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MONITORING FOR RESISTANCE OF FRUIT TREE RED SPIDER MITE (*PANONYCHUS ULMI*) TO ACARICIDES

J. E. Cranham
East Malling Research Station, E. Malling, Kent

Summary. A technique is described of monitoring for resistance using larvae hatched from the winter eggs on to leaf disks. The results of tests in 1968-69 indicate resistance to tetradifon in 25 out of 28 orchard samples where it had been used for 4 or more years intensively; and resistance to dimethoate in 38 out of 42 orchard samples. Where binapacryl had been used for 4-5 years there was evidence of resistance (5x to 6x) to it, but where dinocap had been used for 5-10 years there was no evidence of resistance to dinocap or binapacryl.

INTRODUCTION

From previous work it is clear that fruit tree red spider mite in England, at least in some orchards, has developed resistance to the chlorbenside, fenson and chlorfenson group of acaricides (Collyer and Kirby, 1959; Clinch, 1961; Gould, 1965), to some organophosphates if not to all (Clinch, 1961; Gould, 1965; Anon, 1965) and to tetradifon (Cranham, 1968). There is, however, little precise information on the status and distribution of resistance in field populations, and there appears to be a need for an economical method of assay.

The 'slide-dip' method of Voss (1961) has been widely employed with red spider mite (*Tetranychus urticae*) (Dittrich, 1962; Schulten, 1966) and also modified as a 'slide-spray' method (Herne and Chant, 1965). It seems likely to emerge as a standard test method, not applicable, however, for testing ovo-larvicides. There appears to be only limited experience of this method with fruit tree red spider mite (Schulze, 1967) and in our attempts with it control mortality was too high.

Other methods with adult mites include topical application (Harrison, 1961), which is precise but requires a high degree of manual skill. In addition, variations of leaf-disk or leaf-cage techniques have been widely used with the adult females (e.g. van de Vrie, 1963) or with eggs of known age (Cranham, 1968).

The winter eggs of fruit tree red spider mite are a convenient stage at which samples of orchard populations can be collected and stored, and an assay method has been developed in which the larvae on hatching, move directly on to leaf disks. This eliminates handling of individual mites.

METHOD AND MATERIALS

Supply of mites. Apple shoots with many winter eggs were collected from orchards before the end of March. Small pieces of bark not more than 10 x 5 mm in size and bearing 100-300 winter eggs were cut from each source and stored at 3°C. When needed, samples were incubated at 21°C for 7 or more days, until eggs were beginning to hatch. This provided material for testing from early April to late July, when the viability of eggs declined.

Plant material. Leaf disks were cut from young leaves of Myrobalan plum (Cranham, 1968). A succession of plant material was obtained from rootstocks stored at 1-2°C and grown on under glass.

Assay technique. Leaf disks, 15 or 20 mm in diameter, were placed with the ventral surface uppermost on filter paper resting on the lid of a carton of approximately 100 ml capacity. The filter paper was kept moist by a wick of nylon felt in contact with water within the carton. Pieces of bark bearing incubated eggs were placed on each leaf disk for 24 hours and then removed together with any dead or moribund larvae. The remainder were counted and, though the number per disk varied widely, a minimum of 60 larvae, on 4-6 leaf disks were allocated to each spray concentration. The disks were sprayed on the same day in a Potter tower (Potter, 1952) at a standardised deposit (wet spray) of 4.1 mg (± 5%) cm^2; this is comparable with deposits from H.V. applications in the field.

The test units were then stored for 7 days at 21°C, with a daily photoperiod of 16 hours, in which time untreated mites had developed to adults, and a count was made of (a) adult mites and (b) dead immature mites. In tests with tetradifon on resistant strains, live immature mites were often present after 7 days, indicating retarded development; in such cases a repeat count was made after a further two days. Results were based on the numbers of adult mites, including any dead specimens percentage mortalities at each concentration were corrected by Abbott's formula (Abbott, 1925) for mortality in the controls, which was generally 5-15%.

Commercial formulations were used, dimethoate and tetradifon as emulsifiable concentrates, binapacryl and dinocap as wettable powders. With the exception of dinocap, similar formulations lacking the active ingredients provided valid 'formulation controls'; with these, mortality was no higher than on unsprayed controls.

Orchard sources. To check variability of acaricidal tolerance in populations which were largely unselected in respect of the groups of acaricides to be tested, 'standard' mite stocks were obtained as follows: EM, East Malling Research Station; W/1, Somerset Farm Institute, Cannington, Somerset; W/2, Whiteways Cider Orchards, Whimple, Devon; and W/3, Bicton College of Agriculture, South Devon. The relevant spray history of these samples is shown below.

Stock	tetradifon or tetrasul	O.P.s	binapacryl	dinocap
EM	Nil	Nil	Nil	10 yr
W/1	Nil	7 yr	Nil	Nil
W/2	Nil	2 yr+	Nil	Nil
W/3	Nil	5 yr	Nil	Nil

+ 2 sprays only

RESULTS

Tests with tetradifon. Samples from several orchards in Kent, Essex and S.W. England with no history of tetradifon spraying gave very similar responses which were accepted as susceptible (examples for EM, Table 1). In a series of tests in 1968-1969 on stocks EM, W/1, W/2 and W/3 the greatest difference in LD50's was 2.6x and in LD90's 1.8x. The fit to the probit model was usually good; in 10 out of 12 tests, chi-square was non-significant. In repeated tests all four stocks gave 98-100% kill at 15 ppm and 100% kill at 31 ppm and higher dosages.

Table 1.

Range of values obtained in tests with tetradifon

	EM stock (susceptible)	Resistant field samples
LD50 (ppm)	2.4 - 4.7	13 - 47
LD90 (ppm)	6.4 - 8.6	202 - 877
Slope ($\log_{10}$)	2.6 - 4.8	0.8 - 1.4
Chi-sq. (Goodness of fit)	0.62- 3.15 (NS)	Sign. at $P < 0.05$

NS = non-significant

The response of many samples with a history of tetradifon of four years or more (generally 2 sprays per annum) was markedly different, involving significant survival of mites at 31, 125 and even 500 ppm (examples E8 and E15 in Table 2) and they were clearly resistant.

Table 2.

Dosage-mortality data of tests with tetradifon

Stock	percent mortality at ppm tetradifon 500	125	31	8	2
EM	100	100	100	87	27
E8	82	75	51	4	15
E15	91	89	43	49	35

The statistical significance of percentage survival can be judged from the 95% confidence intervals of the binomial distribution (Anon, 1966, Table 41); for a group of size 60, survival of 3 mites is significant. The results of probit analysis show, in many cases, low slope values and poor fit to the probit model (Table 1), suggesting heterogeneous populations of susceptible and resistant mites. There was often in the data an indication of horizontal plateaux in the log-dosage probit lines, presumably corresponding to the proportion of resistant mites in the sample. In these circumstances, estimates of the LD50's are unsound and taking the ratio of the LD50's (resistant/susceptible) as a measure of the degree of resistance, or 'resistance factor', can be misleading. Clearly the resistance factor is large but cannot be accurately estimated from a heterogeneous sample. The purpose of the tests was to show whether field samples contained a proportion of resistant mites and for this the criterion was that of significant survival at dosages giving 100% kill of susceptible mites.

With the above knowledge it was possible to fix discriminating doses for testing a larger number of field samples. These were tested at 31 ppm and sometimes also at 125 ppm, with a susceptible stock included as standard. The results, expressed as number of samples containing resistant mites/number of samples tested, were as follows:

(1) from orchards sprayed with tetradifon twice per annum for 4-8 years
Essex 22/25 Kent 3/3 Total 25/28

(2) from orchards not, or only occasionally, sprayed with tetradifon (including 3 Kent orchards with one spray annually for 4 years)
Essex 2/13 Kent 0/12 S.W. England 0/3 Total 2/28

Thus the occurrence of resistance clearly reflects the history of usage of tetradifon. Generally, resistant mites formed a substantial proportion, about 50% or more, in category (1) samples. In two Essex samples there was resistance where the recorded usage of tetradifon had been slight; the reasons are not clear but aerial dispersal of resistant mites could play a part.

Tests with dimethoate. There was evidence (unpublished) that the response to dimethoate of resistant mites typified the response to many other organophosphates, and it was used as a standard test chemical. Table 3 gives the results obtained for EM (susceptible) and a range of resistant samples tested at dosages from 2 to 500 ppm dimethoate.

Table 3.

Range of values obtained in tests with dimethoate

	EM stock (susceptible)	resistant field samples (E4, E9, E10, K27)
LD50 (ppm)	2.6 - 5.0	31 - 59
LD90 (ppm)	8.4 - 12.3	183 - 362
Slope ($\log_{10}$)	2.6 - 3.7	1.2 - 2.0
Chi-sq. (Goodness of fit)	0.02 - 4.35 (NS)	sign. at $P < 0.05$

NS = non-significant

Estimates of LD50 and LD90 for EM showed reasonable consistency in repeated tests over two years and the values for three other stocks (W/2, E/1 and K/23) were of a similar order. With these stocks 99-100% kill was usually obtained with 15 ppm and always with 31 ppm.

As with tetradifon, the resistance factor was clearly large and most field samples showed substantial survival at 31 and 125 ppm (examples in Table 4).

Table 4.

Dosage-mortality data of tests with dimethoate

Stock	percent mortality at ppm dimethoate 500	125	31	8	2
EM	100	100	100	82	16
E9	100	85	52	36	16
E10	99	74	38	36	17

For resistant stocks W/1 and W/3 there was, in most tests, good fit to the probit model and slope values similar to those for susceptible stocks, suggesting that they consisted predominantly of resistant mites. Another 4 resistant field samples showed shallower slopes than EM and generally poor fit (Table 3) and on the evidence they were more heterogeneous.

Discriminating doses were fixed at 31 and 125 ppm and samples from other commercial orchards tested, with EM or another susceptible stock as standard. The results, expressed as number of samples containing resistant mites/number tested, were as follows:

Essex 22/23 Kent 14/16 S.W. England 2/3 Total 38/42

There had been considerable use of O.P.s over several years in all orchards where resistant mites were found. In respect of the four samples found to be susceptible, there had been no use of O.P.s (EM) or very limited use (W/2, E/1 and K23). Since there must be relatively few such orchards it is likely that O.P.-susceptible populations are now rather rare, at least in S.E. England.

Tests with binapacryl and dinocap. Samples were taken from dessert apple orchards in which binapacryl or dinocap had been applied as fungicides on about eight occasions in each year of use, and from orchards of Worcester Pearmain or culinary varieties in which other fungicides (often wettable sulphur) had been used.

Table 5 shows the mean LD50's and LD90's obtained in repeated tests with binapacryl in 1968. Samples with a history of binapacryl showed higher LD50's (2x to 3x) and higher LD90's (5x to 6x) than the samples where dinocap or wettable sulphur had been used. There was significant survival of mites at 250 and 500 ppm from orchards sprayed with binapacryl whereas these doses gave 99-100% kill of mites from the orchards sprayed with dinocap or wettable sulphur.

Tests with dinocap showed (Table 5) that mites from an orchard sprayed with dinocap were as susceptible as those from a site receiving wettable sulphur, whereas the LD90's were slightly higher (about 1.5x) for samples from orchards sprayed with binapacryl.

Table 5.

Data of tests with binapacryl and dinocap (1968)

Spray history of sample	binapacryl (ppm) LD50	binapacryl (ppm) LD90	dinocap (ppm) LD50	dinocap (ppm) LD90
binapacryl (4 yr)	164	610	66	203
binapacryl (4 yr)	97	568	73	185
dinocap (10 yr)	48	100	50	121
wettable sulphur	68	128	48	125

Tests with binapacryl on a wider range of samples of the three types were carried out in 1969. All samples with a history of binapacryl showed significant survival at 250 ppm (up to 35%) and usually at 500 ppm (up to 17%) (Table 6). In contrast, samples from orchards sprayed with dinocap or other fungicides showed little variation in tolerance to binapacryl and, with one exception, there was 99-100% kill at 250 ppm.

Table 6.

Tests with discriminating doses of binapacryl (1969)

Spray history of samples	No. of samples with resistant mites/No. tested Essex	Kent	S.W. England	Total
binapacryl (3-5 yr)	4/4	7/7	-	11/11
dinocap (5-10 yr)	1/4	0/4	-	1/8
other fungicides	0/3	0/5	0/3	0/11

Increased tolerance in Kent and Essex was thus correlated with the frequent use of binapacryl and we appear to be dealing with the development of resistance.

Similar tests with dinocap in 1969 again failed to provide any evidence that its use had selected for resistance to dinocap.

DISCUSSION

The technique of using larvae which have hatched from winter eggs on to leaf disks is very economical since it involves no handling of individual mites; nor does it require space and facilities to rear stocks in the laboratory. The method approximates to the field situation in the spring when acaricides are applied during the hatching period. The larva is a sensitive stage to all acaricides, including ovo-larvicides such as tetradifon. Thus the technique is a convenient one for monitoring field populations of fruit tree red spider mite for resistance.

For susceptible stocks there was usually good fit to the probit model and fair reproducibility of results. Also, working with a set scale of doses, the minimum dose giving 100% kill was repeatable from test to test. Thus it was possible to design tests for resistance based on the criterion of significant survival at doses giving 100% kill of susceptible mites. With heterogeneous field populations containing a proportion of resistant mites there is generally a tendency to higher LD50's, reduced slope values, and usually poor fit to the probit model; all these can be indicative but none is a reliable criterion for judging resistance. Significant survival at discriminating doses is reliable, provided there is sufficient knowledge of the range of response of susceptible stocks to fix discriminating doses.

