SESSION 3C

NEW NEEDS, CONCEPTS AND TREATMENTS FOR PEST AND DISEASE CONTROL IN HORTICULTURE

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THE EFFECTS OF DIFFERENT GREEN MANURE CROPS AND TILLAGE PRACTICES ON PEA ROOT ROTS

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ABSTRACT

Several interseason green manure crops (i.e., beans, peas, rye, oats, corn, sudan grass, and sorghum) were grown and incorporated into a root rot-infested field after peas were harvested. Of these seven manure crops, peas and beans contributed to a slight increase in disease severity on peas that were planted in the following spring; rye had little effect while corn, sudan grass, sorghum and particularly oats, reduced root rot severity significantly. During the 3-years of the green manure program, a cumulative decrease of root rot severity was evident. Several tillage practices were also investigated in an attempt to alleviate the effect of soil compaction on pea root rot. Chisel plough plus spring flat seed bed preparation (CP) and fall plough plus spring raised seed bed preparation (FPB) significantly reduced the root rot severity of peas as compared with the conventional fall plough plus spring flat seed bed preparation (FP). Fall ploughing plus compaction resulted in the highest root rot severity.

INTRODUCTION

Root rot diseases of peas, caused by one or more of the fungi, Fusarium oxysporum f. pisi, F. solani f. pisi, Pythium ultimum and Aphanomyces euteiches, are serious disease problems in southwestern Ontario. In 1983, a total of 8600 ha was planted to peas and 26.5% of the pea population sampled had root rots (Tu, 1986a); the average yield of green peas was merely 2.2 T/ha (Tu, 1986b). The severity of pea root rots led to the establishment of a research program in that year to investigate all factors that appeared to be associated with root rots. These factors included etiology, cultivar susceptibility, herbicide predisposition, seed treatment chemicals, soil pH, rotation, drainage, seed bed preparation, tillage practices and interseason green manure cropping (Tu, 1986b). Some findings that have already been integrated into practice include (a) discontinuing use of the herbicide, Tropotox-Plus, (b) replacment of susceptible cultivars with resistant ones, and (c) careful selection of site. As a result average yield/ha increased to 2974 kg in 1984 and to 4151 kg in 1985 (Tu, 1986b). Further yield increases to the 5000-6000 kg/ha level may be achieved when further disease control measures, based on the investigation, are adopted into farming practices.

Soils in southwestern Ontario are generally low in organic matter due to long time intensive cultivation and heavy fertilizer application. Low soil organic matter affects soil texture in terms of reduced porosity and crumb formation. These soils are easily compacted and hinder root development and plant growth (Neal 1953). Root rot diseases are known to thrive in soils of low organic matter, high fertilizer application and high compaction. Incorporation of organic matter into the soil has been reported to reduce root rot in several crops (Borst, 1983; Bouhot, 1981; Pittman and Horricks, 1972, Manning and Crossan, 1969; Snyder et al., 1959, Sirry et al., 1974; Okpala, 1975). Davey and Papavizas (1959, 1960) and Maier (1959)

have shown that soil organic matter with a high C/N (>20:1) ratio hardly ever increases disease whereas soils with a low C/N ratio usually do. Green manure crops such as, barley, wheat, corn, and oats have a high C/N ratio (>20:1), (Synder et al., 1959, Davey and Papavizas, 1959; 1960) and should help to restore the soil organic matter. This would allow reduction of application of inorganic fertilizers, particularly nitrogen in forms of KNO_3, NH_4NO_3 and $(NH_4)_2SO_4$ which have been shown to increase incidence and severity of root rot diseases (Kawase et al., 1970; Huber, 1980). Simultaneously, the added organic matter should improve the soil condition and reduce soil compaction which is known to predispose plants to root rots (Vigier et al., 1983; Burke et al., 1972; 1980; Miller and Burke, 1974). Soils that are low in organic matter are more easily compacted than those with high organic matter (Neal, 1953). Soil compaction can also be affected by tillage practices (Burke et al., 1972) and heavy machinery (Vigier et al., 1983; Raghavan et al., 1978).

In southwestern Ontario, an improvement in culture practices is needed to restore soil organic matter and lessen soil compaction. Different interseason green manure crops and tillage practices have been investigated to develop a new cultural practice as a part of integrated disease control measures. Interseason green manures are chosen because peas are a short season crop which is planted by early May and harvested by mid-July. After harvesting, fields are left bare until the following spring, even though sufficient time, heat units, and precipitation are available to grow green manure crops to their full blossom stage. The first killing frost does not normally set in before mid November. A green manure crop could increase soil organic matter, reduce weed growth, and prevent wind and soil erosion in the winter. This paper reports the effects of different green manure crops and tillage on pea root rots.

MATERIAL AND METHODS

The field experiments were located near the town of Tecumseh, on Brookston clay, a fine textured soil classed as an Orthic Humic Gleysol. This soil type, one of the most widely distributed in southwestern Ontario, has shown favourable response in terms of yield and reduced soil compaction to crop rotation and drainage (Bolton et al., 1982).

A latin square design was used to compare eight different green manure treatments, planted in a north-south direction, with superimposed tillage treatments running east-west. The fields were tile drained, drains 15 m apart.

The experiments were conducted in two fields, one with a heavy, the other with a moderate infestation of root rot fungi (Tu 1986a). This differentiation was based on response of a root rot susceptible pea cultivar such as Green Giant 512. While 100% infection was noted in both fields, the average disease severity on the heavily infested field was 9.0, on the moderately infested field, 5.0, where individual plants were rated on a 0-9 scale of increasing severity (0 = no symptoms, 1 = 0-10% of root area diseased, to 9 = 80-100% diseased).

The green manure treatments involved the control, two legume crops (peas and beans) and five graminaceous crops (rye, oats, sorghum, corn and sudan grass).

The five tillage practices applied were:
(1) Fall plough + spring flat seed bed preparation (FP);
(2) Fall plough + spring flat seed bed preparation + compaction (FPC);
(3) Fall plough + fall flat seed bed preparation (FP-FSBP);
(4) Fall chisel plough + spring flat seed bed preparation (CP);
(5) Fall plough + spring raised seed bed (20-cm in height) preparation (FPB).

Of these five treatments, the latter two would tend to improve soil aeration directly and also by improved drainage in the case of the raised beds.

Spring seed bed preparation involved smoothing the land with a triple-K. Soil compaction was achieved by tractor wheels. Compacted and non-compacted fields had respective penetrometer readings of 11.0 and 18.0 kg pressure at 7 in depth using a 12.83 mm cone attached to a Bush Recording Soil Penetrometer (Model: Mark 1, Findlay, Irvine Ltd. Midlothian, Scotland).

In mid-July, immediately after the peas were harvested, the plots were chisel ploughed, disced and smoothed twice using a triple-K and green manure crops were planted. Rye and oats were solid seeded, peas planted in 15 cm rows, and the others were planted in 60 cm rows. Cultivars of green manure crops used were standard recommended ones, seeded at standard rates for spring seeding. By mid or late October, when growth slowed, plants were chopped and the green manure was uniformly scattered on the ground, averaging 5 to 10 cm in depth depending on crops. Following chopping, as soon as weather permitted, the different tillage culture practices were carried out. The plots were then left until mid-April of the following year. At that time, additional tillage was done on some plots to complete the full range of tillage practices prescribed. Finally, peas (cv. Green Giant 512), were planted again in the first week of May.

Ratings of pea root rot were made in the 3rd week of June. The root rots were rated on a 0-9 scale as described previously. For each rating, 4 replications of 10 plants per plot were examined. The experiments were continued for 3 years (1983-86), in which different green manure crop plantings were successfully tested each year. Comparison of tillage practices was carried out only in 1984 and 1985. In 1983, the weather was too wet in the fall for tillage operations. Pea growth relative to different green manure crop and tillage practices was also assessed in the 1986 season. Pea plants were sampled for fresh weight determination in the first week of July, approximately 2 months after sowing. For each plot, 4 replications of 10 plants were sampled.

RESULTS

Effect of green manure crops on root rot severity

The effect of various interseason green manure crops of the previous fall on the root rot severity of peas planted in the following spring was assessed in the 3rd week of June. The data are summarized in Table 1.

TABLE 1

Effect of 1, 2 and 3 years of different interseason green manure crops on severity of pea root rot in the subsequent year in fields with heavy and moderate root rot infestation.

Green Manure Crop	Average severity of root rot (0-9)+ Heavy infestation			Moderate infestation		
	1984	1985	1986	1984	1985	1986
Control (none)	7.0^{b}	7.3^{c}	7.8^{c}	3.9^{b}	4.1^{c}	4.4^{c}
Peas	8.8^{c}	8.6^{d}	8.7^{d}	4.5^{c}	5.7^{d}	5.0^{d}
Beans	7.3^{b}	7.4^{c}	8.2^{d}	4.0^{b}	4.3^{c}	4.9^{d}
Rye	7.0^{b}	6.8^{bc}	7.4^{c}	3.8^{ab}	4.0^{c}	3.7^{b}
Oats	6.2^{a}	5.8^{a}	5.5^{a}	3.7^{a}	3.3^{b}	3.0^{a}
Sorghum	6.0^{a}	6.5^{b}	5.6^{a}	3.5^{a}	2.3^{a}	3.5^{b}
Corn	6.8^{b}	6.5^{b}	6.4^{b}	4.0^{b}	3.7^{bc}	3.6^{b}
Sudan grass	6.8^{b}	6.3^{b}	6.4^{b}	3.7^{a}	3.4^{b}	3.7^{b}

\+ The severity rating was based on a 0-9 scale where 0 = no symptoms, 1 = 10% or less of root area with disease symptoms, 2 = 10-20%...9 = 80-90%.

a-d Means within column followed by the same letter are not significantly different ($P \leq 0.05$) according to Duncan's multiple range test.

The results (Table 1) showed that even one interseason of green manure incorporation made in the fall of 1983 had an effect on the root rot disease of the subsequent pea crop in 1984. Of the seven green manure crops employed, peas and beans contributed to slight increase in disease severity, pea green manure in particular. Rye had little or no effect, but the other graminaceous species (oats, corn, sudan grass and sorghum) reduced root rot severity significantly; this was especially the case with oats.

In heavily infested fields, when the same operation was repeated for the 2nd and 3rd years, pea root rot severity in plots with oats, corn, sudan grass, and sorghum as green manure showed a gradual but steady decrease over the years. On the contrary, plots with beans, peas and rye as green manure showed either a slight increase or remained unchanged. The pea root rot severity in control plots also increased slightly over the 3-year period. In the moderately infested soil, the year to year variation was greater. Nevertheless, root rot severity decreased considerably in plots that were green-manured with oats, corn, sudan grass and sorghum as compared to the control. On the other hand, a significant increase in the severity of pea root rot due to pea and bean green manuring over the control was also evident. The effect of rye was variable, similar or slightly better than the control.

Effect of tillage practices on root rot severity

Since the analysis of the experimental data showed no significant interaction between green manure practices and tillage methods used, the tillage results can be treated independently.

The two-year study (Table 2) showed that tillage practices played an important role on root rot severity in a root rot infested field. The results of 1985 and 1986 were generally similar. In addition, a similar trend was observed in fields with moderate and heavy root rot infestation.

Most of the variation associated with tillage practices could be associated with the comparison of tillage treatments 1, 2 and 3 with treatments 4 and 5. This would indicate that fall chisel ploughing and spring raised bed shaping after fall ploughing seemed to reduce the incidence of root rot. Fall ploughing with a flat compacted seed bed (FPC) gave the highest root rot severity. Between the chisel ploughing and the raised bed, the latter seemed to have an advantage. The two tillage practices which gave significantly lower root rot severity were CP and FPB.

TABLE 2

Effect of different tillage practices on severity of pea root rot in fields with heavy and moderate root rot infestation.

Tillage practice	Average severity of root rot (0-9)+			
	Heavy infestation		Moderate infestation	
	1985	1986	1985	1986
1. Fall ploughing + spring seedbed	6.8^{c}	7.7^{b}	4.3^{c}	4.7^{b}
2. Fall ploughing plus compaction	8.1^{d}	8.0^{bc}	5.0^{d}	5.4^{b}
3. Fall ploughing + fall seedbed	6.9^{c}	7.5^{b}	4.5^{c}	5.2^{b}
4. Chisel ploughing	5.2^{a}	7.0^{ab}	3.4^{a}	4.6^{b}
5. Fall ploughing, raised beds	6.1^{b}	6.4^{a}	3.9^{b}	4.1^{a}

+ See footnote of Table 1.
a-d See footnote of Table 1.

Pea growth in plots in a heavy and moderately infested field after 3 years of different interseason green manure cropping and two years of different tillage practice was determined (Table 3). The results showed that (a) plant growth and root rot severity data (compare Table 1 and 2 to 3) in general confirm that plants with more severe root rot yield less fresh weight than those with less root rot, (b) differences in tillage practices exerted a more profound effect on plant growth and root rot reduction than the interseason green manure cropping and (c) plant growth data seem more reliable than the root rot severity data. In view of the latter, raised beds appeared better than chisel ploughing.

There was a discrepancy with respect to pea growth after pea and bean green manuring in heavily and moderately root rot infested fields. In the heavily infested soil, pea and bean green manuring adversely affected subsequent pea crops. However, pea and bean green manuring improved subsequent pea growth in the moderately infested field. It can be speculated that the green manuring effect of peas and beans in a heavily infested field could be offset by the population dynamics of the root rot pathogens that green manuring with peas and beans had promoted. As a consequence, the subsequent pea crop was severely diseased.

TABLE 3

Pea growth in plots in a heavily and a moderastely infested field after 3 years of different interseason gren manure cropping and 2 years of tillage practices.

Green manure crop	Fresh wt of pea (g/40 plants) Heavy infestation	Moderate infestation	Tillage practice	Fresh wt of pea (g/40 plants) Heavy infestation	Moderate infestation
Control	47.6[b]	57.4[a]	FP	78.6[c]	83.6[c]
Pea	39.9[a]	69.8[bc]	FPC	29.6[a]	54.4[a]
Bean	48.0[b]	84.2[c]	FP-FSBP	58.4[b]	72.2[b]
Rye	56.1[c]	65.8[ab]	CP	88.4[d]	116.2[d]
Sorghum	56.5[c]	76.2[c]	FPB	115.4[e]	183.0[e]
Oats	65.3[d]	94.8[d]			
Corn	50.5[b]	74.3[c]			
Sudan grass	54.1[bc]	75.8[c]			

a-d See footnote of Table 1.

DISCUSSION

Although the data show considerable variation from one year to the other, such variation can be expected in field experiments which are influenced greatly by weather conditions. It is clear, however, that monocot green manures can reduce disease severity of peas in a root rot infested field and that tillage practices that lessen soil compaction do reduce root rot severity. Possible reasons for the favorable responses of the pea crop to monocot green manuring in general are that (a) they are more distantly related to peas and are not subject to the diseases caused by the pea root rot fungi. Consequently, they do not promote growth of the root rot fungi. Other legumes, that are regularly used as soil improving crops (such as alfalfa and clover) were not tested because they are slow growing, and would not fit into interseason cropping. Also, their seeds are expensive relative to corn; (b) corn, sudan grass, and sorghum are C_4-plants which are quick growing and highly efficient in photosynthesis (Noggle and Fritz, 1983). They can produce large amounts of green manure in a short period of time; (c) their residues are known to have allelopathic effects (Guenzi and McCalla, 1966). Whether they have a suppressive or competitive effect on the root rot fungi is currently under investigation. The question of the amount of green manure provided by different interseasonal crops and its possible effect remains to be examined.

It is generally acknowledged that addition of decomposed green materials to soil not only reduces root rot diseases (Manning and Crossan, 1969; Okpala, 1975; Papavizas and Davey, 1960; Pittman and Horricks, 1972) but also improves soil texture by lessening soil compaction. Soil compaction is known to promote root rots and is also detrimental to yield (Burke et al., 1972; 1980; Miller and Burke, 1974; Raghavan et al., 1978; Vigier et al., 1983).

The two tillage practices that were found to be better than the conventional fall ploughing are chisel ploughing and fall ploughing plus raised beds. CP is basically a no-till operation, thus much of the organic matter from the green manure operation remains on or near the surface of the ground. FPB is a raise-bed operation which reduces soil compaction and facilitates good soil drainage.

In conclusion, adoption of a suitable tillage practice together with proper choice of interseason green manure can significantly reduce root rot severity of peas grown in a field infested with the fungi.

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APPLICATION OF FUNGICIDE TO BRASSICA SEEDS USING A FILM-COATING TECHNIQUE

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ABSTRACT

The use of a prototype fluidised-bed seed treater to apply iprodione in a polymer film coat to cabbage seeds infected with Alternaria brassicae and A. brassicicola is described. Analysis of seed-to-seed variability in dosing demonstrated the greater accuracy of application of iprodione and control of A. brassicae by film-coating than by slurry or dust methods. Some reduction of superficial inoculum of A. brassicicola was obtained by application of polymer film-coat.

