m^2	-23.57	A**
Heat-killed inoculum + cellulose	50 g/m^2 + 5% w/v	-16.73	A
Cellulose	5% w/v	-7.85	A
Heat-killed inoculum	50 g/m^2	19.23	A
Grain inoculum + cellulose	50 g/m^2 + 5% w/v	28.39	A
Grain inoculum	50 g/m^2	52.02	B
Grain inoculum	200 g/m^2	88.87	B
Quintozene	30 kg a.i./ha	95.35	B

* Mean of four values calculated as a percentage of disease in an untreated plot in each block recorded on 30 March 1986.

** Values followed by same letter are not significantly different at $P = 0.05$ according to Cluster analysis.

The rate of sward recovery (i.e. redevelopment of the turfgrass canopy) was significantly more rapid in plots treated with 200 g/m^2 of inoculum of isolate T011 than in plots treated with 50 g/m^2 (Table 2). However, recovery in plots treated with 50 g/m^2 of inoculum or 50 g/m^2 plus cellulose was significantly more rapid than in untreated plots.

TABLE 2

Time required for the turfgrass canopy to redevelop and cover >95% of the area in plots of creeping bentgrass infested with Typhula ishikariensis and treated with inoculum of isolate T011 of T. phacorrhiza

Treatment	Rate	Time*	
Grain inoculum	200 g/m^2	1.25	A**
Grain inoculum	50 g/m^2	3.75	B
Grain inoculum + cellulose	50 g/m^2 + 5% w/v	4.25	B
Untreated	--	7.00	C

* Mean of four values recorded as number of weeks from initial disease rating on 30 March 1986.

** Values followed by same letter are not significantly different at P = 0.05 according to Cluster analysis.

Sclerotia of T. ishikariensis were not found in plots treated with inoculum of isolate T011 or with quintozene. In the remaining plots, the mean number of sclerotia of T. ishikariensis ranged from 8 to 36 per 5 cm diameter soil core. Sclerotia of T. phacorrhiza, ranging from a mean value of 11 to 36 per core, were found only in plots treated with inoculum of isolate T011.

The regression of the intensity of disease suppression against inoculum concentration of isolate T016 was not significant (Table 3). However, a significant (P = 0.01) concentration effect was observed when inoculum concentration was regressed against time required for the turfgrass canopy to redevelop.

TABLE 3

Linear regression of intensity of snow mould suppression, time for >95% of the turfgrass canopy to redevelop, and number of sclerotia of Typhula phacorrhiza recovered versus concentration of isolate T016 of T. phacorrhiza applied to creeping bentgrass

Parameter	Slope coefficient	r^2	t-value
Disease suppression	5.4×10^{-2}	.13	1.43
Time	-7.3×10^{-3}	.44	3.73*
Number of sclerotia	1.2×10^{-1}	.61	5.32**

* regression significant at P = 0.01
** regression significant at P = 0.001

An increase in the amount of inoculum of isolate T016 resulted in a significant (P = 0.001) increase in the numbers of sclerotia of T. phacorrhiza recovered in the spring (Table 3). The mean number of sclerotia of T. ishikariensis ranged from 25 to 34 per core in untreated plots and in plots treated with heat-killed inoculum. No sclerotia of T. ishikariensis were found in plots treated with quintozene or with 100, 200, or 400 g/m^2 of T. phacorrhiza inoculum.

Equal concentrations of isolate T011 and isolate T016 did not differ significantly (P = 0.05) in disease suppression or in the time required for >95% of the turfgrass canopy to redevelop. Inoculum of T011 suppressed disease in 1985, however, no residual disease suppression was observed in these plots in 1986 (Table 4).

TABLE 4

Residual suppression of grey snow mould by isolate T011 of Typhula phacorrhiza applied to creeping bentgrass on 21 November 1984

		Disease Incidence*	
Treatment	Rate	14 April 1985	30 March 1986
Grain inoculum	200 g/m^2	25.00 A**	60.93 A**
Untreated	--	94.14 B	67.18 A
Grain alone	--	94.73 B	67.18 A

* Mean of four values recorded after snow-melt in 1985 and 1986.

** Within a column, values followed by same letter are not significantly different at P = 0.05 according to Cluster analysis.

DISCUSSION

Isolates T011 and T016 of T. phacorrhiza are effective biological control agents for grey snow mould on creeping bentgrass. When applied at equivalent rates, the control provided by the two isolates did not differ. Increasing the concentration of application of each isolate had no effect on the level of suppression of grey snow mould but did reduce the time for >95% of the creeping bentgrass canopy to redevelop. This apparent unrelatedness of concentration to disease intensity may be a result of colonisation of the thatch layer by T. phacorrhiza. This colonisation may result in the protection of the nodes of the turfgrass plant from T. ishikariensis, and result in an increase in sward recovery.

Nutrient amendments are often critical in the establishment and success of an introduced antagonist (Lewis & Papavizas 1984). Isolate T011 of T. phacorrhiza has exhibited a faster rate of growth on cellulose-amended media than isolate T004 of T. ishikariensis (Lawton unpublished). However, the application of cellulose to the foliage of turfgrass did not enhance control

(Table 1). Apparently the wheat grain carrier provided a sufficient nutrient base for colonisation of the turf by isolate T011. It is possible that control achieved with other isolates of T. phacorrhiza or with a different delivery system, such as pellets formulated with sodium alginate (Walker & Connick 1983), may be enhanced by cellulose amendments.

Applications of T. phacorrhiza reduce the inoculum density of T. ishikariensis. However, this reduction does not appear to be significant enough to limit disease one year after a single application of T. phacorrhiza inoculum (Table 4). In addition, the production of sclerotia of T. phacorrhiza in turfgrass thatch and on the wheat grain carrier suggests that a residual population of the biocontrol agent may develop as a result of applications over several seasons.

For the first time, an isolate other than T011 has been shown to be effective in suppressing grey snow mould. This suggests that other isolates of T. phacorrhiza may also be effective. With sclerotia of T. phacorrhiza being abundant on corn stover in the spring in southern Ontario (Lawton unpublished), it is conceivable that a range of suppression of grey snow mould can be obtained by screening a large number of these isolates. Selection of isolates with high disease suppression potential may allow rates of application of biocontrol inoculum to be reduced to below the 200-400 g/m^2 range.

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