The results give an indication of the proportion of resistant mites in the sample, and over a wider range of doses, of the magnitude of resistance. For precise estimation of the latter it is necessary to establish the response of a strain 100% homozygous for resistance. Hence for this purpose and for studies on genetics and cross-resistance spectra, it is necessary to use selected laboratory strains and a test technique employing the adult mites.

However, the results obtained with the larval method give a good indication of the practical significance of resistance, i.e. substantial survival at the field strength (or dosages approaching it) suggests that control will be poor in the field. Table 7 illustrates this point for the acaricides tested.

Table 7.

Results of laboratory tests in relation to field dosages

Acaricide	Approx. LD90 (ppm) for susceptible stocks	resistant stocks	H.V. field dosage (ppm)
tetradifon	8	>200	125 - 150
dimethoate	10	>200	300
binapacryl	100	500	250 - 500
dinocap	120	180	125 - 250

With the development of resistance to tetradifon, dimethoate and binapacryl in some of the orchards sampled, growers had in fact noticed poorer initial control and/or greatly reduced persistence of effect. This entails a rather large change in tolerance to tetradifon and dimethoate, not so large with binapacryl. It is apparent that with dinocap, when the LD90 is so close to the field strength, an increase in tolerance of 2x could well be reflected in poorer control.

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EXPERIENCES WITH 14 ORGANIC FUNGICIDES FOR THE CONTROL OF BLACK CURRANT LEAF SPOT

F. Ó Ríordáin
The Agricultural Institute,
Horticulture and Forestry Division, Kinsealy, Dublin 5.

Summary A range of fungicides was tested for the control of Pseudopeziza ribis leaf spot of black currants under Irish conditions during 1967 to 1969. "Daconil 2787", "Karamate" and maneb gave disease control similar to that of mancozeb, which was used as a standard. Dithianon was equal in effect to mancozeb but in 1969 it gave significantly better disease control. Quinomethionate and zineb were not as effective as mancozeb. The "Daconil 2787" and quinomethionate treatments reduced yields. Benomyl, which was tested for one season only, gave very good control.

INTRODUCTION

Leaf spot (Pseudopeziza ribis) has been one of the main limiting factors of black currant production in Ireland, due principally to the high rainfall. Consequently, a much more comprehensive spray programme is required than that found adequate in Britain (Corke 1962, Schofield 1960).

Experiments to find a suitable spray programme for black currants and gooseberries under Irish conditions have been carried out since 1963. Initially a range of new fungicides was compared with zineb, which was one of the materials currently recommended in both Britain and Ireland. Of the fungicides tested mancozeb was found to be the most satisfactory for leaf spot control on both gooseberries (Ó Ríordáin, F. et al, 1966) and black currants (Ó Ríordáin, 1968). Results of further trials of fungicides for the control of this disease are presented in this paper.

METHOD AND MATERIALS

Six fungicides were compared at the Soft Fruit Research Centre, Clonroche, Co. Wexford, for the control of leaf spot on the cultivar Wellington XXX during the 1967 to 1969 seasons. The fungicides and their rates of application are listed in Table 1. Due to their unsatisfactory performances, zineb and quinomethionate were discontinued after 1967 and 1968 respectively. A randomized block design with five replicates was used; plots consisted of 12 bushes spaced at 10 x 4.5 ft.

Fungicides were applied with a self-propelled, automatic sprayer, constructed at the Centre, at 200 gal/ac and a minimum pressure of 170 psi. The first spray was applied at bud burst each spring. The interval between sprays was 10 days in 1967 and 1968, and was extended to 14 days in 1969.

Leaf spot and defoliation caused by P. ribis were assessed by a method evolved from that of Clarke and Corke (1956). Bushes were individually assessed and an analysis of variance carried out.

RESULTS

Zineb was tested in 1967, when it resulted in significantly poorer disease control than mancozeb, but gave similar yields. On the other hand, in both years of testing, quinomethionate not only gave significantly poorer leaf spot control but also lower yields than mancozeb.

Over the three seasons "Karamate" (77.5% a.i. mancozeb/zineb), mancozeb and maneb were generally equal in their effect on disease and yield. However, late season assessments indicated poorer leaf spot control by "Karamate". "Daconil 2787" (tetrachloroisophthalonitrile) was comparable in disease control to mancozeb in both

Table 1

Effect of fungicides on leaf spot and yield of the black currant cultivar Wellington XXX

Fungicide	Oz a.i./ac per application	1967 % leaf spot July 10	1967 % leaf spot August 23	1967 % leaf spot October 3	1967 Yield cwt/ac	1968 % leaf spot July 31	1968 % leaf spot Sept. 18	1968 % leaf spot October 21	1968 Yield cwt/ac
"Daconil 2787"	18.0	-	-	-	-	10.4	52.7	87.1	29.3*
Dithianon	18.0	1.3	24.4	85.4	68.0	6.4	33.2	75.5**	34.3
"Karamate"	37.2	1.4	28.7	92.5*	69.0	11.0	58.0	90.0*	39.8
Mancozeb	38.4	1.2	25.9	88.1	68.8	8.7	47.1	84.2	40.5
Maneb	38.4	0.9	22.8	87.3	63.4	10.5	50.4	86.7	45.7
Quinomethionate	8.0	2.4	56.7***	99.9***	54.4**	20.3***	74.5***	93.5**	26.1**
Zineb	48.0	2.3	48.1***	99.5***	64.8	-	-	-	-
S.E. of treatment means (df = 20)		0.4	3.7	1.2	3.0	1.5	3.9	1.9	3.0

* Significantly different from mancozeb at the 5.0% level
** " " " " " " 1.0% "
*** " " " " " " 0.1% "

Table 1 (Contd.)

Effect of fungicides on leaf spot and yield of the black currant cultivar Wellington XXX

Fungicide	Oz a.i./ac per application	1969 % leaf spot July 10	August 14	Sept. 10	Yield cwt/ac
Benomyl	8.0[1]	4.0*	31.0***	70.5***	134.6
"Daconil 2787"	18.0	5.8	53.6	93.9	125.7
Dithianon	18.0	4.7*	36.7***	73.8***	135.6
"Karamate"	37.2	8.8	65.7	98.1	126.8
Mancozeb	38.4	7.1	58.8	91.9	127.2
Maneb	38.4	6.7	52.8	91.1	118.7
S.E. of treatment means (df = 20)		0.7	2.9	2.6	9.2

[1] Benomyl was used at 4.0 oz a.i./acre for the first 3 sprays

* Significantly different from mancozeb at the 5.0% level
** " " " " " " 1.0% "
*** " " " " " " 0.1% "

years of testing but resulted in a significantly lower yield in 1968. Disease control by dithianon was equal to mancozeb in 1967, was slightly superior in 1968 and considerably better in 1969. There was, however, no significant difference in yield between the two treatments. Benomyl was tested in 1969 only, resulting in leaf spot control comparable with dithianon and significantly better than mancozeb. In yield it did not differ significantly from mancozeb.

DISCUSSION

When this work was commenced in 1963 zineb was the fungicide in common use for the control of black currant leaf spot. As many Irish growers were obtaining poor disease control with zineb, a number of fungicides were compared with this material as a standard from 1963 to 1967. A proprietory Fe-Zn-Mn dithiocarbamate, captafol, dodine, fentin hydroxide, folpet and metiram were tested and found unsuitable for use against P. ribis on black currants under Irish conditions (Ó Ríordáin, 1968). On the other hand, mancozeb and maneb were shown to be considerably better than zineb (Ó Ríordáin, 1968). The marginal superiority of mancozeb over maneb in late season disease control was probably due to its better fungitoxicity and persistance (Wood, 1963). This difference is not apparent in the results presented here, probably due to the drier summers of the last three years. However, in these trials both mancozeb and maneb gave better late season control than "Karamate".

One disadvantage of the dithiocarbamate fungicides is that they cannot be used on fruit for processing within one month of picking. This long interval without spraying can lead to a serious build up of disease in certain seasons. With a view to overcoming this difficulty fungicides such as "Daconil 2787", dithianon, dodine, and quinomethionate were tested. In previous trials dodine gave better disease control than zineb but resulted in reduced yields (Ó Ríordáin, 1968). Both in the previous trials and in those reported here "Daconil 2787" was as effective in disease control as mancozeb but resulted in reduced yields. Quinomethionate, which had given good leaf spot control in Britain (Corke and Jordan, 1966), was the least effective of the fungicides in each of the two seasonsof testing and also, as Corke and Jordan (1968) found, reduced yields. The most effective of the non-dithiocarbamate fungicides was dithianon. In 1967 this fungicide gave results similar to mancozeb. Late season control by dithianon was superior to that of mancozeb in 1968. This superiority was evident in all assessments in 1969.

It is interesting to speculate as to the reason for the relative increase in effectiveness of dithianon. Possibilities include the drier summers or a change in the reaction of the pathogen.

In view of the relatively high mammalian toxicity of dithianon (Berker, J. et al, 1963) residue analysis was carried out on the fruit. With a ten day spray programme and a four week interval between the last spray and picking in 1968 residues of dithianon were 0.31, 0.41 and 2.2 ppm for three replicates. Two of the 1969 replicates had residues below 0.1 ppm, the limit of detection, the third had 0.2 ppm. These lower levels can be explained by the 14 day spray programme and the eight week interval, due to a late harvest, between the last spray and picking.

Benomyl was first tested in 1968 in a direct comparison with mancozeb. However, leaf spot did not develop in this plantation. As there was no significant difference in yield between the two treatments the indications are that it was not phytotoxic. Of the six fungicides tested in 1969 benomyl gave the best control of leaf spot and was significantly better than mancozeb in each assessment. While much more testing is necessary this fungicide is promising for black currant disease control as it may also have an effect against powdery mildew (Delp and Klopping, 1968).

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FUNGICIDAL CONTROL OF AMERICAN GOOSEBERRY MILDEW ON BLACK CURRANTS

P. Wiggell and Carol J. Simpson
National Agricultural Advisory Service
Area Laboratory, Evesham, Worcs.,

J. Ingram
Luddington Experimental Horticulture Station

Summary

Seven fungicides were compared for the control of American gooseberry mildew (Sphaerotheca mors-uvae) on black currant cultivars Wellington XXX and Baldwin. Drazoxolon consistently gave good control of mildew and leaf spot. E.L.273, used for the first time in 1969, also gave good control of both these diseases.

The results suggest, especially on the variety Baldwin, that (a) biennially cropping bushes should be sprayed for mildew and leaf spot control in their cropping year in addition to their growing year (b) that mildew and leaf spot infection in the cropping year reduced crop (c) the 1% lime sulphur programme reduced yield and gave less crop than the unsprayed control (d) a slight residual effect from the previous years treatments reduced the level of mildew and, to a lesser extent, leaf spot in the following year (e) no benefit was observed by an application of 5% lime sulphur plus wetter or 10% tar-petroleum oil in January/February. The results with cultivar Wellington XXX were not so clear cut.

INTRODUCTION

Jordan (1966, 1967) demonstrated that the American gooseberry mildew fungus (Sphaerotheca mors-uvae) on black currants produces active perithecia and that ascospores are the main source of infection in the spring. Ascospore maturation is reached at about the time of full blossom each season but their production depends very much on the prevailing weather conditions during development. Once first infections have become established rapid secondary spread by conidea takes place. In the experiments reported here a comparison is made on the effectiveness of seven fungicidal treatments for the control of American gooseberry mildew on black currant cultivars Wellington XXX and Baldwin.

METHOD AND MATERIALS

The experiments were commenced in 1966 on black currant cultivar Wellington XXX (designated Phase I) and in 1967 on cultivar Baldwin (designated Phase II). Control of American gooseberry mildew and leaf spot (Pseudopeziza ribis) may not be necessary in the cropping year of black currants harvested mechanically viz: bushes cut down completely at harvest every second year and it is therefore of interest to consider how much effect a programme of spray treatments, carried out to give an adequate control of mildew in one season, can exert on the control of infection in the next. To observe this, all six replicates were sprayed with the fungicidal treatments in the growing year, while in the cropping year three replicates were sprayed and the remaining three unsprayed.

Experiments (Phase I) - on Wellington XXX

This Phase was commenced in 1966 at Luddington Experimental Horticulture Station on the black currant cultivar Wellington XXX to compare the effectiveness of five fungicides for the control of American gooseberry mildew and to determine whether control of mildew (and leaf spot) is necessary in the cropping year as well as in the growing year.

Treatments

In 1966 the following fungicidal treatments were applied to bushes in their growing year

Treatment 1. dinocap 0.25 lb a.i. (1 lb 25% w.p.)/100 gal (H.V.)
2. quinomethionate 0.25 lb a.i. (1 lb 25% w.p.)/100 gal (H.V.)
3. lime sulphur 1% plus 4 fl.oz 60% succinate wetter/100 gal (H.V.)
4. *drazoxolon 0.1% (approx.) (2 pt 33.8% formulated product)/ 100 gal (H.V.)
5. dinobuton 8 fl.oz a.i. (16 fl.oz 50% w.p.)/100 gal (H.V.)
6. control - unsprayed

*It was proposed to use drazoxolon at 0.1% reducing the strength of this treatment to 0.05% if damage to bushes occurred. This was not necessary since no plant injury was noted during the season.

Treatments were applied when mildew infection was first recorded and were repeated at three weekly intervals until the end of August.

In 1967 some of the treatments were modified. The manufacturer altered the formulation of drazoxolon and, as a result, this treatment was applied as a 0.1% application (2 pt 40% formulation)/100 gal (H.V.). In addition, Treatment 5, dinobuton, had given poor control of mildew in 1966 and was replaced by an experimental fungicide under the code number P 2209.