INTRODUCTION

Film-coating involves the application of a relatively thin, durable coat of polymer adhesive to seeds. The coat is water-permeable allowing treated seeds to germinate normally. Polymer adhesives can be used to fix many additives, such as pesticides, to seeds. Film-coating has been used commercially in the vegetable seed trade in the UK for the past 5 years, however, not all commercial film-coating systems are based on one principle and the relative merits of their performances are not known. In commercial practice, low-dose seed treatment fungicides (up to 5 g a.i./kg seed) have been coated onto seeds with up to 90% of the target dose achieved (Suett et al. 1985).

Film-coating would therefore appear to have advantages over the more conventional methods for applying dust and slurry formulations of fungicides to seeds (Maude et al. 1986). Inefficient retention of these formulations may reduce their efficiency and result in practical problems, for example, blockages in seed treatment machinery (slurries) and in field drills (dusts) as well as operator hazards. Although residue analyses of commercially-produced film-coated seeds have been made (loc. sit.), little is known of the biological efficacy of such techniques (Hall 1975, Sauve & Shiel 1980).

To evaluate film-coating on an experimental basis, a prototype unit capable of treating 20-500 g seed was constructed at IHR, Wellesbourne according to a design supplied by the Chemical Engineering Department of Birmingham University. This unit is based, as are related commercial systems, on the Wurster process (Wurster 1959, Hall & Pondell 1980) in which seeds are suspended in a moving column of air (fluidised bed) and are sprayed with a polymer sticker which dries as it coats the seeds. Initial tests of this prototype seed treater were made by film-coating the fungicide iprodione onto cabbage and oilseed rape seed samples, some of which were infected by Alternaria brassicae and A. brassicicola.

Chemical residue analyses were made of the distribution of iprodione on single seeds and on bulked samples of 100 seeds from size-graded seed stocks. Similar analyses, and seed infection tests, were used to assess the performance of iprodione over a range of treatment rates and to compare its efficiency, when coated onto seeds with that of slurry and dust applications of the same fungicide.

MATERIALS AND METHODS

Seeds

Oilseed rape cv Bienvenu was used for tests of recovery of iprodione from seeds of different size grades obtained using a series of round-holed sieves and by shelf-width separation using a Decca Mastercount seed counter. Two samples of Cotswold Queen cabbage seeds which were naturally infected with A. brassicicola only (G738) and with A. brassicae and A. brassicicola together (G960) were used to assess the biological effectiveness of the seed treatments.

Seed treatments

Graded rape seeds were film-coated with iprodione (Rovral Flo - 25% a.i.) at 2.5 g a.i./kg seed. Infected cabbage seeds were film-coated with 0.31, 0.63, 1.25, 2.5 and 5.0 g a.i./kg seed. A polymer concentration of 0.5% w/w was used for all applications and the treatment was applied over 30 min at 30°C. A rotating pan laboratory seed-treater (Maude et al. 1986) was used to apply iprodione (Rovral 50% WP) as a dust and slurry (seeds received 5.6 ml water per kg before fungicide was added) to cabbage seeds at the application rates stated.

Infection assessments

Infection was assessed after 10 d incubation at 21°C on Prune Lactose Yeast Agar and seed and seedling infection after 14 d incubation at 21°C on moist cellulose pads on a Copenhagen tank. Recognition of the pathogen was by colony colour and appearance of the conidia when viewed under a low power stereo-microscope.

Analysis of iprodione on seeds

Iprodione-coated seeds were analysed by (a) extracting single seeds for 1 h in 1 ml hexane/acetone (4:1) and (b) extracting two replicate samples of 100 seeds for 1 h in 50 ml of hexane/acetone (4:1). Solution concentrations were determined using a Packard model 438 gas-liquid chromatograph with a 50 cm column packed with 1.5% OV17 and 2% OV210 on Chromosorb W-HP (80-100 mesh). Detection was by alkali-flame ionisation detector. All samples were injected manually and compared with external standards. Peak areas were measured by a Spectra Physics model 4270 computing integrator.

RESULTS

Relationship between seed size and uniformity of film-coated iprodione on rapeseed

Variability between single seeds

Table 1 shows the variation in individual seed weights in a batch of size-graded rapeseed and in two sub-fractions of that seed.

TABLE 1
Relationship between seed size and uniformity of iprodione film-coat applications to individual rape seeds

Seed dia. (mm)	Untreated seed wt (mg) mean	range	% CV	Iprodione loading, mg/kg mean	range	% CV
2.0 -2.5	4.70	2.6-7.1	16.3	2.15	1.3-2.9	17.6
2.0 -2.25	4.55	3.5-5.8	10.8	1.93	1.4-2.8	19.7
2.25-2.5	5.85	5.0-7.3	9.2	2.41	1.8-3.5	17.0

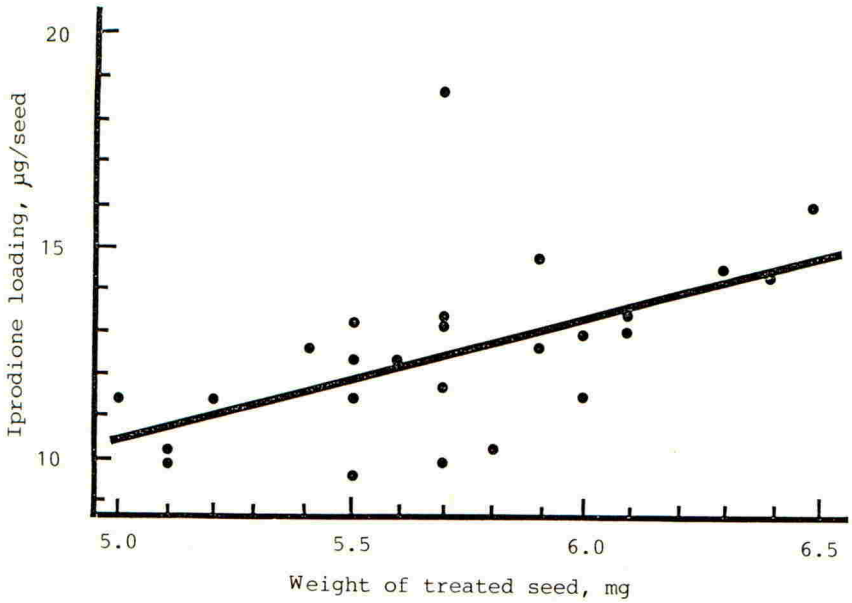

Fig. 1. Relationship between treated seed weight and iprodione loading.

Although fractionation into the two narrower size-grades almost halved the between-seed weight variability of the initial batch of seed, the variability of subsequent iprodione loadings on individual seeds was similar in all three batches. The relationship between iprodione loadings and the weight of 25 individual treated seeds from the 2.25-2.5 mm dia. fraction is shown in Fig. 1. The weights of the treated seeds ranged from 5.0-6.5 mg (CV = 7.0%) whereas the fungicide loadings ranged from 9.5-18.6 µg/seed (CV = 16.2%). Film-coating thus improved the uniformity of seed weight (CV reduced from 9.2 to 7.0%) but the distribution of iprodione between individual seeds was more variable, although much of this increased variability was due to the presence of a single excessively-coated seed, the absence of which would have limited the variability to 13.5%.

Effect of application method on treatment accuracy

Fig. 2 shows the differences between the target fungicide loading and those achieved by the three different application methods at each of the five dose levels. The dust and the slurry applications yielded loadings that ranged from 63-81% and 71-81% of target respectively, compared with loadings of $>$ 93% of target with the film-coat treatment. In all three applications, differences between target and achieved loadings increased with increasing dose.

Effect of film-coating and method of application of fungicide on disease control

Toxicity of the film-coat polymer to seed-borne infection

In initial agar tests of A. brassicicola-infected cabbage seeds (G738), application of 0.5% polymer alone reduced the number of infected seeds from 35.5% to 12.0% (Table 2), a result similar to that obtained with the lowest rate of application of iprodione in film-coat. Reduction of seedling infection (Copenhagen tank assessment) was even greater, i.e. from

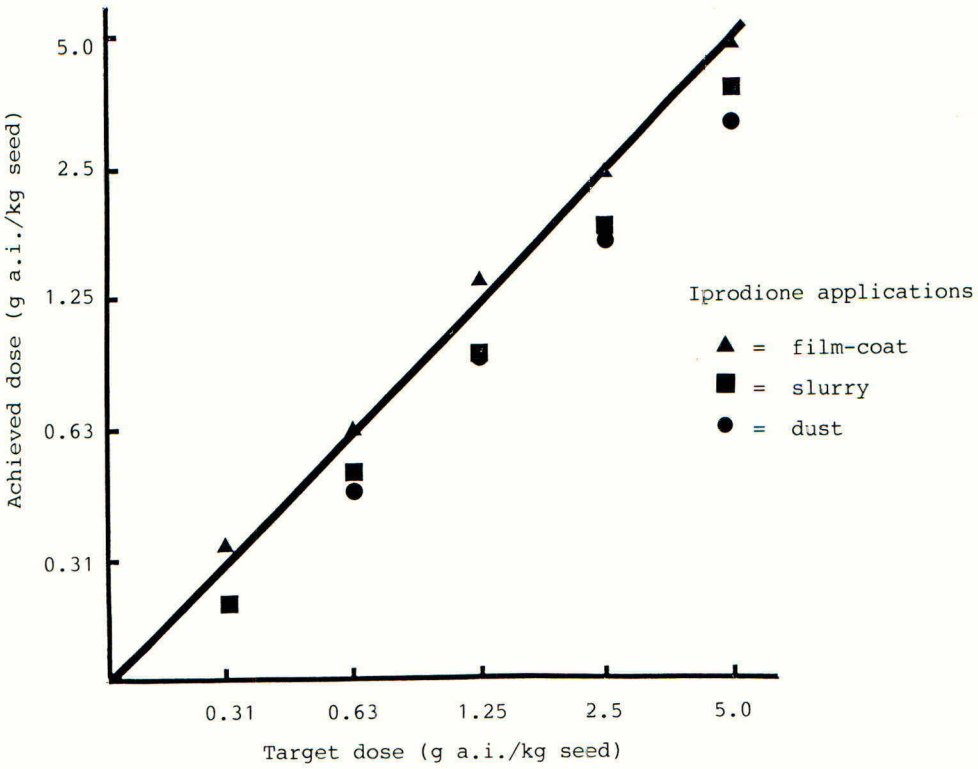

Fig. 2. Comparison of target and achieved doses of iprodione from film-coat, slurry and dust applications.

22.5% (nil treatment) to 1.0% (polymer treatment). In tests of G960 cabbage seed infected with both pathogens, the polymer alone reduced A. brassicicola infection to a similar extent but gave no reduction of A. brassicae infection.

TABLE 2
Effect of polymer film-coat on seed-borne Alternaria

Seed treatment	% seeds infected by A. brassicicola G738	A. brassicicola G960	A. brassicae G960
Nil	35.5	50.3	20.4
Film-coat	12.0	20.1	22.2
Film-coated iprodione (0.3 g a.i./kg)	10.0	8.6	2.0

Surface sterilisation tests on both seed samples and the spraying of water onto seeds in a fluidised bed for 30 min at 30°C gave similar reductions in the incidence of A. brassicicola but not A. brassicae. As it seemed probable that superficial inoculum of A. brassicicola was being reduced by all of the treatments described, the effectiveness of fungicide seed treatments in subsequent experiments was measured against the reduction in incidence of A. brassicae.

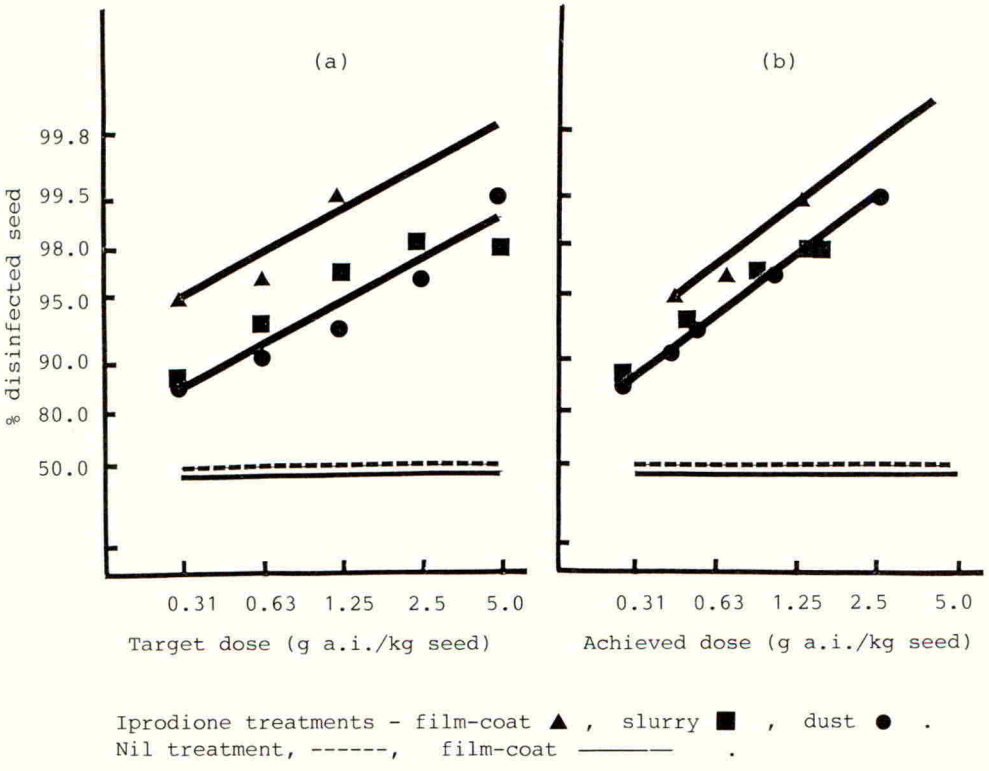

Fig. 3. Comparison of target (a) and achieved (b) doses of iprodione with different application methods on eradication of Alternaria brassicae.

Effect of treatment method on disease control

The results of film-coat, slurry and dust applications of iprodione on eradication of A. brassicae are given in Figs 3a and 3b. They are expressed as the number of disinfected seeds, i.e. those from which the fungus has been eradicated (nil treatment is 79.6% healthy seeds, 20.4% infected seeds) in relation to dose.

Film-coating of iprodione gave significantly better eradication of A. brassicae over the complete target dose range than did slurry and dust applications presumably, because rate-for-rate more iprodione was retained by seeds treated by this method (Fig. 2). When disease control was related to achieved doses of iprodione (Fig. 3b), the significant ($P = 0.05$) improvement with the film-coat application remained.

There were no adverse effects of the seed treatment application method on the germination of G960 cabbage seed. Iprodione dusted seeds (range 92--98%, mean 96.2%), iprodione slurried seeds (range 96.5-98.5%, mean 97.7%) and iprodione film-coated seeds (94.5-98.5%,mean 96.4%) germinated similarly to film-coated seeds (94.5%) and untreated seeds (95.5%).

DISCUSSION

The prototype fluidised bed seed treater was highly effective in that target applications of iprodione with a polymer sticker achieved more accurate loadings on seeds than when equivalent rates of iprodione were applied by slurry or dust methods, so that the resultant eradication of seed-borne Alternaria was greater at all doses. Although the polymer itself was not toxic to Alternaria, it reduced the incidence of superficial inoculum of A. brassicicola in two seed samples. The mechanism of this effect is not fully understood but it is possible that the time/temperature effect (30 min exposure at 30°C) during treatment may have been toxic to the more superficial inoculum on the seed coats of cabbage.

Brassica (rapeseed) seeds are relatively uniform but treatment variability was not always correlated with variability in seed size. Initial grading of seeds would seem to be necessary to minimise this variability. Although film-coating of iprodione increased seed-to-seed variability, with rapeseed, this should not exceed 5%. Optimisation of treatment uniformity will allow larger doses of fungicide to be applied safely and will minimise failure due to underdosing.

Tests are continuing with the prototype system and pesticide mixtures are now being applied to a range of vegetable seeds to control fungal pathogens and insect pests.

ACKNOWLEDGEMENTS

We are grateful to A. A. Jukes and Judith M. Bambridge for technical assistance and to Kathleen Phelps for statistical analyses.

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SPRAY CHAMBER EVALUATION OF CHARGED, UNCHARGED AND HYDRAULIC SPRAYS FOR DEPOSITION AND EFFICACY AGAINST *Tetranychus urticae* [1]

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ABSTRACT

Charged and uncharged sprays from the same air-atomizing nozzle, and hydraulic spray applications were evaluated in a spray chamber for deposition on intact bean leaves and bean leaves cut into 3 different shapes. Sprays containing fenpropathrin or bifenthrin were used. Results were assessed by bioassay with two-spotted spider mites (*Tetranychus urticae*) and, in some experiments, by adding fluorescent tracer to spray mixtures and photographing under UV light.

Based on bioassay and photography, the air-atomizing nozzle applications deposited more pesticide on lower leaf surfaces than hydraulic sprays and the charged sprays were generally more effective than uncharged sprays. Leaf shape had no apparent effect on deposition.

INTRODUCTION

A primary goal of pesticide application research is to improve efficiency. One method investigated involved electrically charged sprays. A spray cloud containing charged droplets will, in theory, induce the opposite charge in the plant and result in better coverage of all leaf surfaces and less spray drift. Research on electrostatic spraying of plants, in theory and practice, has been conducted for over 30 years. However, during the last decade, electrostatic spray application techniques have received more emphasis.

In the USA, Law (1978) developed an embedded-electrode air-atomizing nozzle which charged the spray by induction. Experiments with this nozzle showed that charged sprays increased deposition on both target models and foliar targets of different shape (Law and Lane 1981) by up to seven-fold compared to uncharged application.

In England, electrodynamic spray charging (Coffee 1980) and spinning disc electrostatic sprayers (Arnold and Pye 1980) have also been developed.

Several successes of electrostatic spraying in the field have been documented (Law and Mills 1980; Arnold *et al.* 1984a,b, Lane *et al.* 1984). Often, only one half of the active ingredient has provided the same degree of crop protection as conventional (hydraulic) application at full rate with a large reduction in application volume (Cayley *et al.* 1984). In glasshouse studies, electrostatic spraying resulted in increased deposition on broccoli leaves, compared to that from uncharged and hydraulic sprays (Law 1982).

Electrostatic sprays do not always result in improved pest control (Cayley *et al.* 1984). Foliar canopy penetration is sometimes poor with electrostatic sprays resulting in heavy deposition on apical plant areas, and little on basal areas. Leaf shape can affect pesticide deposition. Law and Lane (1981) found that pointed leaves may ionize the surrounding air, allowing current to flow and partially neutralize the charged cloud, resulting in reduced deposition.

We report here a summary of results after evaluation of an experimental embedded-electrode, internal mix air atomizing nozzle (Nordson Corp., Amherst, OH) in spray chamber experiments. Our objectives were to: 1) compare efficacy of charged and uncharged sprays of various pesticides and application rates from the same nozzle and hydraulic sprays against the two-spotted spider mite (*Tetranychus urticae*); 2) determine effects of leaf shape on efficacy; and 3) record spray coverage and distribution using fluorescent tracer and UV photography.

MATERIALS AND METHODS

Two series of experiments were conducted with the air-atomizing nozzle; one utilizing fenpropathrin 2.4EC and the other bifenthrin 2EC. Both pesticides are pyrethroids with demonstrated insecticidal and acaricidal properties. Based on information from manufacturers, neither compound has systemic or vapor toxicity properties. Air-atomized applications of fenpropathrin (charged and uncharged) were compared with conventional hydraulic applications. Bifenthrin was applied using only the air-atomizing nozzle (charged and uncharged).

All spray applications were made in a spray chamber (Franz 1985). The spray nozzle moved along a track at 3.2 km/h. Target tops were 45.7 (bifenthrin) or 60 cm (fenpropathrin) below the electrostatic nozzle and 25.4 cm below the hydraulic nozzle (fenpropathrin). The liquid flow rate in the air-atomizing nozzle was 75 ml/min, corresponding to an application rate of 78.6 liters/ha. The atomizing air pressure used was 138kPa, liquid pressure was 90kPa and spray current +3.0μA with electrode voltage of -1000V. Under these conditions droplets of

approximately 57 µm (charged) and 86 µm (uncharged) vmd were produced (H. Retzer, pers. comm.).

A flat-fan hydraulic nozzle (Spraying Systems No. 4001) was used for the fenpropathrin experiments at a liquid pressure of 138kPa. The nozzle delivered 280 ml/min (294 l/ha). The approximate vmd of droplets was 660 µm.

Lima bean, *Phaseolus vulgaris*, plants used in the experiments were grown in pots in a greenhouse until approximately 15 cm high. After fenpropathrin was applied, plants were thinned to 2 per pot and trimmed to 2 horizontal leaves. In the leaf shape experiments with bifenthrin, scissors, and cardboard templates were used to cut the first two expanded leaves into one of three target shapes (called shapes 1, 2, and 3) (Figure 1). The three shapes had the same total upper and lower surface area of 47.6 cm^2 but different numbers of points. Shape 2 had a single point with an included angle of 60°. Shape 3 had three points, each with an included angle of 23°.

Fenpropathrin 2.4EC was applied at 0.02 kg a.i./ha to four plants each in a series of five experiments comparing hydraulic, uncharged and charged sprays. In two experiments evaluating the effect of leaf shape on *T. urticae* control, uncharged and charged sprays of bifenthrin 2EC at 0.056 kg a.i./ha were applied to three plants of each shape.

To evaluate pesticide deposition, *T. urticae*, were confined on leaf discs (2.5 cm diam) from the centre of each leaf or leaf shape. Since each plant contained two leaves, one disc was used to assess upper surface deposition and the other the lower surface. The leaf discs were placed on water-saturated irrigation matting in trays, and five adult female mites placed on each disc. The trays were kept at 22-26°C and under fluorescent lighting. Mite mortality and the number of mites found off leaf discs were recorded after 72 h. Feeding injury was also rated on a 0-5 scale, based on the percent of leaf tissue injured.

Because of the range in mortality, data were subjected to an arcsin transformation prior to analysis, but actual percentages are shown in tables. Mean separation was according to Duncan's New Multiple Range Test (P=0.05).

Other experiments were conducted to photographically record spray deposits, using beans and water sensitive paper. Plants were sprayed with a fluorescent pigment (Day Glo Blaze Orange GT-15-N, Day Glo Color Corp., Cleveland OH) using uncharged and charged sprays. Upper and lower leaf surface deposition was photographed under ultraviolet light. Color photographs illustrated coverage well, but black and white photographs were not satisfactory, so are not included.

RESULTS

Fenpropathrin applications at 0.02 kg a.i./ha, resulted in little direct *T. urticae* mortality regardless of application method or exposed leaf surface (Table 1). Based on percentage of mites off leaf discs and feeding injury, all sprays gave good deposition on upper leaf surfaces.

TABLE 1.

Percent *T. urticae* mortality, mites off leaf discs and feeding injury, 72 h after being placed on bean leaf discs treated with hydraulic, charged and uncharged sprays of fenpropathrin (0.02 kg a.i./ha).

Treatment	Leaf surface[a]	%[b] Mortality	%[b] Off Disc	Feeding injury[b]
Hydraulic	U	12a	45 c	0.9a
	L	3a	5a	2.8 b
Charged	U	12a	54 c	0.6a
	L	5a	35 bc	1.4a
Uncharged	U	10a	43 c	1.3a
	L	16a	8ab	2.4 b
Untreated	U	6a	11ab	3.1 b
	L	8a	8a	3.3 b

[a] U = upper; L = lower
[b] Means of 5 experiments; means in each column followed by a letter in common are not significantly different (P=0.05) according to Duncan's NMRT; feeding injury rated as follows: 0 = no feeding, 5 = 75-100% with feeding scars.

However, the charged spray resulted in more mites moving off lower surfaces with less feeding injury than uncharged or hydraulic sprays, indicating more pesticide deposition. Percent *T. urticae* mortality 72 hr after being placed on leaf discs removed from bifenthrin-treated bean leaves of different shapes are in Table 2. There were no differences in mortality or feeding injury among leaf shapes within charged or uncharged spray treatments. All spray treatments resulted in 100% mortality when mites were confined on upper leaf surfaces and there was no feeding damage. On lower leaf surfaces, significantly less mite mortality occurred on leaves treated with uncharged sprays. However, after charged applications mortality on lower surfaces was statistically equal to that on upper surfaces. Feeding damage after uncharged sprays was significantly higher than after charged sprays, but less than that on untreated leaves.

TABLE 2.

Percent *T. urticae* mortality 72 hr after being placed on bean leaf discs treated with uncharged and charged sprays of bifenthrin (0.056 kg a.i./ha).

		Untreated	Uncharged			Charged (-1000V)		
			Leaf shape[a]					
			1	2	3	1	2	3
Exp. 1								
Leaf Surface[b]	U	13.3a	100d	100d	100d	100d	100d	100d
	L	26.7a	33.3bc	46.7c	33.3bc	100d	93.3d	100d
Exp. 2								
Leaf Surface[b]	U	13.3a	100c	100c	100c	100c	100c	100c
	L	6.7a	40b	46.7b	46.7b	86.7c	100c	93.3c

[a] See Fig. 1 for leaf shapes; means of 3 replications; for each experiment, means followed by a letter in common are not significantly different (P=0.05) according to Duncan's NMRT.
[b] U = upper; L = lower.

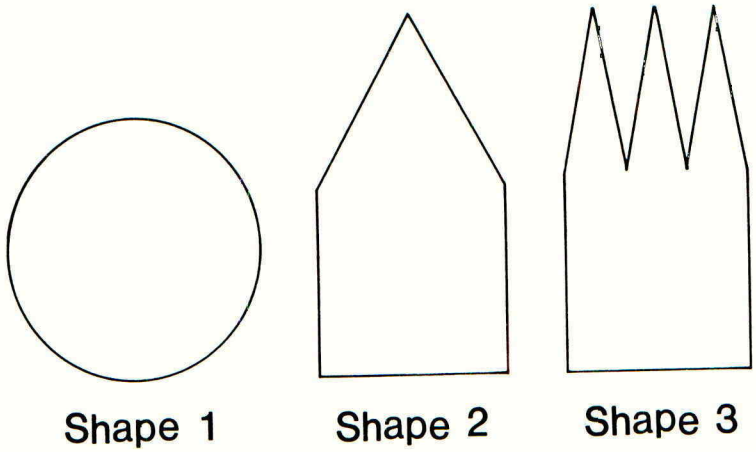

Figure 1. Leaf shapes used to evaluate deposition of fluorescent particles and bifenthrin for *T. urticae* control.

CONCLUSION

These data show that, based on bioassay, charged sprays of fenpropathrin and bifenthrin from the experimental nozzle resulted in more pesticide deposition on lower leaf surfaces than either uncharged or hydraulic sprays. Horizontal leaves cut into different shapes had no apparent effect on deposition with any spray method.

ACKNOWLEDGEMENTS

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THE INFLUENCE OF DROPLET SIZE AND AIR-ASSISTANCE UPON THE DISTRIBUTION OF ELECTROSTATICALLY CHARGED SPRAYS ON TOMATOES

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ABSTRACT

In a series of 8 sprays, the droplet deposition patterns of an air-assisted electrostatic sprayer, at 4 flow rates and using two different fans, were recorded on tomatoes. Droplet density on abaxial and adaxial leaf surfaces was assessed from leaf samples collected at 24 sites throughout each sprayed plot. Laboratory bioassay data were combined with information on application rates and droplet size spectra to demonstrate the effectiveness and efficiency of the treatments. The best combination of spray factors was the smallest droplet size (flow rate 0.8 ml/min; vmd = 18 µm) with the smaller fan (moving c. 1.5 m^3 air/min).

INTRODUCTION

Recent research, aimed at developing an understanding of the efficiency of insecticide application has illustrated that a small droplet size (c. 20 µm diameter) is the most influential of the numerous factors involved (Munthali 1984). Unfortunately, producing such small droplets and applying them to a crop without creating a 'drift' hazard are major obstacles to the feasibility of spraying field crops with small droplets. The advent of electrostatic spraying (Coffee 1979) provides, in theory, a means of reducing drift whilst improving the recovery of the applied chemical from the target area. However, air-assistance may be necessary if penetration of a crop canopy by a charged spray is required (Hislop et al. 1983, Adams & Palmer 1986).

In a preliminary study, where an air-assisted electrostatic sprayer was compared with the Ulvafan, the droplet deposition on abaxial surfaces was far greater when the spray was charged (Adams & Palmer 1986).

This report summarises subsequent research that has been conducted to assess the effect of altering the degree of air-assistance and the droplet size upon the spray deposition pattern and the biological result.

MATERIALS AND METHODS

Bioassays

Marked areas of tomato leaf infested, on the abaxial surface, with 1st instar whitefly (Trialeurodes vaporariorum) scales were sprayed with an oil-based ultra-low volume formulation of permethrin containing a fluorescent tracer (supplied by ICI). Each spray consisted of uniformly sized droplets (vmd:nmd = 1.0) and a range of droplet densities were applied. Mortality was assessed 7 days later.

Sprayer

An air-assisted Microdyne (Micron Sprayers Ltd.) developed from the ICI Electrodyn was used. Four flow rates were applied using the normal (N) fan

(c. 3.5 m^3/min air movement) and a smaller (S) fan (c. 1.5 m^3/min air movement).

Spray application

The plot for each spray treatment consisted of 12 tomato plants, 2.1 m tall, arranged in a double row with an inter-plant and inter-row spacing of 0.5 m. The spray was directed up and down each plant and the gap between plants at an angle of 45° to the horizontal plane.

Sampling

Each plot was divided into 24 sampling sites (Fig. 1). One leaf per site was collected from each of the 8 central plants in every plot. Two leaf discs (1 cm^2 each) were cut from each leaf and examined for adaxial and abaxial spray deposits under u.v. light. The figures for the outer (W and E) and inner (MW and ME) sites were pooled at each of the 6 vertical levels.

RESULTS

The bioassay results are shown in Table 1. The number of droplets per cm^2 required for a 50% kill (LN50) was calculated using logit analysis. On the basis of these results, 6 droplet density classes were chosen to facilitate the assessment of the spray distribution in each treatment (Table 2).

There were two main criteria for comparing the efficiency of each treatment: the proportion of droplets on abaxial and adaxial surfaces; and the droplet densities on the outer sites compared with the deposits in the middle of the row. The scoring systems that were used to quantify these criteria are discussed in greater detail elsewhere (Abdelbagi, 1986). In addition, allowances were made for the LN50s at different droplet sizes, and the total amount of a.i. applied per plot since these parameters will influence the effectiveness and efficiency of insecticide usage. Furthermore, since the more susceptible developmental stages of the pest are found at the top of the plant, deposits at levels 4-6 are most important.

TABLE 1

Droplet densities required for 50% kill (LN50) of 1st instar whiteflies on tomatoes in laboratory ULV spray bioassays

Permethrin concentration (g/l)	Droplet size vmd (µm)	LN50 ($drops/cm^2$)
100	100	39
100	40	52
50	40	60
10	40	104

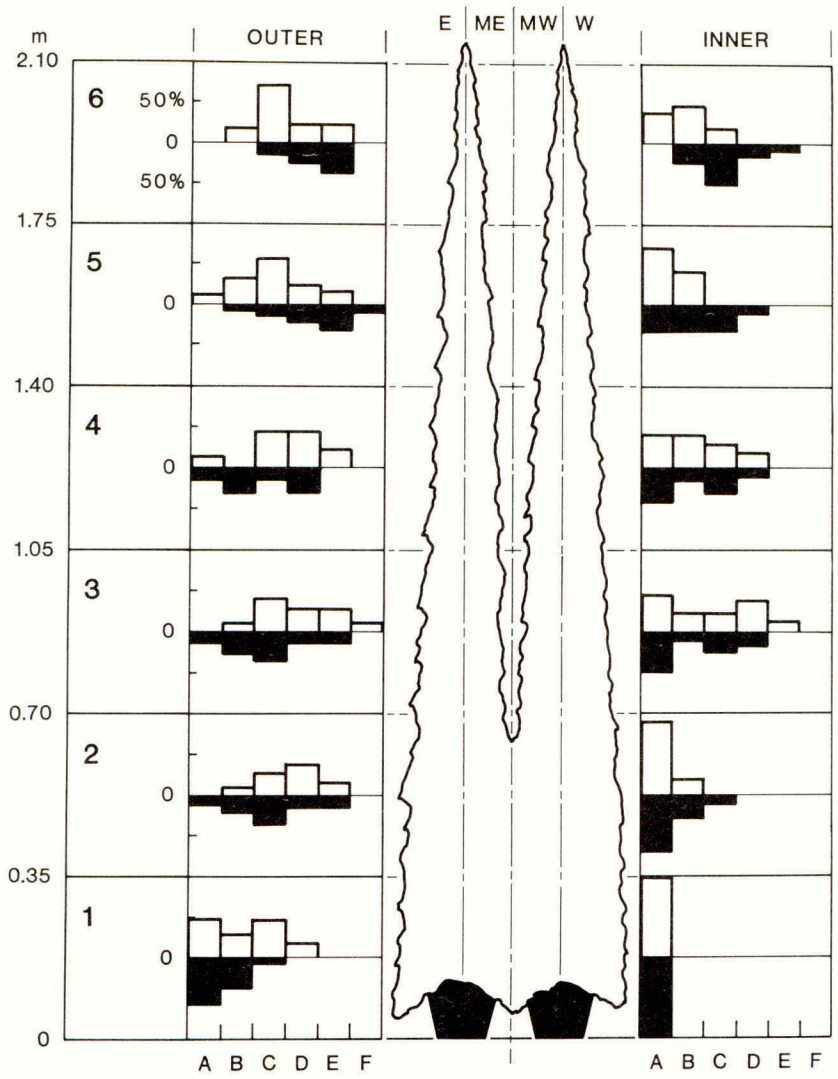

Fig. 1. Diagrammatic section through a row of tomatoes to show the position of the 24 sampling sites. The histograms depict the distribution of spray droplets on the tomato plot sprayed using a flow rate of 0.8 ml/min and the smaller fan. Upper (unshaded) and lower (shaded) deposits are shown in six droplet density classes (see Table 2) and the data have been grouped into outer (E + W) and inner (ME + MW) positions at each vertical sampling level.