In 1968 the treatments used in 1967 were again applied.

In 1969 the treatments were further modified. Experimental fungicide P 2209 was discontinued for use on black currants. As a result, a further experimental fungicide under the code number E.L.273 was introduced to replace the P 2209 treatment.

Layout

The layout comprised six replications of the fungicidal treatments and twelve replications of the unsprayed control treatment randomly arranged in six blocks.

Each plot consisted of six bushes with a single unsprayed guard bush between treatments within the row. A single perimeter guard bush at the end of each row surrounded the experiment.

Cultural Details

Two year old bushes, cultivar Wellington XXX, were planted in 1963 at a spacing of 8 ft x 3 ft. The sprays were applied by hand lance to run-off at 250 to 300 gal/ac. Sprays for gall mite and aphid control (as endrin or endosulfan or demeton-methyl) were applied overall at the appropriate stage of growth.

The bushes were in their growing phases in 1966 and 1968 and in their cropping phases in 1967 and 1969.

Mildew was first recorded on these bushes on 11 May in 1966, 9 May in 1967, 23 May in 1968 and 23 May in 1969. The dates of spray treatments were as follows:

1966 (on all six replicates in the growing year)
12 May; 3 and 25 June; 16 July; 6 and 25 August.

1967 (on three replicates only in the cropping year)
10 and 31 May; 22 June.

An overall spray of 10% lime sulphur plus 2 fl.oz Agral 90 plus wetter per 100 gal was applied to the cut-down stools on 1 August followed by applications of quinomethionate 0.25 lb a.i. (1 lb 25% w.p.)/100 gal (H.V.) on 16 August and 19 September to the autumn regrowth. The appropriate plot spray treatment was applied subsequently to the autumn regrowth.

1968 (on all six replicates in the growing year)
27 May; 17 June; 9 and 29 July; 15 August (19 August for drazoxolon treatment)

1969 (on three replicates only in the cropping year)
27 May; 17 June; 8 July.

An overall spray of 10% lime sulphur plus 4 fl.oz succinate wetter was applied to the cut-down stools on 24 July and was followed by an application of the appropriate plot spray treatment to the regrowth on 4 August, 25 August and 9 September. Stools in the control plots were sprayed with dinocap.

Assessment Procedures

In 1966 two shoots on each of five bushes per plot were assessed for mildew infection on 16 June, 24 July and 11 October. On 16 June the assessment key ranged from 0 = no mildew visible to 5 = mildew present on all expanded leaves and on top surface of more than half of the infected leaves. The later assessments made on 24 July and 11 October used a key ranging from 0 = no mildew visible to 7 = death or shrivelling of the terminal bud with reduction in internode length at top of extension shoot and rosetting.

In subsequent years, the following key was used in July or mid August for the assessment of mildew on the current year's vegetative growth in both the growing and cropping years of the machine-harvested bushes. The average number of leaves per shoot was counted and the number of leaves infected, which fell into the categories slight (infection present on underside of leaf only) and severe (infection present on both sides of leaf or covering at least half the underside and associated with leaf distortion) were recorded. For assessment of mildew on the dormant canes of machine-harvested bushes in their growing year, in the autumn after leaf fall (November/December), representative shoots in the following categories were recorded:

0 = no mildew mycelium visible

1 = mycelium present on shoot: terminal bud normal

2 = mycelium present on shoot: tips pinched and terminal bud thin

3 = mycelium present on shoot: tips and shoot dead

Leaf spot assessments were based on the key by Clarke G. M. and Corke A. T. K. (1955).

RESULTS

Table 1

Black currant - Effect of fungicides on American gooseberry mildew and leaf spot in 1966

Treatment	Mildew Infection Category Cat 0 to 5 16 June	Cat 0 to 7 24 July	Cat 0 to 7 11 October	% shoots with severe mildew 11 October	% leaf spot infection 11 October
1. dinocap	1.8	2.8	4.8	54	32
2. quinomethionate	1.0	1.3	1.8	21	< 5
3. lime sulphur + wetter	1.0	2.4	3.8	36	26
4. drazoxolon	0.9	1.0	1.6	17	< 5
5. dinobuton	2.3	3.6	5.9	100	50
6. control - unsprayed	3.0	5.3	*	100	94

* partially defoliated due to leaf spot, which did not permit reliable mildew assessment

Drazoxolon and quinomethionate gave outstanding control of both American gooseberry mildew and leaf spot whilst dinobuton gave poor control. The level of control was obtained with six applications, commencing mid-May and repeated at three weekly intervals until the end of August.

Table 2

Black currant - Effect of fungicides on American gooseberry mildew in July 1967

Treatment	* Annual % leaves severely infected	% leaves slightly infected	% healthy leaves	** Biennial % leaves severely infected	% leaves slightly infected	% healthy leaves
1. dinocap	7.1	24.4	68.5	56.4	9.9	33.7
2. quinomethionate	40.3	46.9	12.8	52.7	14.1	33.2
3. lime sulphur + wetter	24.2	33.8	42.0	52.4	13.8	33.8
4. drazoxolon	6.4	23.0	70.6	52.7	18.1	29.2
5. P 2209	6.9	58.8	34.3	44.8	17.1	38.1
6. control - unsprayed	43.5	23.2	33.3	55.3	14.4	30.3

* these replicates received fungicidal sprays in 1967

** replicates not sprayed in 1967

Table 3

Black currant - Effect of fungicidal treatments on yield in 1967

Treatment	Annual		Biennial	
	lb/plot	ton/ac	lb/plot	ton/ac
1. dinocap	4.90	0.66	5.43	0.73
2. quinomethionate	6.87	0.93	6.23	0.84
3. lime sulphur + wetter	4.00	0.54	4.97	0.67
4. drazoxolon	9.00	1.21	6.63	0.90
5. P 2209	1.97	0.27	6.10	0.82
6. control - unsprayed	4.20	0.57	5.28	0.71

L.S.D. for treatments versus control = 1.65 lb/plot = 0.22 ton/ac

Drazoxolon again gave outstanding control of mildew and this was reflected in the yield, especially from those plots which received this treatment annually. Quinomethionate did not give a satisfactory control of mildew, whereas in 1966 it was equally as effective as drazoxolon. The yield figures given in Table 3 do not show a clear cut trend in favour of spraying biennially cropping bushes for mildew and leaf spot control in their cropping year, in addition to their growing year. Yields, in 1967, were severely reduced by frost and, as a result, no reliable interpretation can be placed on the figures given in Table 3.

Table 4

Black currant - Effect of fungicides on American gooseberry mildew and leaf spot in 1968

Treatment	American gooseberry mildew						Leaf spot	
	% leaves severely infected		% leaves slightly infected		% leaves healthy		% infection	
	2/7	20/8	2/7	20/8	2/7	20/8	2/7	20/8
1. dinocap	0.2	22.4	28.4	33.2	71.4	44.4	< 5	40.6
2. quinomethionate	14.6	23.3	38.3	53.6	47.1	23.1	<5	<5
3. lime sulphur + wetter	0.2	13.6	21.0	45.5	78.8	40.9	<5	34.7
4. drazoxolon	0.0	25.1	12.7	27.1	87.3	47.8	<5	<5
5. P 2209	0.2	32.6	18.4	22.5	81.4	44.9	<5	42.4
6. control - unsprayed	32.3	65.6	24.4	14.0	43.3	20.4	20.4	73.2

Drazoxolon again gave the best control of mildew whilst P 2209 and dinocap were also promising; however, neither of these two materials gave an adequate control of leaf spot.

Table 5

Black currant - Effect of fungicides on American gooseberry mildew in July 1969

Treatment	* Annual			** Biennial		
	% leaves severely infected	% leaves slightly infected	% healthy leaves	% leaves severely infected	% leaves slightly infected	% healthy leaves
1. dinocap	0.3	26.9	72.8	14.8	29.1	56.1
2. quinomethionate	1.1	25.2	73.7	17.5	26.0	56.5
3. lime sulphur + wetter	0.0	29.2	70.8	19.0	28.0	53.0
4. drazoxolon	0.0	11.1	88.9	13.3	27.7	59.0
5. E.L.273 *** (P 2209 in 1968)	0.3	2.9	96.8	13.9	29.2	60.7
6. control - unsprayed	19.4	27.7	52.9	17.8	25.4	56.8

* only these replicates received fungicidal sprays in 1969

** replicates not sprayed in 1969

*** a.i. = α - (2-4 dichlorophenyl) - α -phenyl-5-pyrimidinemethanol

Table 6

Black currant - Effect of fungicidal treatments on yield in 1969

Treatment	Annual		Biennial	
	lb/plot	ton/ac	lb/plot	ton/ac
1. dinocap	15.5	2.09	18.7	2.52
2. quinomethionate	14.5	1.95	17.6	2.37
3. lime sulphur + wetter	11.7	1.58	12.9	1.74
4. drazoxolon	14.6	1.97	12.7	1.71
5. E.L.273 (P 2209 in 1968)	13.2	1.79	17.2	2.33
6. control - unsprayed	13.30	1.80	16.2	2.19

The results (Table 5), from the three replicates sprayed in 1969, support those results in 1968 where drazoxolon gave the best control of mildew. E.L.273, which was used for the first time in 1969, gave outstanding control of mildew. The assessment of mildew on the three replicates unsprayed in 1969 does not show any apparent 'residual' effect of the 1968 fungicidal treatments when compared with the control treatment which was unsprayed in both 1968 and 1969.

Yields (Table 6) in 1969 were affected by low temperatures although this effect was not so severe as in 1967. In addition, a prolonged drought during June/early July also contributed to yield variations. As a result, no firm conclusion can be drawn from the data given in Table 6.

A marked difference in vigour between the bushes of the respective treatments was apparent after the fourth year of the trial. These differences are given in Table 7.

Table 7

Effect of fungicidal treatments on bush vigour July 1969

Treatment	Average number of leaves per shoot on the current years extension growth
1. dinocap	14.2
2. quinomethionate	15.2
3. lime sulphur + wetter	14.5
4. drazoxolon	16.2
5. E.L.273 (P 2209 in 1968)	14.9
6. control - unsprayed	12.8

Experiments (Phase II) - on Baldwin

This Phase was commenced in 1967 to compare the effectiveness of the five fungicides, as used in Phase I, for the control of American gooseberry mildew on the black currant cultivar Baldwin, to determine whether control of mildew (and leaf spot) is necessary in the cropping as well as the growing year and also whether an application of lime sulphur in January or February reduces the subsequent level of disease.

Treatments

Treatment details are the same as American gooseberry mildew trial Phase I, cultivar Wellington XXX, with the addition of a split plot treatment to all plots viz:

A. One application in January or February of 5% lime sulphur plus 4 fl.oz succinate wetter per 100 gal as 60% Manoxol

B. No lime sulphur spray in January or February

In 1969 the 5% dormant lime sulphur treatment was replaced by 10% tar-petroleum oil 'Para-Carbo'.

Layout

The layout differed from the Phase I trial in that each treatment was replicated six times and each plot contained five rows of seven bushes per row, split for the dormant season treatment to give ten recordable bushes in each sub-plot. The bushes were spaced at 4½ ft between the rows by 3 ft within the rows and arranged in five row beds with a 9 ft tractor alleyway between the beds.

Cultural Details

One year old bushes were planted during the winter of 1965 to 1966, cut down in

1966 to 1967 and carried their first crop in 1968. All sprays were applied by hand lance to run-off at 250 to 300 gal/ac. Sprays for gall mite and aphid control, as endrin or endosulfan or demeton-methyl, were applied overall at the appropriate stage of growth. Herbicides were applied overall as required.

The bushes were in their growing phase in 1967 and 1969 and were in their cropping phase in 1968.

Mildew was first recorded on these bushes on 9 May 1967, 23 May 1968 and 23 May 1969.

The dates of spray treatments were as follows:

1967 (on all six replicates in the growing year)

The 'dormant' application of 5% lime sulphur plus wetter was made on 21 February. The six fungicide applications were made on 11 and 31 May, 22 June, 11 to 12 July, 1 and 23 August

1968 (on three replicates only in the cropping year)

The 'dormant' application of 5% lime sulphur plus wetter was made on 31 January

The fungicide sprays were applied on 27 May, 18 June, 9 July

After the bushes were cut down completely at harvest in 1968, the stools received an overall spray of 10% lime sulphur on 5 August and sprays of the respective treatment fungicides to the regrowth on 14 August, 6 September and 2 October

1969 (on all six replicates in the growing year)

In this year the 'dormant' season application of 5% lime sulphur was replaced by 10% tar-petroleum oil 'Para-Carbo' which was applied on 7 February.

The fungicide sprays were applied on 27 May, 17 to 18 June, 9 July, 4 August and 22 to 26 August.

RESULTS

Table 8

Black currant - Effect of fungicides on American gooseberry mildew and leaf spot in 1967

Treatment	American gooseberry mildew				Leaf spot
	% leaves severely infected 30 August	% leaves slightly infected 30 August	% leaves healthy 30 August	Index of shoot infection 17 November	% infection 13 September
1. dinocap	36	54	10	0.2	8.3
2. quinomethionate	41	48	11	0.0	<5.0
3. lime sulphur + wetter	23	62	15	1.0	7.1
4. drazoxolon	19	58	23	0.0	<5.0
5. P 2209	19	60	21	0.0	7.9
6. control - unsprayed	86	13	1	2.0	15.9

The results showed that drazoxolon and P 2209 gave the best control of mildew with drazoxolon and quinomethionate giving superior control of leaf spot. Slight damage to the bushes was associated with the P 2209 programme.