TABLE 2

Classification of droplet densities on treated leaves

Class	Droplet density (drops/cm^2)
A	<25
B	25–50
C	51–100
D	101–150
E	151–200
F	>200

The best spray treatment was the lowest flow rate with the smaller fan and this deposition pattern is illustrated in Fig. 1. The deposits on the outer leaves were consistently higher than those taken from the middle sites, but this was outweighed by the results at levels 4–6 where, with one exception (4, outer), the abaxial deposits were greater than those on the adaxial surfaces.

DISCUSSION

In a glasshouse, the relatively still air, and the facility to direct a spray upwards towards the apical regions of tomatoes should provide near-ideal conditions for air-assisted electrostatic application of insecticides to control whiteflies.

Using the bioassay data in Table 1 and the droplet density classes shown in Table 2, it is possible to interpret the spray deposition data from each treatment (e.g. Fig. 1) in two ways: the likely biological effect of a standard spray mixture; and the possibilities for altering application parameters such as concentration of a.i., spraying time or flow rate to improve the efficiency of both the chemical and labour input.

Table 3 indicates that, for a standard spraying time, the lowest flow rate is most efficient in terms of spray volume and, as a result, amount of a.i. used. At most flow rates, the normal fan gave better spray distribution and canopy penetration. The notable exception was at the lowest flow rate (Fig. 1) where the lack of momentum of the smallest droplets (vmd = 18 μm) due to the smaller fan may have been responsible for the low adaxial surface deposits on the topmost leaves and which was clearly advantageous in improving the proportion of the spray reaching the abaxial (target) surface. At levels 4–6, in Fig. 1, abaxial droplet densities were commonly in excess of 50 drops/cm^2 whilst it was encouraging that very few discs had densities of over 200 drops/cm^2, thus avoiding "overkill" and waste of chemical.

TABLE 3

Efficiency ranking of the spray distribution on the crop in each treament

Rank	Flow rate (ml/min)	Fan	Spray time (secs)	Droplet size vmd* (μm)	Spray uniformity vmd:nmd*
1	0.8	S	70	18	1.13
2	1.8	N	72	27	1.08
3	0.8	N	66	18	1.13
4	1.8	S	66	27	1.08
5	3.0	N	65	40	1.15
6	3.0	S	72	40	1.15
7	7.0	N	72	56	1.07
8	7.2	S	68	56	1.07

*Data from Malvern 220/330 particle sizer V2.2

The results presented here demonstrate that accurate placement and dose control of insecticides are possible for the control of whiteflies using the air-assisted Microdyne.

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DEPOSITION OF IPRODIONE ONTO POTTED GREENHOUSE CROPS USING A ROTARY ATOMIZER[1]

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ABSTRACT

Deposition of 5% a.i. iprodione onto potted greenhouse crops via a spinning disc applicator was measured using a bioassay technique. Quite good coverage of both upper and lower leaf surfaces of a potted geranium crop growing on benches was achieved if the applicator was aimed ahead into the crop and swept from side to side over the bench. Middle and lower leaves of a densely foliated, closely spaced bench grown azalea crop received only from 1/5 to 1/10 as much iprodione as upper leaves. Treatment of a similar ground bed crop resulted in better foliage penetration.

BACKGROUND AND OBJECTIVES

Air assisted, rotary atomizers are popular low volume pesticide applicators that seem well suited to specialty agriculture, such as glasshouse potted plant production (Freed 1982, Powell 1984, Sheldrake 1984). Greenhouse growers prefer low volume pesticide application technologies because of the savings in time; ease of application with small, portable devices; small amounts of water used; and freedom from visible residues deposited on plant surfaces. Data regarding the actual toxicant residues deposited on plant surfaces of greenhouse crops is scarce (Jarrett, Burges, and Matthews 1978, Powell and Lindquist, 1983). This study was designed to measure deposition and distribution of pesticide on surfaces similar to plant foliage, placed within the canopy of a sparsely foliated crop (azaleas). The crops were growing on benches or on ground beds in actual production greenhouses.

MATERIALS AND METHODS

A Turbair Fox containing Turbair Rovral (5% a.i. iprodione) was used in all deposition studies (Lewis and Sylvester 1980). Two potted crops were used in the study. The first was a crop of florist geraniums (Pelargonium hortorum cv Sincerity) growing in 10 cm pots on a greenhouse bench 80 cm above the ground. The bench was 1 m across and 30 m in length. Spray was applied by walking along one or both sides of the bench, with the sprayer aimed at an agle outward and downward so that spray intercepted plant foliage 2.4 m ahead of the applicator. The sprayer was either held steadily ahead or swept back and forth over the crop. The plants were finished (mature), blooming and spaced on 15 cm centers across and along the bench.

The second crop was azalea (Rhododendron indicum cv Redwing), growing on benches as above or on ground beds. The plants were in 15 cm pots on 30 cm centers. The ground beds were 3 m across. Spray was applied to these azalea crops as described above.

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Iprodione deposition on surfaces in the crop was measured via a bioassay technique (Powell and Lindquist 1983). Unexposed photographic film (35 mm) was cleared with hypo, rinsed well and cut into 25 sq cm pieces. These pieces were clipped onto upward or downward facing leaf surfaces with the emulsion side outwards. After an application, the film pieces were immediately taken to the laboratory, placed in Petri dishes over dampened filter paper, and misted with 0.45 ml of nutrient broth per Petri dish. They were then inoculated with 0.15 ml of a freshly prepared Botrytis cinerea spore suspension (in water). After 24 hours at 27C, germination % was noted and compared with appropriate controls. Five replications per sampling location were examined in each experiment.

RESULTS AND DISCUSSION

Deposition was quite even on all leaf surfaces examined in the geranium bench crop (Table 1). Moving the sprayer back and forth across the crop resulted in more even coverage than holding it steadily ahead. Spraying the crop in two directions via two passes over the bench did not improve the nature of the coverage, but did serve to double the dosage.

With the densely canopied azalea crop, considerable variation in deposition dosage from upper to middle and lower leaves was noted (Table 2). Although aiming the applicator into the crop improved deposition, the screening effect of the foliage on the ground bed azalea crop was not as great (Table 3). Drift and deposit of iprodione into adjacent non-sprayed benches was measured and found to be less than 5% of the iprodione on the sprayed benches (Table 2).

The air assisted, rotary atomizer appears to provide very even coverage onto the leaves of an open canopied crop such as geraniums. However, the screening effect of densely canopied crops was significant and may result in poor crop protection. This would be of special concern for growers spacing such crops closely on benches. Perhaps further changes in applicator procedures will provide more adequate foliage penetration on densely canopied crops.

TABLE 1

Deposition of iprodione onto bench grown potted geraniums using a disc applicator, 2 passes over the bench at 1 pace per second

Plant Location	Leaf Canopy Level	Leaf Surfaces	Deposited Iprodione (ug/sq cm)* Aimed Steadily Ahead	Swept Back and Forth
Near edge of bench	Top	Upper	3.8 DE	4.2 H
		Lower	3.7 D	4.0 G
	Center	Upper	3.5 BC	3.9 FG
		Lower	3.7 DE	3.8 CDE
	Lower	Upper	3.5 BC	3.5 A
		Lower	3.7 CD	3.9 DEF

TABLE 1 (continued)

Plant Location	Leaf Canopy Level	Leaf Surfaces	Deposited Iprodione (ug/sq cm)* Aimed Steadily Ahead	Swept Back and Forth
Center of bench	Top	Upper	4.3 H	4.2 H
		Lower	4.1 G	4.0 G
	Center	Upper	3.9 DEF	3.8 CDE
		Lower	4.0 FG	3.9 DEF
	Lower	Upper	3.9 EF	3.8 BCD
		Lower	4.0 FG	3.9 EFG
Far edge of bench	Top	Upper	3.5 BC	4.0 G
		Lower	3.8 DE	3.7 B
	Center	Upper	3.5 B	3.7 BC
		Lower	3.0 A	3.7 BC
	Lower	Upper	3.1 A	3.7 BC
		Lower	3.0 A	3.7 BC

*The letter(s) following each average indicate the Duncan's New Multiple range groupings. Averages followed by the same letter(s) do not differ significantly at the .05 level.

TABLE 2

Deposition of iprodione onto upper surfaces of leaves of bench grown azaleas using a disc applicator, one pass over the bench at 1 pace per second

Sprayer Aiming	Leaf Canopy Level	Deposited Iprodione (ug/sq cm)*
Level over crop Near edge of bench	Top	0.9 F
	Center	0.2 CD
	Lower	0.1 ABC
Level over crop 4 m from near edge of treated bench	Top	0.1 ABC
	Center	0.0 AB
	Lower	0.0 A

TABLE 2 (continued)

Sprayer Aiming	Leaf Canopy Level	Deposited Iprodione (ug/sq cm)*
Aimed into crop		
Near edge of bench	Top	0.9 F
	Center	0.3 D
	Lower	0.1 ABC
Aimed into crop	Top	0.5 E
Far edge of bench	Center	0.2 BCD
	Lower	0.1 ABC

*The letter(s) following each average indicate the Duncan's New Multiple range groupings. Averages followed by the same letter(s) do not differ significantly at the .05 level.

TABLE 3

Deposition of iprodione onto surfaces of leaves of ground bed grown azaleas using a disc applicator, two passes over the crop from one side at 1 pace per second

Plant Location	Leaf Canopy Level	Leaf Surface	Deposited Iprodione (ug.sq cm)*
Near edge of bed	Top	Upper	7.3 EF
		Lower	2.5 B
	Center	Upper	5.0 D
		Lower	1.3 A
	Lower	Upper	2.5 B
		Lower	1.0 A
Center of bed	Top	Upper	7.7 F
		Lower	2.7 B
	Center	Upper	6.7 E
		Lower	1.4 A
	Lower	Upper	4.4 CD
		Lower	0.9 A
Far edge of bed	Top	Upper	6.7 E
		Lower	2.6 B
	Center	Upper	3.9 C
		Lower	1.4 A
	Lower	Upper	2.5 B
		Lower	1.0 A

*The letter(s) following each average indicate the Duncan's New Multiple range groupings. Averages followed by the same letter(s) do not differ significantly at the .05 level.

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METHODS OF CYROMAZINE APPLICATION FOR LEAFMINER, *Liriomyza trifolii*, CONTROL IN GLASSHOUSES

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ABSTRACT

Three methods of applying the IGR cyromazine were evaluated for the reduction of damage by the leafminer *Liriomyza trifolii*. Foliar sprays of cyromazine (0.15 g a.i./litre) resulted in 100% leafminer mortality. Drenches to substrates, where larvae dropped to pupate, resulted in 100% mortality. However, a rate of 0.48 g a.i./litre (applied at the rate of 32 g a.i./m^2) was required. When the drench was applied to potting media, a solution of 0.2 g a.i./litre was adequate to result in 100% mortality of larvae within leaves of chrysanthemum plants growing in the media. Cyromazine application was compatible with parasite populations.

INTRODUCTION

Over the last decade, the leafminer *Liriomyza trifolii* has been a serious problem on glasshouse ornamentals and vegetable crops in the United States. One of the reasons for the severity of this problem was the lack of registered insecticides effective in controlling this insect. Some materials were effective for a short period of time but then leafminers became resistant to them. The lack of long term success of insecticides has resulted in an emphasis on a thorough study of the methods for use of new insecticides and the interaction of these materials and other alternatives for management of leafminers (e.g. Herbert *et al.* 1984. Trumble 1984/85). The use of and the interaction of insecticides with parasites for leafminer control has been of special interest (e.g. Oetting 1985. Parrella *et al.* 1983. Patel and Schuster 1983).

The purpose of this study was to look at cyromazine efficacy for leafminers utilizing different application methods. Observations were also made on the compatibility of cyromazine and leafminer parasites. Cyromazine is an insect growth regulator which is efficacious against some dipterous insects.

MATERIALS AND METHODS

This study was conducted at the Georgia Agricultural Experiment Station, Experiment, Georgia during 1983-1985. The primary insecticide evaluated in the experiments was an insect growth regulator cyromazine [N - cyclopropyl-1, 3, 5-triazine-2, 4, 6-triamine] formulated as a 75% wettable powder. Abamectin 0.15EC and methoprene 4EC were also used in some experiments. Insects used in these tests were glasshouse reared on green beans (*Phaseolus vulgaris*) and chrysanthemums (*Chrysanthemum morifolium*).

Test plants were placed on glasshouse benches for leafminer infestation by the population present. The potting media used for the tests was a mix of peat moss, pine bark, perlite and sand (2:2:2:1, pH 6.4-6.6) and the soil was Davidson clay loam (Rhodic Paleudult, pH 5.9). All leaf samples and polypropylene containers were maintained in an environmental cabinet at 25°C and 14:10 hr photophase:scotophase. Randomized complete block design was used in each test. Leafminer larvae were obtained by removing last-instars with a camel-hair brush from leaf surfaces or from 30-cm Diam polystyrene trays placed under plants to collect larvae which fell from the leaves. The containers were continuously monitored for adult emergence and the adults were removed and recorded. Data were analyzed by analysis of variance, all percent data were transformed (arcsin), and means were separated by Duncan's multiple range test (P = 0.05).

Experiment 1

This experiment was conducted to determine the effect of foliar application of cyromazine and abamectin on leafminer survival. Foliar applications were to green beans on raised glasshouse benches using a compressed air sprayer at 2.1 - 2.5 kg/cm^2 utilizing a 8003 nozzle. Each plot consisted of 25 pots (15-cm Diam) containing 5-6 plants each and was replicated 4 times. The plants had 2 fully developed true leaves and had been exposed to a leafminer population throughout development. The treatments were abamectin at 0.06 and 0.12 g a.i./l, cyromazine at 0.15 and 0.3 g a.i./l, and a water check. Efficacy was determined by removing 10 leaves from each treatment at 4 different intervals following application: 4 hr and 1, 2, and 4 days. These leaves were evaluated by counting active mines and were then placed in 250 ml paper cartons to observe leafminer development. The survival of *Diglyphus* sp. and *Oenonogastra microrhopalae* parasites was also recorded.

Experiment 2

This experiment was designed to evaluate leafminer survival in soil when larvae were introduced to the soil at different intervals before and after application of cyromazine as a drench. Plots consisted of 5-cm Diam x 3.5-cm tall polypropylene units, each with a snap-on lid containing a 4-cm hole with a voile covering and were filled with clay loam to a depth of 2 cm. Cyromazine was applied as a liquid drench by the addition of 10 ml of insecticide solution (0.12 a.i./l, 8 g a.i./100 m^2) to the soil. The check received 10 ml of water. Twenty five leafminer larvae were added to each container and plots were replicated 5 times. The effect of cyromazine on leafminer pupae already in the soil at the time of application was determined by placing larvae on the soil 7, 5, 3, 2, and 1 day before cyromazine application. The effect of cyromazine on larvae dropping to the soil after application was determined by introductions of larvae 0, 1, 2, 3, 5 and 7 days following application. The containers were then observed for adult emergence. The number of *Opius* sp. and *O. microrhopalae* parasites was also recorded.

Experiment 3

This experiment was similar to experiment 2 except that the treatments were different rates of cyromazine rather than time of application. Twenty five leafminers per container were introduced one day after application with 5 replications of each plot. The treatments were 5 rates of cyromazine drench expressed in g a.i./l (g a.i./100 m^2): 0.06g (4 g), 0.12g (8 g), 0.24 g (16 g), 0.48 g (32 g), and 0.96 g (64 g).

Experiment 4

This experiment was conducted to determine if cyromazine will translocate to the leaves and affect leafminer survival. Plots consisted of 15-cm Diam azalea pots containing potting media and 3 chrysanthemum plants and were replicated 4 times. Cyromazine treatments were 5 rates of application: 0.1, 0.2, 0.4, 0.8, and 1.6 g a.i./l. Chemical treatments were applied by pouring 100 ml of the solution in each pot. The plants were laid on polystyrene trays 10 days after application and the larvae/pupae were collected and placed in the polypropylene containers used in experiment 2.

RESULTS

The data obtained in the above experiments indicate that cyromazine can be efficacious applied as either a foliar spray or a drench. In the first experiment excellent control was obtained with both cyromazine and abamectin (Table 1). There were more pupae collected from samples taken on the day of application than from those taken later. This indicated that mature larvae may not be as susceptible to these materials. The pupal parasite *O. microrhopalae* was greatly reduced by insecticide application but the larval parasite *Diglyphus* was not. The only reduction in *Diglyphus* was from leaves collected 1 day after application indicating mortality of parasite adults the day of application. These data are similar to the results Parrella *et al.* (1983) obtained with *L. trifolii* and its' endoparasite *Chrysocharis parksi*.

TABLE 1

Effect of the IGR cyromazine on *L. trifolii* and its parasites. Leaves collected for analysis at different intervals following application. Data expressed as mean per 10 leaves[a].

Treatment (g a.i./litre)	*Diglyphus*	*O. microrhopalae*	*L. trifolii* pupae	*L. trifolii* adults
Leaves collected at 4 hr				
Abamectin (.06)	7.8 a	0 a	5.8 a	1.8 a
Abamectin (12)	8.8 a	0.5 a	2.0 a	0 a
Cyromazine (.15)	3.0 a	0 a	4.8 a	0.5 a
Cyromazine (.30)	9.0 a	0 a	5.5 a	0 a
Water Check	2.8 a	1.5 a	29.3 b	24.5 b
Leaves collected at 1 day				
Abamectin (0.6)	1.8 a	0 a	0.3 a	0 a
Abamectin (.12)	0.8 a	0 a	0.3 a	0 a
Cyromazine (.15)	1.0 a	0.3 a	0.8 a	0 a
Cyromazine (.30)	0.3 a	0 a	0.5 a	0 a
Water check	4.0 a	2.5 a	52.5 b	27.3 b
Leaves collected at 4 days				
Abamectin (.06)	4.5 a	0 a	0 a	0 a
Abamectin (.12)	1.8 a	0 a	0.5 a	0 a
Cyromazine (.15)	1.5 a	0 a	0 a	0 a
Cyromazine (.30)	2.5 a	0 a	0 a	0 a
Water check	3.0 a	2.8 a	16.3 b	9.5 b

[a] Means followed by the same letter are not significantly different (DMRT, P > 0.05).

In the second experiment cyromazine reduced *L. trifolii* survival but was not efficacious at the 0.12 g a.i./l rate (Table 2). There was about 50% reduction when larvae were introduced to treated soil on the day of and the day after application. On the second day after application there was only 30% mortality.

TABLE 2

Effects of cyromazine drench on L. trifolii development when 8 g a.i./100 m^2 was applied to soil at different times in relation to larval exposure[a].

Day of application in relation to introduction of larvae	Percent survival			Percent leafminer mortality
	Leafminer	Pupal parasites	Total	
Cyromazine				
7 days before	49.6 bc	4.0 a	53.6 bc	26.4
5 days before	64.8 ab	0.8 a	65.6 ab	9.9
3 days before	73.6 a	2.4 a	76.0 a	0
2 days before	50.4 bc	4.0 a	54.4 bc	25.3
1 day before	50.4 bc	2.4 a	52.8 bc	27.5
day of application	34.4 c	2.4 a	36.8 c	49.5
1 day after	36.8 c	4.0 a	40.8 c	44.0
2 days after	48.8 bc	2.4 a	51.2 bc	29.7
3 days after	60.8 ab	1.6 a	62.4 ab	14.3
5 days after	59.a ab	1.6 a	60.8 ab	16.5
7 days after	63.2 ab	0 a	63.2 ab	13.2
Standard: Methoprene (day of)	4.8 d	0 a	4.8 d	93.4
Water check	70.4 ab	2.4 a	72.8 ab	-

[a] Means followed by the same letter are not significantly different (DMRT, P > 0.05)

A drench solution of 0.48 g a.i./litre was required to get 100% control of larvae introduced to treated soil in experiment 3 (Table 3). This was 4-8 times the concentration of the solution used effectively as a foliar spray.

TABLE 3

Effects of different rates of Cyromazine drench on leafminer development when third stage larvae were placed on treated soil[a].

Cyromazine g a.i./litre	Percent leafminers recovered	Percent leafminer mortality
0.06	41.0 a	12.8
0.12	25.6 ab	45.5
0.24	10.2 b	78.3
0.48	0 b	100
0.96	0 b	100
Water check	47.0 a	-

[a] Means followed by the same letter are not significantly different (DMRT, P > 0.05).

Cyromazine was shown to demonstrate systemic activity in experiment 4 (Table 4). When cyromazine was applied to potting media as a drench it was translocated to the leaves. A solution of 0.2 g a.i./litre was required to get 100% suppression of larvae in the leaves but significant reduction was obtained with 0.1 g a.i./litre which is equivalent to the concentration commonly used in foliar sprays. This experiment was repeated on green beans utilizing the 3 high rates. The plants were exposed to adult leafminers after application and the results were the same with 100% mortality for all rates.

TABLE 4

Systemic activity of cyromazine on L. trifolii survival when applied to potting media in which chrysanthemums were growing. Data expressed as mean per plant[a].

Cyromazine (g a.i./litre	Pupae recovered	Adult recovered
0.1	1.3 a	0.8 a
0.2	0 a	0 a
0.4	0 a	0 a
0.8	0 a	0 a
1.6	0 a	0 a
Water check	9.3 b	6.0 b

[a] Means followed by the same letter are not significantly different (DMRT, P > 0.05).

DISCUSSION

Cyromazine was efficacious against leafminer larvae with all application methods. Although it was effective as a drench for larvae dropping to pupate, the application rates were probably too high to be economical. The residual effectiveness was very short also. There was reduced effectiveness on larvae dropping to the soil 2 days following the drench. Therefore, application intervals might have to be as short as 3 days to adequately control larvae in the soil. The application of cyromazine to soil beneath glasshouse benches for larval control would not be a good control method. Cryomazine as a systemic insecticide was much more promising. Cyromazine applied to the potting media was translocated to chrysanthemum leaf tissue and controlled larvae in the leaves. The rates required were lower but no information is available on residual effects. This could be a good method of applying cyromazine or a secondary benefit of spray runoff.

Cyromazine is very effective as a foliar spray. It is not as effective on third stage larvae. However, most of the third stage larvae that did pupate did not survive to emerge as adults. The survival of larval ectoparasites was very encouraging. The application of cyromazine did not adversely affect their survival. Pupal parasites did not appear to be affected if the *L. trifolii* larvae survived until pupation.

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USE OF NEEM EXTRACT AS A SYSTEMIC TREATMENT FOR *Liriomyza trifolii* CONTROL ON GREENHOUSE CHRYSANTHEMUM 1/

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ABSTRACT

Crude neem extract and a neem formulation being developed for commercial use were evaluated as bare root treatments of rooted chrysanthemum cuttings prior to transplanting. Cuttings were placed in a series of aqueous neem concentrations for different time periods. Subsequent effects on *Liriomyza trifolii* and plant growth were measured. On plants infested 2 weeks after treatment with neem, there were significant effects on both plant growth and leafminer survival. All neem treatment rates and times reduced plant growth, with the greatest reduction generally occurring with higher neem concentrations and longer treatment times. Higher rates and longer treatment times also had the greatest effect on *L. trifolii* survival. Plant growth usually recovered after 4 weeks, as did leafminer survival. The treatment method used may be useful in protecting young plants from leafminer injury.

INTRODUCTION

Concern over the hazards associated with the use and manufacture of synthetic insecticides, and the rapid development of insect pests resistant to even the newest synthetic products has evoked interest in other pest control strategies, especially those that employ plant products and other materials that may be more compatible with natural enemies. Neem (*Azadirachta indica*) seed extracts have been evaluated as repellants and insecticides against a wide variety of insect pests (Jacobson, 1981;1985). Three feeding inhibitory triterpenoids (meliantrol, salanin and azadirachtin) have been isolated and identified from the neem seed with azadirachtin being the most effective (Ivbijaro 1983).

As a foliage spray, neem seed extract acts as a feeding inhibitor, an insect growth regulator or an insecticide against a wide variety of insects, including the leafminer *Liriomyza trifolii*. This pest causes severe injury to ornamental and vegetable crops in many parts of the world, due to larval mining of leaves, and has developed a high degree of resistance to several classes of insecticides. Webb *et al.*, (1983) and Stein and Parrella (1985) used neem seed extract in foliar sprays and found that insecticidal efficacy against early- and late-stage larvae was very high. Steam distillates and crushing and pressing of neem leaves yielded preparations effective against *L. trifolii* on bean and onion when leaves were dipped into or sprayed with the extracts

(Fagoonee and Toory 1984). Larew *et al.* (1985) found that insecticidal effects of neem soil drenches were systemic in chrysanthemum and were effective in controlling *L. trifolii* for up to 3 wk.

Neem seed extracts, however, have not been tested for the control of leafminers when used as bare root treatments with young plants or rooted cuttings. Treating cuttings or transplants by placing them in neem solutions could provide early control of leafminers without the labour and material output necessary for foliar sprays and soil drenches, because large numbers of plants could be treated in transit, before shipment or after receipt by the grower. Infested chrysanthemum cuttings have been suspected as a primary cause of the rapid spread of *L. trifolii* to areas where it is not a native species. Reported here are results of using crude and formulated neem seed extracts as bare root treatments for controlling *L. trifolii* on chrysanthemum cuttings.

MATERIALS AND METHODS

Initial experiments were conducted with crude neem extract obtained from Dr. Martin Jacobson, USDA Natural Products Laboratory, Beltsville, MD. Later trials were with an emulsifiable concentrate formulation containing 3000ppm azadirachtin (`Margosan-O´, Vikwood, Ltd., Sheboygan, WI).

Prior to treatment, rooting media was rinsed from chrysanthemum cuttings (cv 'Iceberg', obtained from Yoder Bros. Inc., Barberton, OH). Cuttings were then placed in each of the concentrations for the different time periods. When using the crude neem extract, aqueous concentrations of 0.5, 0.15, 0.075 and 0.037% were used. Cuttings were placed in 150 ml of each solution for 24h. In experiments with the EC formulation, four concentrations and three different treatment times were evaluated. The concentrations used were 0.1, 0.3, 1.0, and 3.0%, and treatment times were 2, 4 and 24 h.

Plants were treated in a laboratory maintained at 25.5°C under fluorescent lights and a 16 hour photoperiod. Immediately after treatment, without rinsing, plants were potted in 10 cm diam pots containing growing media consisting of Canadian peat and processed pine bark. The plants soaked in crude neem extract were kept on a greenhouse bench under a cheesecloth cage with temperatures fluctuating between 12.5 and 29.5°C. They were exposed to leafminer adults 14, 21 and 28 days posttreatment. Plants treated with the EC formulation were placed in an insect-free growing room maintained at 25.5°C and a 16 hour photoperiod for the pre-infestation period. They were exposed to leafminers 14 and 28 days posttreatment. Plants were left unpinched, irrigated as needed, and were fertilized weekly with 200 ppm of N, P, and K.

At the indicated infestation time four plants were selected from each treatment group and placed in a cage, in a greenhouse compartment,

with ca. 150 female *L. trifolii* for 6h. Plants were rearranged midway during the infestation period. Flies were then brushed off the plants and plants placed in insect-free cages to await egg hatch and larval development. After 5 days the number of visible mines per plant was recorded. In experiments with the EC formulation, the number of leaves per plant, and plant height from base to tip also were recorded. Plants were then cut at soil level and placed in 240ml plastic beverage cups filled with 1.25 to 2.5 cm fine moist sand. Cups were placed in a growth chamber maintained at 24°C for 3 days to await pupation. Plantswere then removed and pupae rinsed from the sand and counted. Pupae were then placed in plastic vials, and held in the growth chamber for adult emergence. When adults had ceased emerging from all vials, the number recovered from each plant was recorded.

RESULTS

In experiments using crude neem extracts (Table 1) the number of larvae recorded on treated plants was not affected by the neem treatments. However, percent larval survival (i.e., the number of pupae

TABLE 1

Effect of aqueous crude neem extracts used as pre-plant treatments for for *L. trifolii* control on chrysanthemum.

Wk after treatment	Neem conc. (%)	No. larvae	% Pupation	% Adult emergence
2	0.5	14.8ab	19a	1.5a
	0.15	18.0 b	17.5a	4.5a
	0.075	20.2 b	55 b	29 b
	0.037	13.0ab	23a	11ab
	0.00	6.8a	83 b	83 c
3	0.5	8.8a	17a	9a
	0.15	18.0a	29a	8a
	0.075	13.8a	17a	9a
	0.037	6.0a	48a	38a
	0.00	8.8a	89 b	83 b
4	0.5	22.2a	14a	3a
	0.15	18.2a	25a	13a
	0.075	16.2a	59 b	31 b
	0.037	8.8a	24ab	4.5a
	0.00	12.5a	88 c	88 c

All cuttings placed in neem concentrations for 24 h; means of 4 replications; for each treatment wk, numbers in each column followed by a letter in common are not significantly different (p=0.05) according to Duncan's NMRT.

TABLE 2.

Effect of an EC containing 3000ppm azadirachtin, used as a pre-plant treatment, on chrysanthemum growth and *L. trifolii* control 2 and 4 WK posttreatment.

Wk after treatment	Rate (%)	Treatment time (h)	Plant ht[a] (cm)	No.larvae/ leaf[a]	% survival[a]
2	3.0	2	13.7 bcd	1.1a	3ab
		4	11.3ab	0.8a	0a
		24	8.6a	0.7a	0a
	1.0	2	15.9 def	1.4abc	39abc
		4	14.0 bcd	1.2ab	33 bc
		24	12.1 bc	1.0a	0a
	0.3	2	12.7 bcd	1.2a	36 b
		4	15.2 cde	2.1abc	49 c
		24	11.4ab	1.6abc	8ab
	0.1	2	14.6 cde	1.9abc	48 c
		4	14.9 cde	2.6 bc	53 c
		24	14.0 bcd	0.7a	46 c
	0.0	2	18.7 g	1.5abc	78 c
		4	16.2 efg	1.7abc	67 c
		24	18.1 fg	2.8 c	73 c
4	3.0	2	21.3 bcd	1.2a	68 bcd
		4	20.6abc	1.1a	52 c
		24	*	*	*
	1.0	2	24.1 cde	0.4a	98 d
		4	24.8 def	1.2a	57 bcd
		24	15.6a	1.1a	9a
	0.3	2	19.5abc	1.6a	69 bcd
		4	20.3abc	0.9a	74 bcd
		24	20.3abc	1.0a	35ab
	0.1	2	25.7 ef	1.4a	85 cd
		4	18.7ab	0.9a	77 cd
		24	22.0 bcd	1.1a	83 cd
	0.0	2	26.4 f	1.6a	76 cd
		4	19.4abc	0.9a	87 bcd
		24	21.6 bcd	0.7a	84 cd

* Plants died.

a Means of 4 replications; means in each column for each treatment wk followed by a letter in common are not significantly different (P=0.05), according to Duncan's NMRT.

recovered) on treated plants was significantly lower in all but one case. Neem also affected pupal survival, as measured by the number of apparently healthy adults recovered. The percent adult survival from treated plants was significantly lower than from untreated plants at all intervals posttreatment, indicating that insecticidal effects persisted in chrysanthemum plants for at least 4 wk. For each treatment rate-interval combination there were some differences in larval and adult survival among treatment rates, but these were minimal. Particularly at the higher rates, at all intervals posttreatment, there were reductions in plant growth. However, these were not measured in this experiment.

In the experiment with the EC formulation (Table 2), in addition to leafminer control, plant height and number of leaves per plant were recorded. There were significant differences in both plant growth and leafminer survival. Higher application rates and longer treatment times had the greatest effects on plants and insects. However, these effects were greatest among plants infested 2 wk posttreatment. Plant growth had largely recovered among plants infested 4 wk posttreatment. Most of the insecticidal effects of the neem extracts disappeared between 2 and 4 wk, but there appeared to be some residual suppression of leafminer survival.

CONCLUSION

Our data indicated that pre-planting treatment of chrysanthemum cuttings may be an alternative application method for neem extract. Placing rooted cuttings in the 0.30% to the 1.0% concentrations of the EC formulation for several hours effectively reduced the chances of new *L. trifolii* infestations for several weeks. Control may last long enough to disrupt the leafminer cycle. Treatments using the crude neem extract apparently had a longer residual effect than the EC formulation.