Table 9

Black currant - Effect of fungicides on American gooseberry mildew and leaf spot in July 1968

Treatment	American gooseberry mildew						Leaf spot	
	% leaves severely infected		% leaves slightly infected		% leaves healthy		% infection	
	A	B	A	B	A	B	A	B
(a) replicates sprayed in both growing and cropping years, 1967 and 1968								
1. dinocap	0	0	14	18	86	82	16	13
2. quinomethionate	0	1	30	31	70	68	2	3
3. lime sulphur + wetter	0	0	21	19	79	81	12	9
4. drazoxolon	0	0	6	5	94	95	5	3
5. P 2209	0	1	18	17	82	82	15	20
6. control - unsprayed	20	24	22	22	58	54	21	17
(b) replicates sprayed in growing year only, 1967								
1. dinocap	11	18	28	24	61	58	15	14
2. quinomethionate	14	15	26	27	60	58	9	11
3. lime sulphur + wetter	12	11	28	24	60	65	18	15
4. drazoxolon	10	18	27	21	63	61	15	12
5. P 2209	10	16	27	29	63	55	11	16
6. control - unsprayed	24	28	24	18	62	54	18	18

A = one application of 5% lime sulphur + wetter applied 31 January
B = no lime sulphur spray on 31 January

The results given in Table 9 (a) from the three replicates sprayed in 1968 confirm the results reported in the Phase I trial where drazoxolon gave the best control of mildew and drazoxolon and quinomethionate the best control of leaf spot. The assessment of mildew infection on the three replicates unsprayed in 1968 Table 9 (b) showed the apparent slight residual effect of the 1967 fungicidal treatments when compared with the control treatment which was unsprayed in both 1967 and 1968.

The leaf spot record taken in 1968 shows very little effect from the sprays applied to bushes in 1967. The application of 5% lime sulphur plus wetter in January did not appear to have reduced disease levels on either the replicates sprayed with the summer fungicides or those unsprayed in 1968.

Table 10

Black currant - Effect of fungicides on *yield in 1968

Treatment	Replicates sprayed in growing and cropping years 1967 and 1968 tons/ac			Replicates sprayed in growing year only 1967 tons/ac		
	A	B	Mean of A and B	A	B	Mean of A and B
1. dinocap	1.18	1.18	1.18	1.09	0.71	0.90
2. quinomethionate	0.94	0.81	0.88	0.73	0.78	0.76
3. lime sulphur + wetter	0.55	0.44	0.50	0.42	0.68	0.55
4. drazoxolon	0.96	1.65	1.31	0.64	0.89	0.77
5. P 2209	1.47	1.18	1.33	0.93	0.73	0.83
6. control - unsprayed	0.86	0.67	0.77	0.49	0.50	0.50

A = one application of 5% lime sulphur + wetter applied 31 January

B = no lime sulphur spray on 31 January

* severely reduced by frost

In 1968 the bushes carried their first crop which was severely reduced by frost but the results given in Table 10, which are subject to statistical confirmation, suggest that spraying in the cropping year in addition to the growing year appears to have increased the yield from all treatments with the exception of treatment 3. lime sulphur + wetter. This treatment gave a lower yield than the unsprayed control and if analysis shows this to be significant it is probably due to a phytotoxic effect which has counteracted any advantage from disease control. The one application of 5% lime sulphur in January did not appear to influence yield. Since treatment A did not appear to have had any effect on yield, the comparison between the means of A and B, sprayed in 1967 and 1968, and the means of A and B sprayed in 1967 only, shows more clearly the increased yield where bushes were sprayed in their cropping as well as their growing year. This is shown especially by the two fungicides drazoxolon and P 2209 which, with dinocap, provided the most effective control of mildew.

Table 11

Black currant - Effect of fungicides on American gooseberry mildew and leaf spot in 1969

Treatment	American gooseberry mildew						Leaf spot	
	% leaves severely infected		% leaves slightly infected		% leaves healthy		% infection	
	14 to 19 August							
	A	B	A	B	A	B	A	B
1. dinocap	13.0	12.0	24.0	23.6	63.0	64.4	7.8	7.2
2. quinomethionate	14.3	14.6	32.7	30.8	53.0	54.6	7.5	6.6
3. lime sulphur + wetter	7.1	4.0	32.0	26.0	60.9	70.0	18.7	20.8
4. drazoxolon	5.6	2.4	19.3	20.2	75.1	77.4	6.2	5.3
5. E.L.273	1.5	1.7	16.4	15.0	82.1	83.3	7.7	5.8
6. control - unsprayed	50.2	46.5	13.2	14.0	36.6	39.5	16.3	14.2

A = one application of 10% tar-petroleum oil 'Para-Carbo' 7 February

B = no tar-petroleum oil spray in February

Table 12

Black currant - Effect of fungicides on leaf spot and bush height 1969

Treatment	Leaf spot % infection Sept 1969		Bush height cm Oct 1969	
	A	B	A	B
1. dinocap	28.7	30.7	70.0	72.4
2. quinomethionate	19.7	21.5	67.1	67.6
3. lime sulphur + wetter	39.0	40.8	62.2	65.4
4. drazoxolon	12.3	11.0	68.8	76.1
5. E.L.273	13.0	17.0	70.3	70.5
6. control - unsprayed	49.7	43.7	62.6	61.1

The results in Tables 11 and 12 again show the good control of mildew and leaf spot given by drazoxolon. This material has performed consistently well against both diseases over the whole period of the trials. E.L.273 showed outstanding control of mildew and, in addition, performed equally as well as drazoxolon against leaf spot. Further trials with this material are needed before any firm conclusions can be made. No benefit in disease control was afforded by the dormant spray in February of 10% tar-petroleum oil 'Para-Carbo'.

DISCUSSION

One of the many aspects of black currant investigations at Luddington Experimental Horticulture Station is growing the crop for machine harvesting. This involves cultural trials concerned with plant establishment, spacing, pruning, shoot thinning, irrigation, nutrition and disease control. As a result, many bushes at the Station, in any one year, are in their growing phase when they are extremely susceptible to infection by American gooseberry mildew. This situation leads to an extremely high level of disease inoculum each season. The fungicides compared, in the experiments reported, were applied at intervals of three weeks from the date mildew was first recorded. This is probably a wider interval than would be recommended for the fungicide if commercially available but is a schedule which fully tested the effectiveness of the fungicide against mildew and leaf spot diseases. Under these conditions drazoxolon performed consistently well against both diseases over the period of the experiments. In 1969, E.L.273 when used for the first time, also gave most promising control of both diseases.

Unfortunately, low temperatures over the flowering periods were experienced in each cropping year of the trials 1967, 1969 (Wellington XXX) and 1968 (Baldwin). The yield data presented in Tables 3 and 6 for Wellington XXX do not show a clear cut trend in favour of spraying biennially cropping bushes for mildew and leaf spot control in their cropping year in addition to their growing year. In 1968 the Baldwin bushes carried their first crop which, although severely reduced by frost, results (Table 10) do suggest that spraying in the cropping year, in addition to the growing year, appears to have increased yield from all treatments with the exception of lime sulphur. It is probable that the different response obtained with these two varieties is explained by their different flowering periods, Wellington being slightly earlier. In 1967 and 1969 flowers on this variety were at their most vulnerable stages of growth during the periods when low temperatures were experienced.

No benefit was gained by applying 5% lime sulphur or 10% tar-petroleum oil in the dormant stage during January or February.

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THE CONTROL OF AMERICAN GOOSEBERRY MILDEW ON BLACK CURRANTS

V.W.L. Jordan
Long Ashton Research Station, University of Bristol.

Summary. The severity of mildew attacks in black currant plantations is largely dependent on inoculum level and environmental conditions. Recent changes in cultural practice have led to closer planting and more vigorous growth, producing a micro-climate more favourable for mildew infection. Trials have shown that the timing of summer sprays is critical, and that the greatest benefit is obtained from an application immediately after ascospore discharge has reached its peak. Control during the summer is much more effective if the level of inoculum available for primary infection is markedly reduced by sprays applied during the dormant season.

Although American gooseberry mildew (Sphaerotheca mors-uvae) has been recorded for many years as a pathogen of minor importance on black currants, it has now become a disease of major importance on this crop, resulting in stunted growth, reduction in leaf efficiency and loss of crop in the following season. It is unlikely that a new race of American gooseberry mildew specifically pathogenic to black currants has recently appeared (Jordan, 1968), and there is no evidence to suggest that the increased attack is due to the introduction of new varieties, since the most recent are generally less susceptible (Jordan, 1967).

A possible explanation is that the many changes in methods of cultivation which have taken place during the last decade have given rise to a complex situation in which black currant bushes are subjected to new growing conditions (Corke, 1964).

Infection and sporulation of the pathogen is encouraged by a relatively low soil moisture content, temperatures above 15°C, 60% relative humidity and good illumination (Jordan, 1968). It can therefore be assumed that these conditions may occur frequently and be more prolonged in a closely-planted black currant plantation compared with a more open one. Susceptibility of black currant bushes to infection is positively correlated with plant vigour, and soil or other factors which promote vigorous plant growth favour mildew infection (Jordan, 1967).

For the control of American gooseberry mildew on black currants, repeated spray applications will often be necessary to give the degree of disease reduction required to ensure an undiminished crop in the following year. An important factor in attempts to find a chemical control of this disease is the timing of spray applications (Corke & Jordan, 1966). It was found that at least two applications were required for an effective reduction in the level of infection providing that the first spray was applied not later than 'first green fruit'. In two successive years this stage in the development of black currant bushes coincided with the 'peak' ascospore discharge period.

The more recently-introduced fungicides, quinomethionate and drazoxolon, have shown reasonable promise in reducing infection (Corke & Jordan, 1966) and avoid the danger of causing damage by using lime sulphur. Applications of either of these two materials at 'first open flower', 'first green fruit' and 'fruit set' gave complete protection for at least three weeks, and a reduction of over 50% infection until mid-August. A winter assessment using the 'key' developed by Corke & Jordan (1965) showed that bushes receiving three applications of quinomethionate and drazoxolon had mean disease levels of 1.97 and 1.89 respectively, compared with 3.02 in the unsprayed bushes. In the following year, these bushes carried significantly more crop, 7.69 ton/ac. and 6.80 ton/ac. respectively, than those unsprayed, 3.90 ton/ac. ($\underline{P}$ = 0.001).

Greenhouse and field trials at Long Ashton have shown the powerful protectant and eradicant action of a series of 4-substituted-2,6-dinitrophenols[+] against American gooseberry mildew (Byrde et al. 1969), even at low concentrations, and most compounds were markedly superior to dinocap isomers. Highest activity in the greenhouse was shown by members of the 4-(1-cyclopentyl alkyl)-2,6-dinitrophenol and 4-(1-cyclobutyl alkyl)-2,6-dinitrophenol series. From the greenhouse screening tests, four compounds were selected and applied three times in the field. All four compounds gave a significant reduction (P = 0.001) in the disease intensity level at the end of the season, using the 'key' assessment method, although the general level of infection on the unsprayed bushes was low (mean infection grade 2.32). However, no significant differences in the crop weights were recorded between the treatments and the unsprayed bushes in the following year: the mean weight for all treated and unsprayed bushes ranged between 5.34 and 5.83 lb/bush.

It is necessary to pay much greater attention to the reduction of the source of overwintering inoculum than was paid in the past; summer spray applications would most certainly be more effective if the amount of perennating inoculum was at a low level.

Perithecia of American gooseberry mildew remain embedded in the superficial mycelium of shoots and fallen leaves throughout the winter, and discharge viable ascospores in the spring, when conditions are favourable, thus initiating the primary infection (Jordan, 1966).

Attempts were therefore made to evaluate possible materials for use as winter washes in order to reduce the inoculum potential of the overwintering fruiting bodies.

The following materials were used in the greenhouse screening test.

A. Tar Oil at 5%
B. Petroleum Oil at 5%
C. Tar/Petroleum Oil at 5%
D. DNOC/Petroleum Oil at 0.1% a.i. DNOC
E. Lime Sulphur at 10%
F. o-Phenyl phenol (e.c.) 1% a.i.
G. o-Phenyl phenol (Sodium salt) 1% a.i.
H. 2,4,6-trichlorophenol at 500 p.p.m.
J. Untreated.

Infected black currant shoots, bearing numerous perithecia, were dipped in the materials under test to ensure complete cover and penetration. Perithecia were removed at weekly intervals for microscopic examination of their development. Ascospores from the treated shoots were trapped by means of suction spore traps (a modification of the 'Hirst' spore trap) so that the numbers discharged could be recorded daily.