Leafminer management now is difficult and is based on frequent insecticide applications. This management program has contributed to destruction of beneficial insects, development of insecticide resistance by the leafminer, resurgence of primary and secondary pests and hazards to humans and the environment (Stein and Parrella 1985). As pointed out earlier, neem formulations apparently will not pose as much hazard to humans and non-target organisms. Thus it is a strong candidate for inclusion in an integrated pest management programme for leafminer control on chrysanthemum. The U.S. Environmental Protection Agency has approved the registration of the EC neem formulation used in these experiments for leafminer control on ornamentals, shrubs and trees.

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MANAGEMENT OF *FUSARIUM* WILT OF CARNATION: AN INTEGRATION OF DIFFERENT CONTROL MEASURES (*)

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ABSTRACT

Several experiments have been carried out in recent years at Albenga (Northern Italy) using a combination of control measures with the aim of identifying an integrated system to control *Fusarium* wilt of carnation, incited by *Fusarium oxysporum* f. sp. *dianthi*. The use of soils partially suppressive to *Fusarium* wilt, carnation cultivars partially resistant to the most frequent races of *F. dianthi* and the application of fungicides during cultivation effectively reduced wilt symptoms. Several fungal antagonists, isolated from suppressive soils, particularly *Fusarium oxysporum* and *F. solani*, reduced *F. dianthi* growth and soil colonisation under glasshouse conditions. Benzimidazole-resistant strains of the most active antagonists, selected and used in combination with benomyl, reduced pathogen reintroduction in disinfected soil.

INTRODUCTION

Fusarium wilt still represents a serious threat in all the Italian carnation production areas (Garibaldi 1979). The control of this disease is difficult for many reasons, because of: 1) the easy reintroduction of *Fusarium oxysporum* f. sp. *dianthi* in disinfected soils through infected rooted cuttings; 2) the high cost of some cultural control methods (i.e. the use of raised benches); 3) the limited effectiveness of other control measures, such as soil fumigation and systemic fungicides; 4) the easy differentiation of new races by the pathogen. This last phenomenon, particularly frequent in Italy (Garibaldi 1983), complicates the work of carnation breeders in identifying cultivars resistant to *Fusarium* wilt. Although recently a few cultivars resistant to the 8 races of *F. dianthi* described in Italy were obtained by Italian breeders (Garibaldi, unpublished results), at present only the integration of different control measures offers the best prospects of control of *Fusarium* wilt.

The aim of a series of experimental trials carried out during recent years was to evaluate the effectiveness of combining different control methods in order to reduce wilt severity under glasshouse conditions in Northern Italy (Albenga) (Garibaldi & Gullino 1984). In this paper the

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results obtained by combining chemical and biological control measures are summarised.

MATERIALS AND METHODS

The experiments were carried out under glass and plastic houses at the Centro Orticolo Sperimentale of the Chambre of Commerce of Savona, located at Albenga (Northern Italy).
Cultures of F. dianthi, belonging to race 2 (isolate Fod 75) and 4 (isolate Fod 310) were used throughout the work. The pathogen was either grown in shake culture on casein hydrolisate for 5-7 days at 25°C or on sterile wheat kernels at 25°C for 15-20 days. The inoculation was carried out by dipping roots of rooted cuttings, before transplanting, for 30s in conidial suspensions (10^6 conidia/ml) of the pathogen or by accurately mixing with the first 20 cm of the soil, 20 g/m^2 of inoculated wheat kernels. A randomised block design, with 3 replicates, was used. Wilt severity was evaluated every 15-20 days using a disease index, previously reported by Garibaldi (1966).

Experiment I

A soil partially suppressive to F. dianthi, either steam disinfected or unsteamed, was artificially inoculated with 20 g/m^2 of wheat kernels infected with races 2 and 4. Before transplanting carnation plants, the soil was mixed or drenched with two fungicides (benomyl and captafol) used alone or in mixture. Five cultivars ('Elsy', 'Pallas', 'Oscar', 'Sonia', 'Raggio di Sole') showing different reaction to the 2 races of F. dianthi used (Garibaldi 1983) were transplanted a week after inoculation and treatment. Each plot (5 m^2) contained 28 plants/cultivar.

Experiment II

Steam disinfected soil was inoculated with a mixture of 5 antagonistic Fusaria (Garibaldi et al. 1986) resistant to benomyl and/or mixed before transplanting with 20 g/m^2 of benomyl. One week later 140 rooted cuttings/plot of 'Raggio di Sole', a Mediterranean cultivar very susceptible to race 2, were transplanted. Ten plants/plot had been inoculated before transplanting by dipping their roots in a conidial suspension (10^6 conidia/ml) of race 2, then randomly transplanted and marked in order to evaluate soil reinfestation originating from these artificially inoculated plants. This tecnique simulates transplanting in steam disinfected soil of infected plants, a situation often encountered in practice.

RESULTS AND DISCUSSION

Among the cultivars tested in the first trial, 'Elsy' confirmed its high resistance to races 2 and 4 of F. dianthi, 'Pallas' was partially resistant, 'Raggio di Sole' moderately susceptible and 'Sonia' and 'Oscar' highly susceptible (Table 1). Steam disinfection of the suppressive soil increased wilt severity, thus confirming that the use of a partially

suppressive soil significantly reduces disease incidence in susceptible cultivars. Benomyl and captafol, applied at high dosage (20 g/m^2) caused a significant reduction of disease severity. These fungicides in mixture were more active when mixed with the soil than when applied as a soil drench.

The antagonistic Fusaria isolated from a suppressive soil (Garibaldi et al. 1986) confirmed their capacity to reduce the spread of the pathogen from several foci, represented by plants already infected (Table 2). This activity was not lost after selection for resistance to benzimidazoles or, at least, was not lost by all resistant strains (Garibaldi, unpublished results). The combination of the antagonistic capacity of Fusaria and fungicidal activity of benomyl significantly reduced wilt severity. The control shown was higher than that obtained by using the two control measures separately.

The results confirm and enlarge those previously reported (Garibaldi & Gullino 1984), particularly the integration of different control measures such as the selection of moderately susceptible or partially resistant cultivars, the use of partially suppressive soil and the application to the soil of high dosages of fungicides wich can effectively reduce the severity of Fusarium wilt.

The efficacy of saprophytic Fusaria, under glasshouse conditions in reducing soil reinfestation by F. dianthi confirms results already reported (Garibaldi et al. 1985, Tramier et al. 1983). The additive action of saprophytic Fusaria resistant to benzimidazoles together with high dosages of benomyl is of relevant interest in that it prevents or at lest delays recolonisation of the disinfected soil by the pathogen, thus extending the control of Fusarium wilt in the glasshouse.

It will be interesting to examine the effect of adding antagonistic Fusaria and fungicides to fumigated soils to see if it will increase the efficiency of fumigation, thereby reducing further the risk of severe epidemics of F. dianthi.

TABLE 1

Severity (disease index 0-100) of Fusarium wilt in some cultivars grown in partially suppressive soil (steamed and non-steamed), artificially inoculated with races 2 and 4 and drenched with different fungicides

Fungicides	Steam disinfected soil					Non-steamed soil				
	cv					cv				
	Elsy	Pallas	Oscar	Sonia	Raggio di sole	Elsy	Pallas	Oscar	Sonia	Raggio di sole
Untreated control	0.6 a	17.3 bc	95.7 f	72.0 c	57.0 d	0.0 a	0.3 a	28.3 c	22.3 c	6.6 a
Benomyl (20 g/m^2) mixed with the soil	0.0 a	2.3 a	24.5 c	22.3 c	12.0 b	0.0 a	0.0 a	0.6 a	0.6 a	0.6 a
Captafol (20 g/m^2) mixed with the soil	1.3 a	2.3 a	52.7 d	26.0 c	16.3b c	0.0 a	0.0 a	5.3 a	1.0 a	0.6 a
Captafol (10 g/m^2) + Benomyl (10 g/m^2) mixed with the soil	0.0 a	0.5 a	14.5 b	13.1 b	9.6a b	0.0 a	0.3 a	3.3 a	0.0 a	0.3 a
Captafol (10 g/m^2) + Benomyl (10 g/m^2) soil drenching	0.6 a	10.3 ab	27.6 c	18.0 b	10.3a b	0.0 a	0.0a	4.0 a	2.0 a	1.3 a

* Means separation by Duncan's multiple range test, 5% level.

TABLE 2

Effectiveness of artificial colonisation of steam disinfected soil with antagonistic Fusaria and of soil drenching with benomyl against soil infestation by F. dianthi (transplanted on 4.4.85; experiment completed 9.1.85) (cv 'Raggio di Sole)

Treatment	No. healthy plants at completion of the experiment	% dead plants
Untreated control	75.6 c (*)	28.7 a
Antagonistic Fusaria grown on wheat kernels (100 g/m^2)	103.5 b	13.8 b
Antagonistic Fusaria (100 g/m^2) + benomyl (20 g/m^2) before transplanting	128.6 a	4.3 c
Benomyl (20 g/m^2)	101.5 b	15.8 b

(*) See Table 1

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POSSIBILITIES FOR REDUCED SPRAY PROGRAMMES FOR THE CONTROL OF BOTRYTIS IN TOMATOES

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ABSTRACT

A study of the effect of relative humidity on germination and infection of Botrytis cinerea spores on tomato flowers showed that at least 18 hours with relative humidity at or above 90% was necessary for significant flower infection to occur at 20°C. In 2 trials designed to test the effectiveness of a number of criteria to rationalise the timing of protectant fungicide sprays to control grey mould (Botrytis cinerea) it was found that sprays applied immediately after the first infection period following a 2-week spray interval gave good control of the disease. Waiting until lesions could be seen on the haulm before spraying resulted in poor control of ghost spot. There was an indication that reduced spray programmes resulted in higher yields than a routine fortnightly programme, which may have been due to a phytotoxic effect of the chemicals in the full programme.

INTRODUCTION

Tomato grey mould (Botrytis cinerea) attacks all parts of the plant causing ghost spotting and calyx end rot of the fruit and lesions on vegetative structures. Lesions on the latter are often initiated by infected fallen flowers or other plant debris lodging on the leaves or trusses. Smith (1970) found that Botrytis conidia did not infect undamaged non-senescent tomato leaves and stems but were highly infective to tomato flowers. She suggested that a study of the effect of temperature and humidity on the process of Botrytis flower infection might indicate how environmental control could limit disease spread and Winspear *et al.* (1970) have shown that the use of automatic humidity control to reduce periods of humidity in excess of 90% relative humidity (r.h.) can lead to a decrease in the incidence of grey mould.

In situations where complete humidity control is not feasible, it has been shown that spraying at intervals of 14 days is necessary to keep new growth protected (Smith *et al.* 1975). However, a knowledge of the conditions required for flower infection should provide a means for rationalising the timing of protective sprays to prevent infected fallen flowers from initiating lesions on other parts of the plant.

This paper describes an experiment carried out in controlled environment cabinets to study the effect of relative humidity on flower infection, and 2 trials to compare the effectiveness of a number of criteria for timing sprays to control grey mould.

MATERIALS AND METHODS

Flower infection experiments

Ten tomato plants at the first truss flowering stage were placed in each of six controlled environment cabinets. Each cabinet received a light intensity of 30,000 lux from Philips de-luxe warm white fluorescent tubes during 16 h per day. Each cabinet was maintained at a constant

temperature of 20°C and at one of each of the following relative humidity levels:- 75%, 80%, 85%, 90%, 95%, 100%.

Eighteen fully open flowers in each cabinet were labelled and inoculated with conidia obtained from 14-day B. cinerea cultures grown on potato dextrose agar. Two labelled flowers from each cabinet were sampled at 4, 12, 18, 24, 29 and 48 h after inoculation and bleached in chlorine gas in a fume cupboard for 5 min using the method described by Janes (1962). The anther tubes were then removed and the flowers opened and mounted on slides in lactophenol cotton blue, inner surface uppermost. The slides were warmed gently to remove air bubbles before putting a cover slip in place. The percentage of spores germinated and the percentage which had produced appressoria and penetrated the host were calculated by observing and counting 100 spores on a transect of the central petal to the left of the main vascular bundle.

Trial 1

A spray timing trial was carried out in 1984 in a crop of cold-grown tomatoes, cv. Sonatine, to determine whether the recommended 2-week spray interval for Botrytis control could be extended and the start of the spray programme delayed using either a) the incidence of flower infection as an indicator of the need to spray or b) the occurrence of flower infection periods defined as a continuous period of at least 18 h when r.h. has not fallen below 90%.

The trial consisted of 16 plots each containing 8 plants with four replicates of each treatment arranged in a Latin Square design. The treatments applied were as follows:-

(1) A routine fortnightly spray application commencing at flowering of the second truss.

(2) A routine fortnightly spray application commencing when the number of fallen flowers infected reached 5% following flowering at the second truss.

(3) The first spray applied after the second truss was in flower and a continuous period of 18 h or more had occurred during which r.h. did not fall below 90%. Subsequent sprays were applied following the first infection period after a 2-week spray interval.

(4) Unsprayed control.

Iprodione (Rovral) was used for all spray treatments at the rate of 100 g product per 100 l of water applied to run-off.

The total number of sprays applied was as follows:-

Treatment 1 (Routine)	11
Treatment 2 (Flower infection)	10
Treatment 3 (90% r.h. criterion)	7

The occurrence of flower infection used for spray timing in treatment 2 was determined by weekly sampling of 100 flowers which had fallen and lodged on leaves. The flowers were incubated in a humid chamber and examined for Botrytis growth after 3 days. Observations from previous years suggested that a 5% increase from zero in the number of fallen flowers infected predicted the start of disease development in the crop 2 weeks later.

The number of haulm lesions (leaf + stem + truss lesions) and ghost spots on four plants per plot were recorded each week. Fruit was picked, graded, counted and weighed at frequent intervals to the end of cropping.

Relative humidity and temperature were recorded continuously using a thermohygrograph and micrometeorological instruments with a data logger.

Trial 2

The trial was carried out in 1985 in a cold-grown crop, cv. Sonatine. Four replicates of each of 6 treatments were arranged in a randomised block design with 8 plants per plot. The treatments applied were as follows:-

(1) Routine spray treatment. A fortnightly application commencing when the second truss was in flower.

(2) First spray applied after the second truss was in flower and a continuous period of 18 h or more had occurred during which r.h. did not fall below 90%. Subsequent sprays were applied following the first infection period after a 2-week spray interval.

(3) As (2) but spraying delayed until the occurrence of a second high r.h. period (for both first and subsequent sprays).

(4) As (2) but first spray delayed until there was an average of 2 lesions (stem, leaf, petiole or truss) per plot in the unsprayed plots.

(5) As (4) but spraying delayed until the occurrence of a second high r.h. period (for both first and subsequent sprays).

(6) Unsprayed control.

The first routine spray was applied on 5 June. A mean lesion count of 2/plot occurred on 3 July, although this level was subsequently reduced by de-leafing and trimming operations.

Dichlofluanid (Elvaron) was used in all treatments until the start of picking and was always the first spray applied to any treatment. From the start of picking onwards, iprodione (Rovral) and dichlofluanid sprays were alternated in all treatments. The total number of sprays applied was as follows:-

	Dichlofluanid	Iprodione	Total
Treatment 1 (Routine)	7	4	11
Treatment 2 (1st 90% r.h.)	5	2	7
Treatment 3 (2nd 90% r.h.)	2	2	4
Treatment 4 (Lesions + 1st r.h.)	3	2	5
Treatment 5 (Lesions + 2nd r.h.)	2	1	3

Disease, yield and temperature and humidity records were obtained as in Trial 1.

RESULTS

Flower infection experiments

No spore germination or infection was observed at r.h. of 75%, 80% and 85%. At 90% and 100% r.h. significant levels of spore germination and infection were observed at 18 h after inoculation. At 95% r.h. some germination occurred after 12 h but a marked increase was recorded after 18 h (Table 1).

TABLE 1

Percentage germination and infection of B. cinerea spores on tomato flowers under various relative humidity regimes at 20°C

% r.h	Time (h) after inoculation	% spores germinated	% spores causing infection
85	4	0.0	0.0
	12	0.0	0.0
	18	0.0	0.0
	24	0.0	0.0
	29	0.0	0.0
	48	0.7	0.7
90	4	1.0	1.0
	12	0.9	0.0
	18	10.7	4.9
	24	28.9	12.5
	29	7.8	0.9
	48	11.9	8.3
95	4	0.0	0.0
	12	9.8	3.9
	18	42.1	31.6
	24	38.5	26.0
	29	34.2	27.6
	48	59.5	56.8
100	4	1.5	0.8
	12	0.0	0.0
	18	36.4	20.3
	24	36.3	11.4
	29	8.6	6.9
	48	29.8	26.5

Trial 1 (1984)

Disease progress

Ghost spotting increased rapidly in the control plots from the end of the first week in August, reaching a peak in early September (Table 2). The incidence of ghost spotting did not appear to be associated with the occurrence of defined infection periods and more work needs to be done on the effect of environmental factors on the development of this symptom.