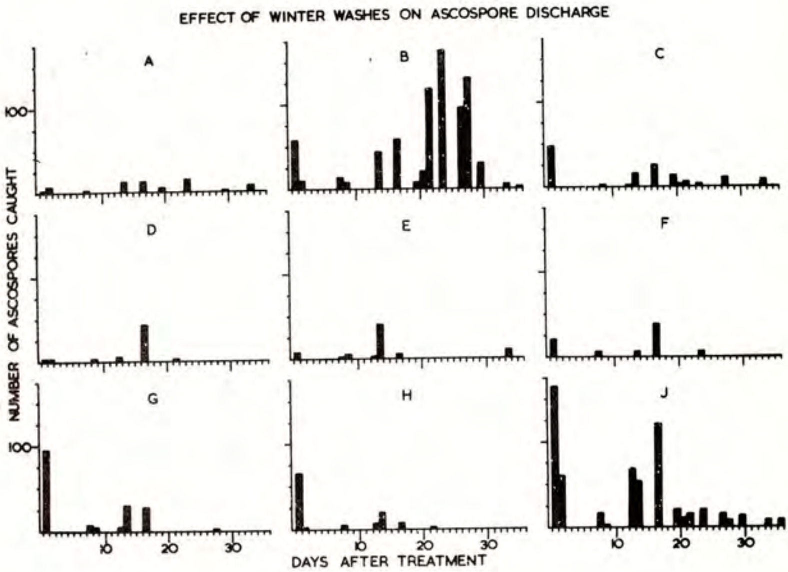
Table 1
Percentage degenerate perithecia

Treatment	Days after application					
	2	10	17	24	31	38
A	40	50	88	87	78	96
B	40	40	53	48	67	62
C	52	88	99	92	84	94
D	33	71	99	87	89	99
E	0	59	93	72	59	53
F	17	88	85	88	87	51
G	45	91	90	68	77	76
H	36	78	99	54	62	76
J	10	19	12	9	2	4

[+] Brit. Pat. Applic. 23,712/67

As can be seen from the results (Table 1), all treatments caused degeneration of the contents of the majority of developing asci and ascospores, and this was reflected in the counts of discharged spores (Fig. 1), where all treatments, with the exception of petroleum oil, reduced the number discharged by more than 78 per cent compared with those left unsprayed. Mildew infections were recorded only on leaves from treatments B, E and J.

Fig. 1



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FIELD TRIALS WITH BENOMYL ON SOFT FRUIT IN 1969

R.G. Tapley and R. Woodroffe

Fisons Limited, Chesterford Park Research Station, Nr. Saffron Walden, Essex

P.S. Atkins

Fisons Limited, Levington Research Station, Ipswich, Suffolk

Summary Benomyl applied as a high volume spray at 8 oz a.i./acre at 14 day intervals has given excellent control of the major diseases of blackcurrants, strawberries and gooseberries. In many cases benomyl has increased yields above standard treatments. Benomyl has a wider range of activity than any single standard material tested. No phytotoxicity has been observed in any of these trials including raspberries, and strawberries grown under glass cloches and polythene tunnels. Fruit finish is excellent, and treated fresh strawberries are free of taint. Benomyl is compatible and safe to use when tank mixed with commonly used insecticides on the most common cultivars of blackcurrant and strawberry.

INTRODUCTION

The objects of the 1969 trials were to determine the optimum dose rate and frequency of application of benomyl, recently invented by Du Pont de Nemours & Co. (Inc), against the major soft fruit diseases and to compare its performance with materials in general use. Delp & Klopping (1968) have demonstrated the unique fungicide properties of benomyl (then Du Pont 1991) and outlined the fields of activity.

Replicated and large plot non-replicated trials were conducted in blackcurrants and strawberries and some limited trial work was carried out in gooseberries and raspberries. Particular attention has been paid throughout on the effect of benomyl on crop quality and crop safety.

METHOD AND MATERIALS

The median dose rate used throughout the trials, 8 oz a.i./acre, was indicated by the trial work in 1968 largely conducted by official workers in the U.K. and elsewhere. The higher dose rate used was 12 oz a.i./acre and the lower 4 oz a.i./acre. In all but one trial benomyl as a 50% wettable powder and standard materials were applied in up to 200 gal water per acre. A surfactant 'Spreadite' was used with benomyl in the spray mixture. In replicated trials the spray was applied by knapsack sprayers, and where single rates were applied on large unreplicated plots growers used their normal mechanised fruit spraying equipment.

The actual rate of fungicides applied and the intervals of 14 days between sprays were very much as intended. In practice 200 gal spray per acre seemed excessive in all crops since not only were the bushes thoroughly wetted but there appeared also to be excessive runoff. In some few cases spraying was delayed by inclement weather. The longest delay was 5 days on one of the blackcurrant trials during the spring.

RESULTS

The season as a whole was disappointing in that disease incidence was generally not severe, and where it occurred was rather late in the season. The season as a whole was slow in starting and, in parts of Eastern England especially, late in finishing. The blackcurrant trial in Norfolk for example was not picked until mid-August, about two weeks later than anticipated.

Blackcurrants

A replicated trial (3 replicates, 8 treatments) was conducted on a farm in each of three fruit growing areas of Hereford, Lincolnshire and Norfolk. Plot size was varied according to the size and number of bushes available, but was not less than 5 bushes in single row plots, with no guard trees between the plots.

In addition 4 large plot non-replicated trials on non-bearing blackcurrants were conducted in Lincolnshire, Norfolk and Suffolk to control mildew. Growers applied benomyl on a normal spray schedule and comparisons were made between these plots and adjacent bushes treated on the farmer's normal spray programme. High volumes were used on three farms, but one farm in Norfolk used low volume.

Additional supplementary trials were conducted for residue analysis, taint tests of fruit and compatibility studies.

Leaf spot (Pseudopeziza ribis) Details of the treatments, the number of applications and leaf spot assessments before and after harvest are presented in Table 1. Leaf spot appeared late in the season in Hereford and Lincs and little was seen up to harvest. In Norfolk, where the harvest was delayed until mid-August, differences between the treatments were first evident in mid-June and became increasingly wide until at harvest time the control plots were almost completely defoliated. Assessments of leaf spot damage, based on the Clarke & Corke (1956) visual scale, are summarised in Table 1. The end trees of the plots were ignored, only the centre trees being assessed. At times the grades of damage appeared to be too wide and needed further qualification by 'greater than' or 'less than'. In the benomyl plots leaf spot would sometimes occur high up the bush, while the lower leaves remain green and healthy. Where a range of assessments are given in Table 1 this is due to differences between the replicates rather than differences within single plots.

Leaf spot only occurred on one of the non-bearing trials. Benomyl gave a good control of this disease where the standard used did not (see Table 3).

Mildew (Sphaerotheca mors-uvae) Mildew failed to appear in the replicated Norfolk trial in any appreciable amount. In the Hereford and Lincolnshire replicated experiment some of the plots showed some slight mildew damage at the apices in mid-July, but the outbreaks did not develop and by September there was little evidence of mildew damage in any plot.

Severe mildew appeared in some of the non-replicated plots on non-bearing bushes and assessments on the incidence of mildew was assessed during the autumn. The method used is employed by NAAS and is based on a leaf count on 20 branches, ignoring all leaves of less than a 1 shilling piece (Wiggell 1969). The data are shown in Table 3.

Grey mould (Botrytis cinerea). Grey mould was only observed at the Norfolk site. A slight incidence of mould was observed early season in the control plots but it was impracticable to make any assessment at this stage.

Table 1

Leaf spot control in blackcurrants

The percentage leaves damaged and lost by leaf spot on benomyl, standard and untreated blackcurrant bushes at 3 sites. The assessments were made pre and post-harvest on the Clarke & Corke scale. The treatments are given in the table, the first application coinciding with the first open flower (25th April-2nd May) and then at 2 weekly intervals. The standard treatment was dichlofluanid at 12 oz a.i. and quinomethionate 4 oz a.i./100 gal. All treatments were sprayed to run-off, i.e. about 200 gal/acre, by knapsack sprayer.

Trial site:-	Hereford (W)		Lincs. (B)		Norfolk (B)	
Treatment per 100 gal and no of applications	Pre-harvest 14/7/69	Post-harvest 5/9/69	Pre-harvest 9/7/69	Post-harvest 12/9/69	Pre-harvest 12/8/69	Post-harvest 28/8/69
Control		95%		40-80%	95%	95%
Standard x 4		25-40%		40-60%	40-60%	>80%
Benomyl 2 oz a.i. x 4	Little	25-60%	Little	5-40%	<5%	25-40%
" " x 6	disease	5->5%	disease	-	<5% *	5-25%
" 4 oz a.i. x 4	noted	5-<25%	noted	5%	<5%	5-25%
" " x 6		5->5%		-	<5% *	5->5%
" 6 oz a.i. x 4		5-<25%		5%	<5%	>5-25%
" " x 6		5->5%		-	<5% *	5%
Date of harvest	29/ 7/69		23/ 7/69		14/ 8/69	

* 5 applications only W = Wellington xxx B = Baldwin

At harvest time grey mould again appeared. It was not observed a few days before the expected picking date which was delayed by a short rainy period. On the day of harvest grey mould was evident and a hurried assessment was made by picking 20 strings of fruit per plot and then counting the number of infected fruit. The details of the assessment are shown in Table 2 in which is also shown mean fruit weight. The numbers of infected fruit were probably greater than indicated since fruit showing grey mould fell easily from the bushes. Considerable number of infected fruits could be found under standard treatments and control but almost none could be found in any benomyl plot.

Table 2

Botrytis in blackcurrants, and fruit size

The total number of fruits, mean fruit weight and the numbers of fruit infected by grey mould on 20 strings of fruit per plot (3 plots) with respect to treatments on the Norfolk site.

Treatment a.i./100 gal 4 applications		No of fruit	Mean fruit weight	No of fruit with mould At harvest	3 days after harvest
Control		388	.41 gm	13	18
Standard		330	.60 gm	8	10
Benomyl	2 oz	300	.63 gm	0	0
"	4 oz	405	.70 gm	0	1
"	6 oz	454	.63 gm	0	0

Undetermined leaf necrosis. While observing and assessing plots during the season cases of brown necrosis of leaves were noted, particularly on the non-bearing plots. The cause of the necrosis is believed to be due to a fungus, probably Botrytis sp., but this has yet to be confirmed. Benomyl appears to have controlled this condition almost completely but quinomethionate and drazoxolon appear not to have done so. See Table 3 for comparative data.

Yields of fruit. The replicated trials were picked and the mean plot yields are shown in Table 4.

Compatibility. On bearing Baldwins grown at Chesterford Park benomyl was found to be compatible and safe with tank mixtures of azinphos-methyl, DDT, demeton-S-methyl, dimethoate, endosulfan and malathion respectively.

Strawberries

Three replicated field trials (9-10 treatments, 6 replicates) were supported by four non-replicated grower trials and supplementary studies were made on compatibility with insecticides. Three simple trials on protected strawberries were conducted to observe crop safety. The main target diseases were grey mould and mildew.

The results were disappointing in that grey mould appeared on an appreciable quantity of fruit only at Levington farm, and mildew did not occur at any of the 10 sites under detailed observation.

Grey mould (Botrytis cinerea). The results of the trial at Levington Research Station farm where grey mould occurred late in the season are shown in Table 5.

Table 3

Mildew and an undetermined leaf necrosis control on non-bearing blackcurrants

The effect of benomyl, quinomethionate and drazoxolon on the control of mildew, an undetermined fungal necrosis of leaves and leaf spot on non-bearing blackcurrants in non replicated trials treated by growers. The numbers of applications at each site were equal except in Lincolnshire where the final quinomethionate application was not made. The data presented here were obtained from 20 branches per treatment and all leaves larger than a one shilling piece were included in the counts. Benomyl was applied at 8 oz a.i./acre with a surfactant and the standards as recommended by the manufacturers.

Locality and treatment :-	Norfolk* (W)			Lincs. (W)		(B)	N. Suffolk		(W)	S. Suffolk (B)	
	Quino	Beno	Draz	Beno	Quino	Beno	Draz	Beno	Draz	Beno	Quino
Total no of leaves	455	468	389	464	331	503	472	443	408	473	472
% of healthy leaves	31	54	44	55	44	98	98	93	94	76	50
% of mildewed leaves (mild and severe)	53	46	46	25	42	2	0.6	7	3	24	50
% of leaves with necrosis	17	0.4	12	0	20	0	1.3	0	4	0	0
No of dead apices	0	0	0	4	12	0	0	0	0	0	0
Leaf spot infection	Nil	Nil	Nil	Nil	Severe	Nil	Nil	Nil	Nil	Nil	Nil
Date of assessment	15/ 9/69			12/ 9/69		1/10/69				1/10/69	

* Applied l.v. - about 3 gal/acre

Quino = quinomethionate
Draz = drazoxolon
Beno = benomyl

B = Baldwins
W = Wellington xxx

Table 4

Yields of blackcurrants

Mean yields of fruit in lb/plot obtained with respect to treatment including no spray (control), standard treatment and varying doses and applications of benomyl. The standard treatment at all sites was dichlofluanid and quinomethionate.

Treatment: rate a.i./100 gal and no of applications		Hereford 3 reps. (W)	Lincs. 2 reps. (B)	Norfolk Θ 3 reps. (B)
Control		50.3	11.4	21.3
Standard	x 4	42	14.3	38 *
Benomyl	2 oz a.i. x 4	31	16.5	44.5 *
	x 6	47.7	-	48.3
	4 oz a.i. x 4	50.7	17.3	49.5 *
	x 6	47.3	-	45.5
	6 oz a.i. x 4	45.3	19	48
	x 6	49.7	-	38.5 *

* one plot not available   Θ In Norfolk plots the last of the 6 application treatments was not applied.

W = Wellingtons   B = Baldwins

Table 5

Yields of sound and Botrytis damaged strawberries

The yield cwt/acre of dessert grade strawberries, total yield of sound fruit (dessert and jam grade) and diseased fruit with respect to treatment at Levington.