Infection periods occurred on the 18 and 29 June, 12 July, 4, 13, 15, 16 and 24 August and frequently from 11 September onwards. There was a slight increase in the number of haulm lesions recorded after 21 August which may have been associated with the infection periods in mid-August. The disease increased rapidly in the control plots from the second week in September following a series of infection periods on 11, 14, 15, 16, 17, 20, 23 and 27 September. Aggressive stem lesions resulted in severe damage to 3 plants in the control plots. A high level of flower infection (42%) was present in early June which decreased to 17% in mid-July before rising to 90-100% by mid-August.

There was little difference between the spray treatments in the observed level of lesion control. Ghost spotting appeared to be better controlled in the routine and flower infection-based treatments than in the 90% r.h. criterion-based treatment, although the latter showed considerable improvement compared to the unsprayed plots. Good control of ghost spotting was not expected since iprodione is only partially effective against this phase of the disease (Morgan 1979).

TABLE 2

Mean number of ghost spots and haulm lesions per plot at the time of highest recorded symptom level (for ghost spot) and at the end of the season (for haulm lesions) - Trial 1.

Symptom	Treatment			
	Routine (1)	Flower infection (2)	90% r.h. (3)	Control (4)
Ghost spots/plot (4 September)	7.5	6.8	13.0	28.8
Lesions/plot (29 October)	0.5	1.0	0.8	24.0

Yields

There were no significant differences in yield between the treatments, although there was a significantly higher proportion of small fruit (grade E, 40<47 mm) in the routine treatment compared to the control (Table 3). This could have been caused by an effect of the chemical although the same effect was not evident in treatment 2 where only 1 less spray was applied.

TABLE 3

Fruit yield and yield component values calculated at the end of picking for Trial 1.

Yield components	Treatment			
	Routine (1)	Flower infection (2)	90% r.h. (3)	Control (4)
Total yield/plot (kg)	28.7	30.1	32.4	30.6
% fruit wt 35<40 mm	2.2	2.0	1.6	0.9
40<47	21.0**	12.9	11.8	11.5
47<57	76.7	83.5	83.2	86.5
>57	0.1	1.6	3.5	1.1
Fruit no/plot	494.0	482.5	495.5	477.8

**Significantly higher than control (p <0.01)

Trial 2 (1985)

Disease progress

Ghost spotting increased rapidly at the end of June in treatments 4, 5 and 6. In the remaining treatments levels remained very low throughout the season (Table 4). An initial increase in the number of haulm lesions

at the end of June was checked following de-leafing and several weeks during which only one marginal infection period was recorded on 16 July. A series of 4 infection periods on 2, 4, 5 and 7 August was followed by a gradual increase in disease levels in all treatments except 1 and 2 but incidence generally remained low. Aggressive stem lesions resulted in severe damage to 2 plants in the control plots and 1 plant in each of treatments 3, 4 and 5.

TABLE 4

Mean number of ghost spots and haulm lesions per plot at the time of highest recorded symptom level (for ghost spot) and at the end of the season (for haulm lesions) - Trial 2.

Symptom	Treatment					
	Routine(1)	1st rh(2)	2nd rh(3)	Lesions + 1st r.h. (4)	Lesions + 2nd r.h. (5)	Control(6)
Ghost spots/plot (16 July)	1.3	1.3	0.3	10.0	11.5	14.3
Lesions/ plot (28 October)	0.5	0.5	3.3	1.8	1.3	3.5

Yields

There was a significant increase in total yield in all the reduced spray programme treatments compared with the control (Table 5). Fruit size was significantly increased in treatments 2, 4 and 5 and fruit number in treatments 3, 4 and 5. As in the 1984 trial there was some suggestion that the intensive routine spray programme, although giving good disease control had a depressing effect on yield.

TABLE 5

Fruit yield and yield component values calculated at the end of picking for Trial 2.

Yield components	Treatment					
	Routine (1)	1st r.h. (2)	2nd r.h. (3)	Lesions + 1st r.h. (4)	Lesions + 2nd r.h. (5)	Control (6)
Total yield/plot (kg)	14.5	16.0*	16.4*	17.0*	16.6*	12.1
% fruit wt 35<40 mm	15.1	12.9	16.2	14.7	11.2*	21.0
40<47	40.5	30.9**	40.2	34.3*	36.9*	46.3
47<57	43.7	55.5**	43.0	49.6*	51.4*	32.5
>57	0.7	0.8	0.5	1.4	0.5	0.2
Fruit no/plot	333.2	328.8	377.0**	363.5*	356.0*	304.3

*, ** = Significantly different from control (p <0.05, <0.01 respectively)

DISCUSSION

The results from the two trials indicated that delaying spray applications until the occurrence of an infection period following a 2-week spray interval gave good control of ghost spotting and haulm lesions and in Trial 2 resulted in a significant yield increase compared with the unsprayed control. Waiting for the occurrence of a second infection period before spraying also produced a yield increase although control of haulm lesions was less satisfactory.

Sprays based on the results of flower infection monitoring (Trial 1, treatment 2) did not provide a useful guide for spray timing. High levels of flower infection were recorded in early June and this indicated a need to start the spray programme early in that treatment. Lack of subsequent disease development in the control plots throughout June, July and the first half of August indicated that sprays applied during that period were unnecessary.

Delaying spraying until lesions could be seen on the haulm resulted in a lack of control of ghost spotting.

The relative humidity criteria can probably be regarded as minimum requirements for flower infection. The duration of high humidity necessary for infection to occur could be expected to increase at mean temperatures below 20°C, the temperature used in the controlled environment experiment. Disease risk from infected flowers is not taken into account, and circumstantial evidence from Trial 1 suggests that infected flowers which have fallen and lodged on leaves or other plant parts will not cause lesions to develop under conditions of low humidity. It would therefore seem reasonable to suppose that the grower would run little risk by delaying the application of protectant fungicides until the occurrence of an infection period as defined in this paper.

Further work is needed to define the conditions required for the development of ghost spotting so that chemical sprays, such as dichlofluanid, which are effective against this form of the disease can be timed more accurately. Smith (1970) demonstrated that leaf scars and petiole stumps were susceptible to conidial infection when plants were grown in moist, shaded conditions and that this could lead to the development of aggressive stem lesions. Again, characterisation of the conditions needed for such infection to occur could assist with spray timing decisions or indicate when de-leafing and side shooting should be avoided. However, flowers are highly susceptible to conidial infection, and given favourable environmental conditions can provide a source of conidial inoculum which could lead to ghost spotting and stem infection, and saprophytically-based mycelial inoculum which can cause lesions when they lodge on leaves and trusses. Sprays timed to protect the crop from infected flowers following the occurrence of infection periods could thus be expected to play a large part in controlling the spread of Botrytis to other parts of the plant.

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PROCHLORAZ MANGANESE FOR BROAD SPECTRUM DISEASE CONTROL IN WOODY ORNAMENTALS

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ABSTRACT

In a series of trials over a seven year period, prochloraz manganese complex ('Octave' (R)) has demonstrated a high level of activity against a broad-spectrum of pathogens of woody ornamentals. Control of a number of foliar diseases of established plants has been achieved with high volume sprays at 1,000 mg a.i./l. Diseases occurring during vegetative propagation have been controlled by various combinations of cuttings-dip, and/or drench and spray treatments at 250-500 mg a.i./l, resulting in a higher yield of top quality rooted cuttings. Safety to a wide range of crop species has been excellent.

INTRODUCTION

The grower of woody ornamentals may have several hundred different species/cultivars growing at very high density on the same nursery. In addition to an assortment of foliar diseases of mature stock, some fairly specific, others affecting a wide host range, a number of soil-borne (or cuttings-borne) fungi can cause serious losses during vegetative propagation by rotting or impairing rooting of cuttings. The warm, humid conditions of the propagation bench are particularly conducive to many diseases. Due to the diversity of pathogens occurring on woody ornamentals there is a genuine need for an effective broad spectrum fungicide which can be tolerated at effective rates of application by a very wide range of crop species, grown under different systems of production.

Prochloraz, a novel imidazole fungicide, was introduced in the UK as an emulsifiable concentrate formulation in 1980 for the control of a number of stem-base, foliar and ear diseases in cereals (Harris et al. 1979). Its broad-spectrum activity indicated potential for the diverse problems of woody ornamentals, and in 1978 trials were started using the prochloraz manganese complex wettable powder formulation (Smith 1979, 1980). The wettable powder formulation was considered to be more suitable for application to some of the more tender ornamentals than the emulsifiable concentrate formulation recommended for cereals.

This paper describes trials work with prochloraz manganese complex on woody ornamentals, carried out over a period of seven years, which formed the basis of commercial recommendations when the product was introduced to this market sector in April 1986.

(R) Octave is a Registered Trade Mark of Schering Agrochemicals Limited

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MATERIALS AND METHODS

Procedural methods were governed by the particular experiment and were related to the type of plant material under test, the system of crop production and the type of pathogen(s) which might be expected. In some trials young plants were inoculated with spores of the appropriate fungal pathogen. Details of particular procedures are outlined together with the results of individual experiments, but prochloraz manganese complex 50% WP and other fungicides for comparison were applied to plants by one or more of the following methods:-

1. To rooted plants for the control of foliar diseases:
as a high volume spray applied to run-off using a hand-held or knapsack sprayer.

2. During propagation by cuttings for the control of diseases during root initiation:
(a) as a dip into which cuttings were fully immersed, and/or:

(b) as a drench applied to the substrate prior to insertion of cuttings, using a watering can, and/or:

(c) as a high volume spray applied to run-off using a hand-held or knapsack sprayer.

RESULTS

1. Fungicide treatment of rooted plants
Two experiments are described as examples:-

1.1 Control of Monochaetia karstenii on young rooted camellias.

High volume fungicide sprays were applied to run-off and 24 h later plants were sprayed with a spore suspension of M. karstenii (3 million spores/ml). The container-grown (c. 150 mm tall) plants were stood on capillary matting in a glasshouse environment maintained at c. 85% r.h. and mean temperature c. 15°C (winter) and c. 18°C (summer). Fungicide treatments were re-applied after 10 and 16 weeks, with a further application of spore suspension 24 h after the second treatment. Disease incidence was finally assessed as length of stem lesions per plant and growth measured as length of new extension growth 64 weeks from commencement of the trial. Data are mean values of two plants of each of four cultivars, (Table 1).

TABLE 1

Effect of fungicides on incidence of M. karstenii and extension growth

	mg/l	Mean stem lesions per plant (mm)	Mean length of extension growth per plant (mm)
Prochloraz manganese complex	1,000	0	149
Carbendazim/maneb	100/640	23	149
Untreated control	-	66	113

None of the fungicide-treated plants developed phytotoxicity.

1.2 Control of Pestalotiopsis funerea on Juniperus x media 'Pfitzerana'

Young plants, eight months after rooting, were either clipped (cut) or left unpruned (uncut). The clipping procedure was designed to mimic commercial practice of 'cutting over' stock plants. High volume fungicide sprays were then applied to run-off and after 1 day and again 4 days later half of the plants from each treatment were each sprayed with c. 3 ml of a spore suspension containing c. 500,000 spores/ml of P. funerea (inoculated series). The remainder of the plants were left as the uninoculated series. All plants were kept in a humid environment in a glasshouse and growth was determined 5 months from commencement of the trial as total fresh weight of foliage/stem per plant. Dead foliage/stem, which was mainly attributable to infection by P. funerea and/or Botrytis cinerea, was determined as fresh weight of dead tissue (Table 2).

TABLE 2

Effect of fungicides on plant growth measured as fresh weight

		Mean total fresh wt (g) foliage/stem					Mean fresh wt (g) dead foliage/stem	
	mg/l	Plants inoculated		Mean	Plants uninoculated		Plants inoculated	
		Cut	Uncut		Cut	Uncut	Cut	Uncut
Prochloraz manganese complex	1,000	22.92	26.72	24.82	44.6	44.2	0.05	0.0
Benomyl	500	20.91	20.84	20.88	42.6	47.6	0.01	0.0
Untreated control	-	17.36	21.30	19.33	39.1	43.1	0.36	0.04
L.S.D. (P = 0.05)				3.349				

Means based on 7 replicate plants

No phytotoxic symptoms developed in any of the fungicide-treated plants.

Experimentation by other workers has demonstrated control by prochloraz manganese complex of leaf blotch and die back of camellia, caused by Glomerella cingulata, at rates from 250 to 1,000 mg/l a.i. (Cook, R.T.A. personal communication); of powdery mildew of rhododendron, caused by Erysiphe cruciferarum and Sphaerotheca pannosa, at 1,000 mg/l a.i. (Griffin G.W., personal communication); of leaf blotch of horse chestnut, caused by Guignardia aesculi, at 500 mg/l a.i. (R. and D. Rept. Ag. Sci. Service 1984) and, in vitro, of the complex of Alternaria sp. and Stemphyllium sp. implicated in a leaf-spotting disease of Pseudopanax 'Gold Splash' at 100 mg/l a.i. (Ann. Rept. NZ Nursery Research Centre, 1983).

2. Fungicide treatments during propagation
Four experiments are described as examples:-

2.1 Rooting of camellia cuttings inserted under polythene film.

In October terminal cuttings of camellia cvs, Henry Turnbull, Tiptoe and Emmett Barnes were immersed in fungicide suspension, drained, dipped in a hormone rooting powder then inserted in a 50:50 peat/perlite medium previously drenched with the same fungicide. The cuttings were covered with polythene film. Base temperature was c. 20°C. Two replicate trays each of 8 cuttings per variety per treatment were randomised on the bench. Cuttings which rotted were removed and stem sections surface sterilised in 1% 'Chloros' for 3 min, washed in sterile water and plated onto potato dextrose agar (PDA). Monochaetia karstenii was the predominant pathogen isolated from these rotted cuttings. Six months after insertion all the remaining cuttings were lifted and the percentage which had rooted was determined (Table 3).

TABLE 3

Effect of fungicides on rooting of camellia cuttings

		Mean % of camellia cuttings rooted			
	mg/l	cv Emmett Barnes	Tiptoe	Henry Turnbull	Mean
Prochloraz manganese complex	250	87.5	31.2	62.5	60.4
Benomyl	500	56.2	18.7	43.7	39.5
Carbendazim/maneb	100/640	62.5	18.7	18.7	33.3
Untreated control	-	75.0	25.0	0.0	33.3
Mean		70.3	23.4	31.2	
LSD (P = 0.05) between horizontal means				22.58	
" between vertical means				26.07	

2.2 Rooting of Erica, Calluna and Daboecia cuttings inserted under mist.

In July, cuttings of Erica carnea cv James Backhouse, Erica hybrid Furzey, Calluna vulgaris cv Elsie Purnell and Daboecia cantabrica were inserted 16 per tray in a 50:50 peat/perlite medium after immersing them in the treatment fungicide. The rooting medium was in each case drenched with the same fungicide prior to insertion. Base temperature was c. 20°C. Treated trays of cuttings were randomised over the propagation bed. The fungicide treatments were re-applied as a coarse spray 3 weeks after the initial application. After 7-9 weeks, cuttings were lifted and rooting graded on a 0-4 scale. Cuttings which were well-rooted were graded 3 and 4 and designated top grade. These were suitable for potting on. Poorly rooted cuttings graded 1 and 2 would have been discarded in commercial practice (Table 4).

TABLE 4

Effect of fungicides on rooting of Erica, Calluna and Daboecia cuttings

Results based on means of the above four species

	mg/l	% cuttings rooted	% cuttings top grade (well-rooted)
Iprodione	250	90.6	76.6
Benomyl	500	89.1	75.0
Prochloraz manganese complex	250	93.8	84.4
Prochloraz manganese complex	500	92.2	78.1
Untreated control	-	67.2	46.9
LSD (P = 0.05)		19.74	25.53

Species of Pestalotiopsis and Botrytis were isolated from the surface of unsterilised cuttings which were plated on PDA prior to treatment of the remainder of the batch and also from rotted cuttings removed during the experiment, which were surface sterilised before 'plating' as described for the previous experiment.

2.3 Rooting of hydrangea cuttings inserted under mist.

In September, cuttings of Hydrangea hortensis were inserted 14 per tray in a 50:50 peat/perlite medium after immersion in the treatment fungicide and dipping in a hormone rooting powder. The rooting medium was in each case drenched with the same fungicide prior to insertion. Base temperature was c. 20°C. Two replicate trays of cuttings per treatment were randomised on the bench. The fungicide treatments were re-applied as a coarse spray 10 days after the initial application. Four weeks after insertion, cuttings were lifted and assessed as % total rooted, % top grade, % rotted and % unrotted/unrooted (Table 5).