Treatment a.i./acre & no. of applications		Selected Dessert	Total Sound Fruit	Diseased Fruit (Botrytis)
Control spreader		44.9	73.6	3.78
Control no spreader		40.9	70.9	3.10
Benomyl	4 oz x 3	47.2	73.9	1.43
	8 oz x 3	53.3	84.6	1.73
	12 oz x 3	64.9	99.0	1.87
	4 oz x 1	50.3	83.7	2.43
	4 oz x 2	46.7	75.4	2.37
	6 oz x 1	59.1	85.6	3.28
	* 4 oz x 1	53.0	84.2	2.60
Dichlofluanid 2 lb x 3		53.8	85.0	2.59
LSD	(0.05)	11.5	12.6	0.90
	(0.01)	15.5	17.0	1.22

* no spreader

Yields. The other replicated field trial yields suggest that the benomyl treatments gave slightly greater crop than the untreated and standard treated plots. Benomyl at 8 oz a.i. x 3 applications yielded 30.2 and 32.1 kg fruit respectively at the 2 sites compared with 28.0 kg and 29.2 kg from the untreated plots, and 28.2 kg and 27.3 kg from the standard treated plots. (2 lb a.i. x 3 applications of dichlofluanid). A full statistical analysis will be carried out later.

The yield from the protected strawberries is shown in Table 6. It can be seen that the benomyl treated fruit was heavier at all three sites compared with untreated and captan treated fruits. Benomyl caused no phytotoxicity at any site.

Table 6

Yields of protected strawberries

The yield in kg of strawberries with respect to treatment, and the mean weight of each fruit in brackets. Benomyl was applied at 8 oz a.i./acre, captan at 4.8 lb a.i./acre.

Treatment	Site 1 (Vigour)	Site 2 (Vigour)	Site 3 (Favourite)
Control	3.95 (9.2g)	2.66 (8.4 gm)	2.96 (7.1 gm)
Benomyl	4.02 (10 gm)	2.79 (8.6 gm)	3.67 (8.0)
Captan	-	2.38 (7.4 gm)	3.79 (7.4)
Cover:-	Glass	Polythene	Polythene

Compatibility. Cambridge favourite strawberries in the field were treated with benomyl mixed with demeton-S-methyl, dimethoate, DDT and dimethoate + DDT respectively without damage or any indication of phytotoxicity.

Fruit quality. Strawberries from benomyl treatments at all sites were bright and attractive and neither the Levington nor Chesterford Park food tasting panels in a series of tests could detect any off flavours and taints in the fresh fruit.

At all sites strawberry foliage sprayed with benomyl appeared completely healthy and substantially free of red colouration. In the trials conducted by growers the benomyl treated plots stood out by their deep green colouration. At one site the growth of benomyl treated plants had become more vigorous than dichlofluanid and control plots.

Gooseberry

Gooseberry bushes (Careless) in Norfolk and Cambridgeshire were treated with three sprays of benomyl at ¼ and ½ lb a.i./acre from first flower and at 2 weekly intervals in order to assess effectiveness against grey mould, leaf spot and American gooseberry mildew. The plots were replicated three times, and the standard treatment was dichlofluanid at 1½ lb a.i./acre per application and dinocap at ¾ lb a.i./acre.

Grey mould (Botrytis cinerea) Owing to picking difficulties not all replicates on each site were picked on the same date as intended. Instead, complete replicates were picked successively. Details of the mean plot yields and the incidence of the infected fruit are shown in Table 7 and 8. None of the fruit showed signs of the infection at the time of picking, in fact visibly infected fruit could be found on the ground under bushes in both controlled and standard treatments, but very few under benomyl treated bushes. First signs of the latent infection on picked fruit could be detected within 24 hrs and were very clear at 7 days. It was noted that sporulation did not take place in polythene bags in which the fruit was stored, but only when placed on open trays.

Table 7

Botrytis in gooseberries

The percentage by number of gooseberry fruit showing latent infection of Botrytis after storing in polythene bags. The date of picking is in brackets.

Treatments a.i./ac x 3 applications	Rep. 1 (25/6)	Rep. 2 (26/6)	Rep. 3 (6/7)	Rep. 1 (3/7)	Rep. 2 (8/7)	Rep. 3 (25/7) *
Control	45%	58%	32%	69%	-	76%
Standard	12%	37%	40%	18%	-	34%
Benomyl	2%	2%	26%	5%	-	34%
Benomyl	2%	2%	14%	2%	-	26%

* too ripe for canning

Leaf spot (Pseudopeziza ribis) The benomyl treatment at both rates gave excellent control of leaf spot at the Norfolk site where the disease was prevalent. Defoliation was severe on the control and standard plots but the situation was confused by a post harvest gooseberry sawfly outbreak. Benomyl appeared to have given complete control of the sawfly since, although the bushes showed signs of egg laying and early larval damage, the bushes remained well foliated and free of severe sawfly damage. The other treatments were severely affected both by sawfly and leaf spot and were soon defoliated. All plots were uniformly treated with insecticides up to harvest against sawfly, but treatments were not continued after harvest.

Mildew (Sphaerotheca mors-uvae) Mildew did not appear on any treatment up to harvest and there was very little to be seen in any plot afterwards.

Yields. The yields of gooseberries are shown in Table 8. The effect of treatment on fruit size is indicated by the percentage of fruit by weight retained on a 20 mm mesh screen.

Table 8

Yields of gooseberries

The mean yields in kg of gooseberries per plot (3 replicates) of untreated, standard (dichlofluanid and dinocap) and benomyl treated trees. The percentage by weight of fruit retained by a 20 mm mesh screen is shown in brackets.

Treatments	Norfolk	Cambs.
Control	15.1 (61%)	12.8 (47%)
Standard	17.9 (57%)	12.3 (43%)
Benomyl 4 oz a.i./ac	16.6 (65%)	17.0 (43%)
Benomyl 8 oz a.i./ac	19.9 (60%)	15.2 (40%)

Raspberry

In a single trial in Cambridgeshire using benomyl on Malling Jewell no significant amount of disease appeared in the plots. The fruit was picked for taint tests and residue analysis and then abandoned. There was no sign of fruit damage.

DISCUSSION

The data presented here shows that benomyl used at 8 oz a.i./acre applied at two weekly intervals over critical infective periods will control many of the important diseases of soft fruit. It is outstandingly effective against grey mould of strawberries, gooseberries and blackcurrants and leaf spot of blackcurrants and gooseberries. It is also effective against American gooseberry mildew in blackcurrants. The remarkable feature of benomyl is its range of activity and many soft fruit growers may well be able to base their entire fungicide programme on this one compound. It is believed that other research workers will be able to support this view as soon as their results are published, and add to the list of diseases of soft fruit which are controlled by the fungicide.

Benomyl when sprayed alone and with commonly used insecticides has caused no crop damage. The fruit finish is outstandingly good and there is no visible deposit left on the fruit or foliage. Benomyl has not altered the flavour of fresh strawberries. In many cases the crop has been enhanced by benomyl when compared with standard materials in current use. Benomyl treated plants including blackcurrants, gooseberry and strawberry appear exceptionally vigorous, and differences are particularly evident from harvest onwards. In one instance strawberries have been stimulated to extra growth after the crop is picked and the effect of this is to be investigated.

Benomyl would appear to show great promise in the soft fruit industry in U.K. Naturally, its availability depends on clearance under the Ministry Pesticides Safety Precaution Scheme, and the freedom of processed fruits from taints and any adverse storage characteristics. It is hoped to resolve these matters in the near future.

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A COMPARISON OF FUNGICIDES FOR THE CONTROL OF BOTRYTIS OF OUTDOOR AND PROTECTED STRAWBERRIES

T. Kavanagh
The Agricultural Institute, Horticulture & Forestry Division, Kinsealy, Dublin 5
T. F. O'Callaghan
Horticulture & Forestry Division, Clonroche, Co. Wexford

Summary In 1968 and 1969 yields of healthy fruit of the strawberry cultivar Cambridge Vigour were significantly higher from plots sprayed with dichlofluanid than from unsprayed plots. Frequent applications of low rates of the fungicide gave better results in 1968 than fewer applications of higher rates but these differences did not occur in 1969 possibly due to the exceptionally dry weather. Of five fungicides tested in other experiments for their effectiveness in controlling Botrytis of outdoor strawberries benomyl, "Daconil 2787" (tetrachloroisophthalonitrile) and dichlofluanid were best. Two or three applications of benomyl were equally effective. Benomyl was also best of five fungicides tested for Botrytis control on strawberries in polythene tunnels.

INTRODUCTION

In the short span of a decade control of Botrytis rot or grey mould (Botrytis cinerea) of strawberries has become a reality. Work on the life history of the pathogen, the susceptibility of the host and environmental and other factors affecting the epidemiology of the disease by Hennebert and Gilles (1958), Powelson (1960), and Jarvis (1962a, b, 1964) was complemented by studies on timing of spray applications, effective spraying techniques and fungicides by Müller (1964), Gilles (1964), Freeman (1966), Moore et al (1966) and Jarvis (1969). This and other work showed the importance of applying fungicides during flowering and the superiority of dichlofluanid over thiram and captan. Work in Ireland from 1963 to 1967 on these and other fungicides for the control of Botrytis of strawberries, on methods of applying fungicides, and on residues and flavour has already been reported (Kavanagh 1966, Kavanagh et al 1968). The present paper gives results of experiments in 1968 and 1969 on both outdoor and protected strawberries using several fungicides.

METHOD AND MATERIALS

These experiments were carried out at the Soft Fruit Research Station, Clonroche, Co. Wexford. Cambridge Vigour, the most widely grown cultivar in Ireland, was used in all experiments. The plants were grown on drills or ridges mostly 36 inches wide with 18 inches between the plants. Spraying of outdoor strawberries was done with a specially designed sprayer (O'Callaghan 1966) which applied the fungicide to two rows at a time at 170 gal/acre and 140 psi through a triple arrangement of nozzles over each row. Strawberries under tunnels were sprayed with a hand operated knapsack sprayer at 60 gal/acre and 60 psi. In all experiments, the first application was given at early flower, usually the 1 to 5% flower stage. Further applications were given at intervals of about 10 to 14 days except where more than three applications were given when shorter intervals were necessary.

RESULTS

Experiment 1 : In both the 1968 and 1969 seasons six treatments consisting of combinations of numbers of applications and rates of dichlofluanid were compared for Botrytis control. The experimental design was a randomized block with four replications in 1968 and five in 1969. Details of treatments and results are given in Table 1.

Table 1

Effect of different combinations of numbers of sprays and rates of dichlofluanid on Botrytis control in strawberries, cultivar Cambridge Vigour

Rate of dichlofluanid 50% w.p. per application (oz a.i./ac)	No. of applications	Fruit yield (cwt/ac)			
		1968		1969	
		Healthy	Diseased	Healthy	Diseased
24	4	139.2	6.1	197.9	9.1
32	3	128.7	7.0	187.4	7.8
48	2	120.3	7.6	197.0	7.5
16	4	153.0	5.0	187.8	9.6
16	6	152.8	6.7	199.6	4.6
0	0	61.9	20.6	145.6	11.4
F test		***	***	***	NS
SE		±6.8	±1.1	±6.9	±2.1
		(df=15)		(df=20)	

In both seasons, the yield of healthy fruit from each of the dichlofluanid-treated plots was significantly higher than the control ($p < 0.001$). In 1968 four and six applications of 16 oz a.i./acre were significantly better than three applications of 32 oz and two of 48 oz/acre in yield of healthy fruit. In 1969 there was no difference between any of the sprayed plots.

Experiment 2 : In 1968 and 1969 several fungicides were compared for their effectiveness in controlling Botrytis. Unsprayed plots were included as a control treatment. The experimental design was a randomized block with five replications. Details of the treatments and results are given in Tables 2 and 3.

Table 2

A comparison of four fungicides for their effectiveness in controlling Botrytis of strawberries, cultivar Cambridge Vigour, in 1968

Fungicide	Rate per application (oz a.i./ac)	No. of applications	Fruit yield (cwt/ac)		Average no. healthy fruits per lb
			Healthy	Diseased	
Benomyl[1] 50% w.p.	4.0	1	162.4	16.1	30.4
"Daconil 2787" 75% w.p.	36.0	3	183.8	12.0	33.3
Dichlofluanid 50% w.p.	32.0	3	188.1	6.2	36.8
Dichlorophen 10%	7.5[2]	3	140.9	19.7	31.6
Control	0.0	0	120.1	26.0	34.6
F test			***	***	NS
SE (df = 16)			6.8	2.3	3.5

1 Plus 4 oz non-ionic wetter per 100 gal spray

2 Fluid oz

Table 3

A comparison of fungicides for their effectiveness in controlling Botrytis of strawberries, cultivar Cambridge Vigour, in 1969

Fungicide	Rate per application (oz a.i./ac)	No. of applications	Fruit yield (cwt/ac)	
			Healthy	Diseased
Benomyl 50% w.p.	8[1]	2	185.9	10.2
Benomyl 50% w.p.	8[1]	3	185.3	12.9
"Daconil 2787" 75% w.p.	36	3	165.2	15.7
DDAB[2] 50%	30[3]	3	153.5	15.6
Dichlofluanid 50% w.p.	32	3	183.0	12.4
Control	0	0	149.7	15.4
F test			**	NS
SE (df = 20)			7.2	3.6

[1] Plus 4 oz non-ionic wetter per 100 gal spray

[2] "Steriquam 208"

[3] Fluid oz

In 1968 each of the fungicides caused a significant increase in yield of healthy fruit over the control. Plots sprayed with "Daconil 2787" (tetrachloroisophthalonitrile) and dichlofluanid gave highest yields of healthy fruit significantly different from the other treatments though not from each other. Benomyl was next best followed by dichlorophen which were significantly different from each other and from the control. Berry size was not affected significantly by any of these treatments. In 1969, the two benomyl treatments and dichlofluanid gave significantly higher yields of healthy fruit than the control and DDAB (didecyldimethylammonium bromide) but were not better than "Daconil 2787" which was also not significantly better than DDAB and the control.

Experiment 3 : In 1969, five fungicides were compared for their effectiveness in controlling Botrytis of strawberries grown in polythene tunnels. The design of the experiment was randomized block with four replications of six treatments including unsprayed control plots. Details of the treatments and results are presented in Table 4.

None of the treatments had a significant effect on yield of healthy fruit but benomyl-sprayed plots exceeded the control by a substantial amount, the difference being significant at $p < 0.1$.

DISCUSSION

Losses in strawberries from Botrytis can be very severe under climatic conditions in Ireland. In addition, Cambridge Vigour, the principal cultivar grown, is very susceptible to this disease. Experiments on the control of Botrytis in this cultivar in 1966 and 1967 with dichlofluanid had resulted in increases in yields of healthy fruit which averaged 50% and ranged as high as 77% (Kavanagh *et al* 1968). Though the 1968 and 1969 seasons were both drier than normal, yields of healthy fruit from plots sprayed with dichlofluanid were again significantly higher than from unsprayed plots. This was especially the case in 1968 when increases of up to 147% were obtained in sprayed plots over unsprayed controls. If these increases are possible in a season considered to be not particularly favourable for Botrytis, it is interesting to speculate on how great increases could be obtained in a severe Botrytis year.

Table 4

A comparison of five fungicides applied twice for Botrytis control to strawberries, cultivar Cambridge Vigour, grown in polythene tunnels

Fungicide	Rate per application (oz a.i./ac)	Fruit yield (cwt/ac) Healthy	Fruit yield (cwt/ac) Diseased	Average no. healthy fruits per lb
Benomyl 50% w.p.	8.0[1]	63.8	3.5	46.5
Captan 50% w.p.	40.0[1]	49.6	3.1	41.1
DDAB[2] 50%	20.0[3]	46.2	3.1	46.6
Dichlofluanid 50% w.p.	8.0	53.8	3.0	43.9
Thiram 80% w.p.	38.4	51.2	2.8	40.9
Control	0.0	53.7	5.5	36.3
F test		NS	NS	
SE (df = 15)		6.9	0.6	

[1] Plus 4 oz non-ionic wetter per 100 gal spray

[2] "Steriquam 208"

[3] Fluid oz

In the 1968 season, frequent applications of lower rates of dichlofluanid gave highest yields of healthy fruit. This could be interpreted as reduced phytotoxic effect rather than improved protection from the disease. This is further supported by the equally good results obtained from four and six applications of 16 oz a.i. The residues of dichlofluanid in canned fruit of the 1968 season from the various treatments in Experiment 1 were all of negligible amount being 0.04 ppm or below (Gardiner et al 1968). In frozen fruit residues were higher and were directly proportional to the number of applications given (ibid.). The highest, 4.65 ppm, where six applications of 16 oz a.i. was given was higher than some countries would accept. A trained taste panel did not find a significant difference between the flavour of samples from any of the sprayed or unsprayed plots in either fresh or canned fruit (Gardiner et al 1968).

The fact that significant differences in yield did not occur in 1969 when rates of dichlofluanid and numbers of applications were varied is possibly a weather effect the months of June, July and August 1969 being the driest in Ireland for 10 years and the fourth driest in over 50 years. However, even in this dry summer, spraying resulted in increased yields of at least two tons of healthy fruit per acre (Table 1).

Some of the other fungicides tested in comparison with dichlofluanid for their effectiveness in controlling Botrytis of strawberries were found to be equally effective. "Daconil 2787" was less impressive in 1969 than in 1968 but in both seasons was not significantly different from dichlofluanid in yields of healthy fruit. Benomyl was impressive in both seasons. In 1968 though only one application of benomyl was given, a significant increase in yield of healthy fruit resulted. In 1969 two and three sprays of benomyl gave results equal to dichlofluanid applied three times. This suggests that fewer sprays of this systemic fungicide may be necessary than of other fungicides. However, it will need to be tested in seasons more favourable for Botrytis than 1968 and 1969 to ascertain the optimum rate and number of applications. With at least three fungicides available to growers for control of this disease, the use of one or other will depend on factors such as number of applications necessary, the required interval between the last application and harvest, phytotoxicity hazards and compatibility with other chemicals, residues, taint and, of course, cost.

With increasing affluence consumers are prepared to pay for out of season luxury foods such as strawberries. Hence the expansion in strawberry production in polythene tunnels and glasshouses. Dichlofluanid is not recommended by the manufacturers for use on strawberries under glass or polythene because of the danger of phytotoxicity. This was confirmed by the failure of this fungicide to increase yields in the trial under polythene in which phytotoxic symptoms were severe even at 8 oz a.i./acre per application. Fruit size with this as with all other treatments was reduced compared with the control. Neither thiram nor captan treatments resulted in yields as high as the control though the differences were not significant. These are the standard fungicides used under polythene though the rate employed here was lower than that normally used on crops in the open. The DDAB treatment also resulted in yields lower than the control. Benomyl was the only treatment which increased yields though it too reduced fruit size. The poor response to fungicidal treatments in this experiment may be attributed, in part at least, to the fact that an infestation of leaf and bud eelworm occurred in part of the experimental area. In view of the increasing importance of out of season strawberry production more information is needed on fungicidal control of Botrytis under tunnels and in glasshouses.

In these experiments, particularly on outdoor strawberries, there was little relationship between the amount of diseased fruit recorded in sprayed plots and the increase in weight of healthy fruit resulting from the fungicide treatments. There are several explanations for this (a) "woolly ball" fruits usually have a lower specific gravity than healthy fruits (b) fruits become affected with Botrytis at all stages of development (c) spraying presumably results in fewer Botrytis-induced flower abortions. Points (a) and (b) are illustrated by the higher number of diseased than healthy fruits per lb. Counts of diseased berries per lb during the 1968 and 1969 seasons ranged from 70 to 135 and averaged 99 whereas healthy fruits averaged 35 per lb. Point (c) can be appreciated in the light of the extreme susceptibility of the flower stage to invasion (Hennebert et al 1958, Jarvis 1962a, Powelson 1960). Hence the importance of commencing spraying in the early flower stage (Gilles 1964, Moore et al 1966).

Botrytis has long been regarded as the major factor limiting strawberry production in many areas. Previously, no grower could specialize in this crop because of the risk of crippling loss of income in a wet season. The effective control measures now available could have far-reaching effects on location of production areas and on unit size.

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CONTROL OF RED CORE DISEASE OF STRAWBERRY

Isabel G. Montgomerie
Scottish Horticultural Research Institute, Invergowrie, Dundee

Summary The effects of Bayer 22555, sodium 4-(-dimethylamino)-benzenediazo-sulphonate, used as a plant dip, a soil drench, or as a combination dip and drench; of soil applications of a prill formulation of dazomet (methyl isothiocyanate); and of growing plants on ridges, on the incidence and severity of symptoms of red core disease were studied in a field trial of 10 months duration.

Drenching the soil around each runner with Bayer 22555 immediately after planting resulted in the greatest decrease in both the number of infected plants and the percentage of infected roots. This was not accompanied by increased vigour or yield compared with untreated plants due to the reduction in the number of primary roots. Plants grown on ridges had a significantly lower incidence of disease and percentage of infected roots while dazomet (100 lb/ac) resulted in a significant decrease in the number of infected plants but not in the percentage of infected roots. There was no significant difference in yield as a result of any treatment.

INTRODUCTION

Since intensive breeding for resistance to red core started over 30 years ago, little work has been done in this country on alternative methods of control. In the U.S.A., Stoddard (1951) reported that a liquid formulation of nabam (disodium ethylene bisdithiocarbamate) when absorbed by strawberry roots acted as a chemotherapeutant, protecting plants from infection for at least 2 months and that when injected into soil it prevented spread of the disease into the treated area, thus also acting as a soil sterilant. Also in the U.S.A., Converse (1960) described a field trial of five fumigants all of which resulted in decreased incidence of the disease but 'Trizone' (8% propargyl bromide, 31% chloropicrin, 61% methyl bromide) proved to be the most effective. In recent years, the increase in the number of infected areas and losses in yield suffered by many growers has resulted in more intensive efforts to discover chemical or other methods of control in this country.

METHOD AND MATERIALS

The site selected for this trial was a sloping one in which drainage was slow and in which the previous crop had been strawberries severely affected with red core. The soil was rotovated several times to distribute diseased roots evenly and to produce a fine tilth. The 7 treatments with 7 replicates were allocated at random, in a Latin Square arrangement, to plots of 30 yd^2 which consisted of four sub-plots of 10 plants each. A prill formulation of dazomet was applied to the soil on appropriate plots by hand applicator in August 1968 at the rate of 100 lb/ac in one treatment and 200 lb/ac in another. These plots were then rotovated, rolled and covered with polyethylene sheets for 2 weeks. The soil was opened up with 3 rotary cultivations at weekly intervals after which a cress test indicated that the areas were free from gas and ready for planting. Bayer 22555 (0.175% a.i.) dip treatments consisted of dipping roots for 3 to 5 min. before planting. In one treatment, plants were dipped before planting and a soil drench of Bayer 22555 at the same concentration applied around each plant (½ pint/plant) in March 1969. A similar drench was applied immediately after planting in the third Bayer 22555 treatment. Ridges of approximately 12 in in height were set up by spade in a treatment to assess the effect of improved drainage. The susceptible cultivar Merton Princess was planted at the beginning of October 1968 throughout the site at 18 in x 30 in spacing. One sub-plot from each treatment replicate was lifted in May 1969 and scored for red core (on primary or lateral roots) and the percentage diseased roots on each plant was estimated from scores of primary roots only. Fruit from the remaining three sub plots was weighed in July 1969 to enable a comparison of yield to be made between treatments.

RESULTS AND DISCUSSION

Table 1 summarises observations made on 10 plants/replicate (70 plants in all) lifted in May 1969 and fruit yields harvested in July 1969 from the remaining 30 plants/replicate (210 plants in all). The weight of marketable fruit has been divided by 3 so that all comparisons are based on 70 plants.

The most striking feature of this experiment was the relationship between topography of the site and the incidence of disease. Despite repeated rotovations aimed at distributing diseased roots from the previous crop evenly over the site, plots at the top and driest end of the slope contained significantly fewer diseased plants than those at the bottom and wettest end of the site. Incidence of the disease in fact followed the pattern of drainage, emphasising the crucial role of soil water on infection. This is further borne out by the performance of plants grown on ridges. Compared with the controls, about half as many become diseased and the proportion of diseased roots decreased from 52% to 9%.

The results from the chemical treatments were less clear cut. Dazomet at either 100 lb or 200 lb/acre had virtually no significant effect. Perhaps it was ineffective in destroying the oospores which would constitute the initial inoculum in the soil or possibly these plots became swamped with zoospores transported in soil water from adjacent plots.

All Bayer 22555 treatments decreased the numbers of primary roots significantly ($P < 0.01$) and this was reflected in decreased vigour of the

Table 1.

Effect of dazomet, Bayer 22555 and growing plants on ridges on red core disease, no. of primary roots and yield in Merton Princess planted 3 October 1968 (n = 70)

Treatment	No. diseased plants	Percent diseased roots	Mean no. primary roots/plant	Yield (oz)
Dazomet, 100 lb/ac	34*	40.6	12.7	28.7
Dazomet, 200 lb/ac	36	53.7	11.9	16.8
Bayer 22555 dip (0.175% a.i.)	37	36.8	4.4**	15.1
Bayer 22555 drench (0.175% a.i.)	5***	4.0***	5.1**	19.3
Bayer 22555 dip and drench (0.175% a.i.)	16**	10.1**	4.4**	19.2
Ridges	21**	9.2**	13.5	29.0
Untreated control	52	52.3	13.2	21.7

* Significantly different from control at 5.0%

** " " " " " 1.0%

*** " " " " " 0.1%

tops. Drenching after planting was effective in decreasing disease incidence and the proportion of diseased roots whilst dipping before planting was not. Indeed the 5 diseased plants in the drench treatment were all in one plot suggesting an error in application rather than a failure of the treatment. The combination of dip and drench was less effective than drenching alone which indicates a greater degree of control in applying the soil drench immediately after planting than in the following Spring. The depressant effect of Bayer 22555 on plant vigour was such that despite the effectiveness of the drench treatment, healthy and diseased plants were virtually indistinguishable.

None of the treatments significantly improved the yield of marketable fruit but further increases might be expected in the second year after planting because of the number of plants which would die in untreated plots before fruiting for a second time.

Thus at the concentration used in this experiment the effectiveness of Bayer 22555 was offset by its depressant effects on root growth and plant vigour and there was no evidence from the dipping treatment that this chemical acted as a chemotherapeutant. In the absence of a cheap and effective fungicide, growing plants on ridges seems an obvious means of increasing the chances of disease escape by draining soil water away from the root system. The fact that this is already common practice in some red core infected areas points to the crucial importance of soil water and drainage in the development and spread of disease outbreaks.

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EXPERIMENTS IN THE CONTROL OF STRAWBERRY RED-CORE USING SODIUM - 4 -(DIMETHYLAMINO)- BENZENEDIAZO - SULPHONATE

D.C. Clark
Baywood Chemicals Limited, Bury St. Edmunds, Suffolk

Summary Experimental work is described with the soil fungicide Bayer 22555 for the control of red-core in both newly planted and established strawberries. Trials carried out from 1966 to 1969 showed that by dipping plant roots in suspensions prior to autumn planting and following this up with a spring drench gave a control of red-core. In addition to this protectant action it was found possible to reduce existing infection, and allow infected plants to grow satisfactorily following application of drenches.