TABLE 5

Effect of fungicides on rooting of hydrangea cuttings

		Mean % cuttings			
	mg/l	Rooted	Rooted Top Grade	Rotted	Unrooted/ unrotted
Prochloraz manganese complex	250	96.4	85.7	3.6	0
Prochloraz manganese complex	500	96.4	78.6	0.0	3.6
Benomyl	500	71.4	60.7	28.6	0.0
Iprodione	250	39.3	35.7	57.0	3.6
	500	64.3	57.1	25.0	10.7
Untreated control	-	57.1	53.6	42.9	0.0

Botrytis cinerea was isolated from 30% of unsterilised cuttings sampled before fungicide treatment. Subsequently Cylindrocarpon was isolated from rotted cuttings from the untreated and iprodione-treated batches, Botrytis from those treated with benomyl and Fusarium from iprodione-treated cuttings. Failure of these fungicides to control these pathogens may account for the high proportion of rotted cuttings associated with these treatments (Table 5).

2.4 Rooting of cuttings of Juniperus communis 'Depressa Aurea' inserted under mist.

In December, cuttings were immersed in the fungicide, dipped in a hormone rooting powder and inserted in a 50:50 peat/perlite medium which had been previously drenched with the same fungicide. Fungicide treatments were re-applied (as drenches) 12 and 27 days after the initial application. Cuttings were lifted and graded after 8 weeks (Table 6).

TABLE 6

Effect of fungicides on rooting of J. communis 'Depressa Aurea' cuttings

	mg/l	% cuttings rooted	% cuttings Top Grade
Benomyl	500	75.0	35.0
Prochloraz manganese complex	250	77.5	51.3
Prochloraz manganese complex	500	87.5	61.3
Carbendazim/maneb	50/320	78.8	58.8
Untreated control	-	60.0	23.8
LSD (P = 0.05)		19.29	21.02

Pathogens isolated from surface-sterilised rotted cuttings included Cylindrocarpon, Phomopsis, Botrytis and Fusarium.

Additional experiments have demonstrated similar enhancement of rooting following prochloraz manganese treatment of cuttings of Rhododendron (Smith 1982), Chamaecyparis lawsoniana, Juniperus x media 'Pfitzerana' and Cotinus coggygria.

DISCUSSION

The production of woody ornamentals presents the horticultural industry with many disease problems because of the large number of possible host/pathogen interactions. The experiments described in this paper demonstrate that the prochloraz manganese complex has the potential to control a broad spectrum of diverse and commonly occurring fungal pathogens (particularly Ascomycetes and Fungi Imperfecti) and that frequently this fungicide was more effective than the other compound(s) included for comparison. Phycomycetes are not controlled by prochloraz manganese complex.

The indications are that a range of important woody ornamental species show a high tolerance to prochloraz manganese and the crop safety threshold is high. In none of the experiments described has prochloraz manganese complex caused any symptoms of phytotoxicity, though in two of the experiments with propagation material the higher rate of application (500 mg/l) has given marginally inferior results to the lower rate, suggesting that the optimum has been exceeded. Several hundred woody ornamental species have now been treated with prochloraz manganese complex without sign of damage.

For use at propagation 250-500 mg/l has been shown to be the effective range of concentration, but the optimum rate will depend on the crop species and system of production. In addition, the frequency of application must be related not only to the likely inoculum pressure of pathogen(s) but also by the method of humidification (mist, fog, polythene covers) and the time of year. For high volume spray applications to rooted plants a concentration of 500-1000 mg/l prochloraz manganese complex is more appropriate. The dose and frequency of application will be determined by the plant species, stage of growth, and system of production.

The indications are that prochloraz manganese complex will be a useful addition to the armoury of nursery stock producers and a valuable alternative fungicide for controlling diseases associated with strains of fungi which are tolerant to other compounds.

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COMBINED FORMULATIONS OF NUARIMOL WITH CAPTAN, CHLOROTHALONIL OR MANCOZEB FOR THE CONTROL OF POWDERY MILDEW AND SCAB ON APPLES

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ABSTRACT

Combined formulations of low application rates of nuarimol with reduced application rates of captan, chlorothalonil or mancozeb provided excellent control of powdery mildew (Podosphaera leucotricha) and scab (Venturia inaequalis) on apples in field trials under different growing conditions. The products were applied in fixed spray schedules or following a scab warning system. Growth effects on leaves were minimal. The combination with captan is preferred where russetting is a major problem.

INTRODUCTION

Nuarimol is a broad spectrum systemic fungicide. Its activity against cereal diseases was first described in 1977 (Casanova et al. 1977). After its development in cereals, nuarimol has been tested extensively on apples since 1981. After its introduction by Brown et al. in 1975, fenarimol has been developed for use on apples and has been widely used in commercial practice since 1978. Information concerning the mode of action, systemic movement and experience from the use of fenarimol and nuarimol for disease control in apples under field conditions has been reviewed recently (Huggenberger 1985). Fenarimol and nuarimol are ergosterol biosynthesis inhibitors (EBI). They are locally systemic. They penetrate rapidly into plant tissue and are distributed by apoplastic movement. They have shown excellent curative activity against apple scab (Venturia inaequalis) at reduced application rates. Under heavy disease pressure combinations of fenarimol or nuarimol with classic protectants have provided more consistent control of fruit scab than when used alone. Because nuarimol has also shown excellent efficacy against primary and secondary infections of apple powdery mildew (Podosphaera leucotricha) at reduced application rates, it is especially suitable for the development of co-formulations containing nuarimol and classic protectant scab fungicides

at reduced rates. Formulations of nuarimol + captan 2.4 + 72.6DF (dry flowable), nuarimol + chlorothalonil 6 + 60SC and nuarimol + mancozeb 1 + 60WP were selected for development and were evaluated in field trials in 1984 and 1985. This report summarises the main results obtained in this field programme.

MATERIALS AND METHODS

Trials on Cox's Orange Pippin apples (United Kingdom)

Trials were carried out on mature trees, 2-3 trees per plot, with 4 replications arranged following a randomised block design. Treatments with fungicide combinations to be tested were started at bud burst (Fleckinger stage B) to green cluster (stage E) from middle to end of April and applied at approximately 10 d intervals until mid-July. Treatments were applied with a motorised knapsack sprayer as concentrate sprays at approximately 500 l/ha. Control of primary mildew was assessed in June. Control of secondary mildew and scab was assessed after the end of the regular spray programme at the end of July. Incidence of russetting on fruit was assessed at harvest.

Trials on Rome Beauty and Red Delicious apples (Po Valley, Italy)

Trials were carried out on mature trees, 1-4 trees per plot, with 3-4 replications arranged following a randomised block design. Treatments were started at mouse ear (stage C3) from early April and applied at 7-8 d intervals until fruits were 1/3 of their final size in early June. Spray schedules were then extended and in some cases products or application rates changed. Treatments were applied with a motorised knapsack sprayer as dilute sprays at 800-1500 l/ha depending on the development of the vegetation. Control of primary mildew was assessed in mid-May. Control of secondary mildew and scab was assessed on completion of the spray programme in June.

Trial on Golden Delicious apples applied following a scab warning system (Trentino Alto Adige, Italy)

Treatments against apple scab were applied after infection periods were recorded following the Mills table (Mills & La Plante 1951). A medium infection was recorded on May 3. Three heavy infections were recorded on May 14, 20 and 26. Subsequently, another medium infection was recorded on June 4. Applications were made 72, 77, 112, 118 and 120 h after the start of the infection periods respectively. The trial was carried out on mature trees, 4 trees per plot, with 4 replications. Treatments were applied with a motorised knapsack sprayer as dilute sprays at 1000 l/ha. Disease control and russetting ratings were made on June 29 and July 15 respectively.

Statistical analysis

All data were analysed by analysis of variance. Treatment means were separated by Duncan's multiple range test. Treatment means followed by different letters are significantly different ($p = 0.05$).

RESULTS

Trials on Cox's Orange Pippin apples

Disease Control

The control of primary infections of powdery mildew with the combined formulation of nuarimol + captan at both application rates was clearly better than with the tank mix application of binapacryl + captan. At the higher rate nuarimol + captan was clearly the best treatment (Table 1). Against secondary infections the efficacy of nuarimol + captan at both application rates was at the same level as tank mix applications including triadimefon.

The combination of nuarimol with reduced rates of captan was at least equivalent to the full rate of captan applied in tank mix with binapacryl against leaf scab (Table 2). There was not enough infection on fruits in these trials for valid product comparisons.

TABLE 1

Efficacy against apple powdery mildew (var. Cox's Orange Pippin)

		Disease control (%)			
Treatments	g a.i./ha	primary infections		secondary infections	
Nuarimol + captan (2.4 + 72.6DF)	24+726	86ce	93bb	92cc	76bb
	30+908	91ee	93bb	92cc	83bb
Binapacryl + captan (50WP + 50WP)	900-1000 + 2250	48bb	79bb	54bb	72bb
Triadimefon[1/] (5WP)	50	83cc	95bb	91cc	81bb
Untreated (% leaf area infected)		(27)aa	(14)aa	(16)aa	(59)aa
Year		84	85	85	85
Trial number		351	502	500	503

1/ tankmixed with captan 2250 g a.i./ha or dithianon 800-1200 g a.i./ha

Fruit finish

All treatments clearly improved fruit finish but the difference between the two application rates of nuarimol + captan DF and the reference treatment binapacryl plus captan at full rate was small (Table 2).

TABLE 2

Efficacy against apple scab and effect on fruit finish (var. Cox's Orange Pippin)

Treatments	g a.i./ha	Disease control (%)		Fruit surface russetted (%)		
Nuarimol + captan (2.4 + 72.6DF)	24+726	99bb	90bc	4.7bc	5.6bb	5.6bb
	30+908	97bb	92cc	3.3cd	5.6bb	6.6bb
Binapacryl + captan (50WP + 50WP)	900-1000 + 2250	90bb	82bb	2.6dd	3.0bb	5.1bb
Untreated		(17)aa[1/]	(49)aa[1/]	7.9aa	14.5aa	17.2aa
Year		85	84	84	85	85
Trial number		503	351	351	500	503

1/ % leaf area infected

Growth effects

In four out of seven trials minor growth effects on the foliage were noticed following the first sprays. These effects consisted of smaller, darker green leaves and were expressed and recorded as leaf vigour in relation to untreated controls (Table 3). In three trials, plots treated with EBI fungicides could be consistently distinguished from untreated controls or the non-EBI reference binapacryl + captan. The slight growth effects noticed with EBI fungicides in May largely disappeared later in the season with the exception of one trial where the leaf vigour of the treatment including triadimefon was significantly worse than untreated control and the non-EBI reference.

TABLE 3

Effect on leaf size, colour and vigour (var. Cox's Orange Pippin)

Treatments	g a.i./ha	Leaf vigour (%) early rating (May)				late rating (July/August)			
Nuarimol+ captan (2.4 + 72.6DF)	24+726	99ab	98cc	98bc	96cc	99ab	99ab	105bb	98aa
	30+908	99ab	99bc	98bb	98bc	99ab	96ab	106ab	99aa
Binapacryl+ captan (50WP + 50WP)	900-1000 + 2250	99ab	100aa	100aa	99ab	101aa	103aa	107aa	100aa
Triadimefon[1] (5WP)	50	101aa	98cc	98bc	97cc	101aa	86cc	105bb	98aa
Untreated		100ab	100aa	100aa	100aa	100aa	100ab	100cc	100aa
Year		85	84	85	85	85	84	85	85
Trial number		502	353	503	500	502	353	503	500

[1] tank mixed with captan 2250 g a.i./ha or dithianon 800-1200 g a.i./ha

Trials on Rome Beauty and Red Delicious apples

Results from trials on varieties susceptible to apple scab carried out in the Po Valley of Italy where conditions for the development of the disease are very favourable during spring are summarised in Table 4. Combination products including nuarimol at low application rates together with chlorothalonil, captan and mancozeb at reduced rates provided excellent control of leaf and fruit scab under these difficult conditions. As is confirmed in commercial use, protectant fungicides (mancozeb) used alone at regular 7-8 d intervals did not provide adequate disease control.

In addition to providing excellent control of apple scab the combinations including nuarimol were also effective in the control of primary and secondary infections of powdery mildew.

Trial on Golden Delicious apples applied following a scab warning system

In the Adige Valley of Northern Italy the commencement and duration of scab infections can usually be determined with a high level of confidence. A well established scab warning system has been operational for many years (Oberhofer 1985) allowing the use of spray programmes following recorded infection periods. The results of a trial on Golden Delicious are summarised in Table 5. Applied within 3-5 d after the start of an infection period combinations containing nuarimol at low application rates provided excellent control of leaf and fruit scab. Because of its shorter curative efficacy (30-36 h after beginning of a scab infection, Oberhofer 1985) the efficacy of the reference treatment captan + sulphur was lower.

TABLE 4
Efficacy against apple scab and powdery mildew (var. Rome Beauty (I), Red Delicious(R))

Treatments	mg/l a.i.	Disease control (%) leaf scab				fruit scab				primary mildew	secondary mildew
Nuarimol + chlorothalonil	24+240	94bb	96ef	98dd	100bb	99ce	93bd	97bc	96bd	90cd	96df
(6 + 60SC)	36+360	97bb	98ef	99de	-	100ee	99ff	98bc	-	97dd	100ff
Nuarimol+ captan	24+726	95bb	97ef	99de	100bb	99ce	97df	98bc	100dd	90cd	96df
(2.4 + 72.6DF)	36+1089	97bb	97ef	99de	-	100ee	98df	99bc	-	93cd	100ff
Nuarimol+ mancozeb (1 + 60WP)	20+1200	-	-	-	100bb	-	-	-	96bb	-	-
Bitertanol + propineb (25WP + 65WP)	200+1050	85bb	91cd	94cc[2/]	96bb[1/]	97bd	90bb	95bc[2/]	97bd[1/]	59bb	90be
Mancozeb (80WP)	1600	-	-	83bb	-	-	-	89bb	-	-	-
Untreated		(69)aa	(100)aa	(84)aa	(71)aa	(80)aa	(100)aa	(71)aa	(94)aa	(81)aa	(33)aa
		(% leaf area infected)				(% infected fruit)				(% leaf area infected)	
Variety		I	I	I	R	I	I	I	R	I	I
Year		84	84	85	84	84	84	85	84	84	84
Trial number		201	202	204	203	201	202	204	203	202	202

[1/] application rate 160+840 g a.i./ha

[2/] co-formulation 8 + 42WP

The incidence of fruit russet was low. All treatments improved fruit finish slightly with treatments containing captan tending to give the best results.

TABLE 5

Efficacy against apple scab and effect on fruit finish when fungicides were applied according to a scab warning system (var. Golden Delicious)

Treatments	mg/l a.i.	Disease control (%)		Fruit surface russetted (%)
		leaf scab	fruit scab	
Nuarimol + chlorothalonil (6 + 60SC)	18+180	95cc	100bb	1.5bd
Nuarimol + captan (2.4 + 72.6DF)	24+726	96cc	100bb	1.3cd
Nuarimol + mancozeb (1 + 60WP)	20+1200	95cc	100bb	2.3bb
Bitertanol + captan (25WP + 50WP)	125+750	92cc	100bb	1.2cd
Captan + sulfur (50WP + 80WP)	1200+1200	41bb	78bb	1.2dd
Untreated		(31)aa	(5)aa	3.2aa
Year		84	84	84
Trial number		206	206	206

CONCLUSIONS

The results demonstrate that combined formulations of low rates of nuarimol with reduced rates of chlorothalonil, captan or mancozeb provide excellent control of apple powdery mildew and apple scab under a range of growing conditions. On varieties where fruit finish is of major importance and in areas where russetting is a problem the combination with captan is preferred. The combination with chlorothalonil can be applied at a wide range of application rates depending on spray schedules and disease pressure. For areas where mancozeb is the preferred protectant fungicide, e.g. for orchards interplanted with rows of different varieties, the combination of nuarimol + mancozeb has been developed.

The above combinations enable the grower to benefit from the advantages of systemic and classic protectant components in a single product. The systemic component provides penetrant activity, curative activity and efficacy against powdery mildew. The protectant complements the preventive activity of the systemic component and is redistributed on the surface of developing fruits.

The combinations can be used in fixed weather independent spray schedules or following scab warning systems. In the latter case applications can be made at least four days after the start of an infection period, thereby providing useful flexibility under difficult conditions.

The use of reduced rates of the systemic component should minimise growth effects and the more widespread use of combinations of fungicides with different modes of action should prevent the development of resistance.

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