Although these experiments demonstrated the ability of this chemical to give a degree of protection from red-core further work is necessary to determine rates and timings which preclude the possibility of phytotoxicity.

INTRODUCTION

Red-core (*Phytophthora fragariae*) is becoming an increasing problem in the strawberry growing areas of south-east England. The fungus attacks the roots of strawberry plants in the wet cool months causing them to rot, and is particularly troublesome in areas of poor drainage. Newly planted runners may fail to establish while established plants cease growth during the dryer months, and may eventually collapse and die. Infected plants that remain alive produce dwarfed leaves and small unmarketable fruit. The fungus is spread in soil water, infected plant material and in contaminated soil via tools, boots and machinery.

Control of red-core is currently limited to improvements in drainage including sub-soiling and growing on ridges early establishment of plants before the wet autumn months, or the use of resistant or field tolerant varieties. The use of resistant varieties is unsatisfactory because of the existence of a number of different strains of the fungus which differ in their ability to attack different varieties.

Because of the difficulties experienced with cultural methods of control investigations were initiated in 1966 using Bayer 22555.

Sodium - 4(dimethylamino) - benzenediazo - sulphonate, was developed by Farbenfabriken Bayer AG, and subsequently is referred to as Bayer 22555 in this paper. It had proved effective as a seed-dressing and soil treatment for the control of damping-off and root-rotting fungi in the genera *Pythium*, *Aphanomyces* and *Phytophthora*, and is registered in other countries for use on corn, cotton, sorghum, sugar beet, beans, peas, cucumbers, spinach, pineapple, turf, ornamental shrubs and flowers and fruit trees.

The first indication of its effectiveness in controlling red-core came in a trial laid down in 1966 when the roots of plants that had been dipped in a suspension containing 3500 ppm were planted in early September into infected soil. Assessments the following summer showed that the treated plants had grown satisfactorily and produced an abundance of white fibrous roots, while those in the untreated plots failed to establish because of loss of roots (Wiggell 1969).

Concurrently it was shown that infection of healthy runners was reduced by a soil drench of Bayer 22555, 980 ppm, two weeks prior to inoculation. In vitro studies demonstrated that sporangial production and zoospore mobility was inhibited by the same concentration (Montgomerie 1967).

Pot trials carried out using dips at varying strengths demonstrated that concentrations below 1500 ppm were non-phytotoxic in the absence of red-core, but at this rate only 60% control of the disease was obtained. The optimum rate of dip appeared to lie between 1500-2500 ppm, and although slight phytotoxicity occurred at the higher rate this was outweighed by the increased control of red-core (Wiggell 1968).

In the 1967/68 and 1968/69 seasons replicated field trials were laid down by the author and D. Wiggell, Wye N.A.A.S. in both clean and infected soils.

METHODS AND MATERIALS

In all the trials Bayer 22555 was used in the form of a 70% wettable powder, but the rates given in the tables are expressed as active ingredient.

Pre-planting dips were applied by immersing the plant roots in a suspension of the material for 5-10 minutes. The drenches were applied at 10 fl. oz per plant unless otherwise stated, pouring the suspension around the plant. It was hoped to apply the drenches as early after February as possible, but the timing was dictated by the suitability of soil conditions.

Assessments were carried out in June and July by grading the vigour of plants from 0 = dead and 5 = completely healthy. Runner counts were made, and where possible yield data were obtained.

RESULTS

Effects of Bayer 22555 Root Dips

Table 1

Challock, Kent. Cv. Red Gauntlet planted September 1967 in infected soil.

Bayer 22555 treatment	Mean Vigour	% plants in grades 4 and 5*
3500 ppm	2.56	35
2625 ppm	2.61	35
1750 ppm	2.65	40
Untreated Control	1.61	7

*These grades were considered commercially acceptable.

Table 2

Otham, Kent. Cv. Cambridge Favorite planted September 1968 in infected land.

Bayer 22555 Treatment	Runners/Plant	Leaves/Plant
1750 ppm	3.51	6.71
875 ppm	3.87	7.18
Untreated Control	2.48	6.15

These two trials demonstrated that a pre-planting root dip of Bayer 22555 at rates from 875 to 3500 ppm resulted in more vigorous plants in the presence of red-core infection, indicating a controlling effect of the root-dip.

Effect of Bayer 22555 Dip and Drench Treatments

Table 3

Ulcombe, Kent. Cv. Red Gauntlet planted in October 1967 in infected land. Drenches were applied at the same concentrations as the original dips in April 1968.

Bayer 22555 Treatment	Mean Vigour	Runners per plant	Mean Berry Weight (oz)	Yield (lb) 1968	Yield (lb) 1969
3500 ppm Dip	2.08	0.78	0.23	4.2	7.3
2625 ppm Dip	2.15	0.70	0.23	4.5	6.1
1750 ppm Dip	1.85	0.41	0.20	4.1	5.9
3500 ppm Dip + Drench	2.78	1.40	0.19	4.0	9.2
2625 ppm Dip + Drench	3.25	1.75	0.28	6.8	11.2
1750 ppm Dip + Drench	3.73	2.09	0.28	7.2	10.2
Untreated Control	1.96	0.35	0.18	3.3	5.3

In this experiment no increase in vigour or yield resulted from the dip treatment alone. However when the dips were followed by a spring drench, the plant vigour and runner production were increased. Yield increases were only recorded at the two lower rates indicating that Bayer 22555 at 3500 ppm was phytotoxic. The effect of this damage was not reflected to such an extent in the 1969 yield, suggesting that the plants were recovering and responding to the red-core control.

In April 1969 half of each plot, which had previously received the dip and drench treatment, was treated with Bayer 22555 drench at 1750 ppm, but this did not further increase yield.

Table 4

Otham, Kent. Cv. Cambridge Favorite planted in October 1967 in infected land. Spring drenches applied February 1968. A single rate of 3500 ppm was used except where indicated.

Bayer 22555 Treatment October 1967	February 1968	Runners/Plant 1968	1969	Leaves/Plant
Untreated	Untreated	1.21	4.18	14.2
Dip	Untreated	1.63	4.23	14.1
Dip	Drench	3.90	4.43	18.7
Untreated	Drench		4.71	16.5
Dip	Drench 350 ppm*		5.68	22.2
Dip	Drench 350 ppm		6.55	23.4

* This treatment included a drench of 3500 ppm in September 1968.

Also included in this trial were drenches applied immediately post-planting which resulted in severe phytotoxicity in the form of plant death.

Little if any benefit was derived from a pre-planting dip alone, but where followed by a spring drench a considerable increase in vigour was recorded in the year after planting. However by the second year the differences between this combined treatment and the untreated control were less noticeable.

The most successful treatment in this trial was the pre-planting dip followed by a spring drench at 350 ppm indicating that there had been phytotoxicity at 3500 ppm. Where this treatment was followed by a drench in September no benefit was obtained.

Table 5

East Sutton, Kent. Cv. Red Gauntlet planted in October 1967 in infected land. Spring drenches applied February 1968. A single rate of 3500 ppm was used.

Bayer 22555 Treatment October 1967	February 1968	Mean Vigour 1968	Runners/plant 1968
Untreated	Untreated	2.17	1.21
Dip	Untreated	3.22	1.75
Dip	Drench	3.78	2.04
Drench	Untreated	1.71	0.45
Drench	Drench	1.82	0.45

The pre-planting root dip gave an increase in vigour which was further increased by a drench the following spring.

The drenches applied immediately post-planting proved phytotoxic. This effect also occurred in a trial laid down in uninfected soil. In this latter trial spring drenches proved only marginally phytotoxic. (Wiggell 1968)

Effect of Bayer 22555 Drenches alone.

Table 6

Challock, Kent. Cv. Red Gauntlet planted 1965 and so severely infected with red-core that many plants appeared dead. Drenches were applied in September 1967.

Bayer 22555 Treatment	Vigour pre-treatment	No. of healthy crowns per plant July 1968
3500 ppm Drench	2.22	4.18
Untreated Control	2.60	0.13

The treated plants grew away healthily the following spring and were exhibiting no leaf or fruit symptoms of red-core infection or other root damage.

Table 7

Lamberhurst, Kent. Cv. Cambridge Favorite planted Autumn 1967 and severely affected by red-core at the time of treatment in May 1969.

Bayer 22555 Treatment	Mean Vigour July 1969
700 ppm Drench	4.6
1050 ppm Drench	4.9
1400 ppm Drench	3.4
Untreated Control	3.0

These two trials demonstrated that drenches of Bayer 22555 at rates from 700-3500 ppm could improve the vigour of established infected plants. In table 7 there is an indication that a rate of 1400 ppm was phytotoxic.

In several trials in 1969 drenches of Bayer 22555, 1750 ppm were applied to clean and infected plants, in the majority no phytotoxicity occurred, but in a few severe damage was recorded.

Table 8

Boughton Monchelsea, Kent. Cvs. Red Gauntlet (1) and Cambridge Favorite (2) planted Autumn 1968 in uninfected land. Drenches applied March 1969 at 8 fl. oz /plant.

Bayer 22555 Treatment	Runners/Plant		% Plant Mortality	
	Cv. 1	Cv. 2	Cv. 1	Cv. 2
1750 ppm Drench	0.6	0.44	78	72
Untreated Control	4.7	2.72	8	9

DISCUSSION

Bayer 22555 had shown fungistatic activity against Phytophthora fragariae, and in field trials control of the disease, measured in terms of plant vigour, runner production and yield, had been obtained.

Pre-planting root dips in concentrations of from 875 to 3500 ppm have conferred a degree of protection against attack in some trials where the main infective period of the fungus was believed to be in the autumn. However when there is also a high infective risk in the spring, a supplementary drench had proved necessary to control the fungus and allow the plant to grow healthily.

In the case of drenches phytotoxicity had been observed at rates from 1400 to 3500 ppm. In two trials the plant damage was severe at 1750 ppm but this occurred on heavy soils which were cracked at the time of application with the result that the drench penetrated straight to the roots of the plants, which at that time were starting to grow and at their most susceptible stage. Only slight phytotoxicity has been observed with drenches applied in February, April or May.

The results of this work suggest that Bayer 22555 as a pre-planting root dip at 1750 ppm. followed by a 10 fl. oz per plant drench at 700-1750 ppm could be used to allow strawberry plants to be grown successfully in red-core infected land. Additionally the vigour of established infected plants can be improved by the application of drenches in September or May.

Further work should be directed towards determining optimum rates and timings, the suitability of different soil types, and optimum soil conditions for safe and effective treatment.

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CONTROL OF CANE SPOT AND SPUR BLIGHT OF RASPBERRY WITH FUNGICIDES

F. Ó Ríordáin
The Agricultural Institute,
Horticulture and Forestry Division, Kinsealy, Dublin 5.

Summary Seven fungicides were tested for control of cane spot and spur blight of raspberries. All fungicides reduced cane spot significantly, the most effective being captafol, dichlofluanid, dithianon and thiram. Spur blight incidence, however, was not reduced, but actually increased in one experiment by dichlofluanid and mancozeb.

INTRODUCTION

Copper fungicides, lime-sulphur or thiram are currently recommended for the control of cane spot (*Elsinoe veneta*) and spur blight (*Didymella applanata*) of raspberry (Martin, 1965). Many newer organic fungicides have proved superior to these materials for the control of other fruit diseases but few appear to have been tested on raspberries. This paper describes preliminary results of trials for the control of cane spot and spur blight using some of these newer fungicides.

METHOD AND MATERIALS

The main experiment was carried out at the Soft Fruit Research Centre, Clonroche, Co. Wexford. Seven organic fungicides (Table 1) were compared with an unsprayed control on the raspberry cultivar Malling Jewel. The experimental design was a randomised block with four replicates. Each plot consisted of one 11 yd line of canes. The fungicides were applied at high pressure (minimum 170 psi) and volume (200 gal/ac) with an automatic self-propelled sprayer, which was constructed at the Centre. Three applications were given each spring, beginning when the buds were $\frac{1}{2}$ in long and repeated at three week intervals.

A number of extension experiments was carried out on growers' holdings in different areas. In 1968 dithianon, mancozeb and thiram were compared for cane spot and spur blight control. Unsprayed plots were also included. Dichlofluanid was substituted for dithianon in these experiments in 1969. A motorised air-blast knapsack sprayer was used. The design used in the experiments, was a randomised block. In the Gorey, Co. Wexford, experiment, each plot consisted of one 120 yd line of the cultivar Malling Jewel. There were four replicates. The cultivar in the two Co. Longford experiments was Malling Notable and plots consisted of 10 yd lines of canes. There were five replicates in Experiment I and six in Experiment II.

In all experiments 10 canes were assessed per plot. Cane spot was assessed by counting the spots per cane. In the case of the fruiting canes spots on the top 12 in of cane and on the laterals on this section of cane were counted. For spur blight each of the 10 canes was given a rating of 0 to 3 (0 = free of spur blight, 3 = severely affected).

RESULTS

In the Clonroche experiment all fungicides gave a significant reduction in cane spot on the young canes each year (Table 1). This was true also on the fruiting canes in 1968. Of the seven fungicides tested best control of cane spot, in order of effectiveness, was given by captafol, dithianon, dichlofluanid and thiram. Dichlofluanid, maneb, thiram and captafol gave significant increases in yields in 1968. In 1969, there was negligible cane spot on the fruiting canes and significant differences in yield did not occur.

In the extension experiments, all fungicides reduced cane spot considerably, dithianon and dichlofluanid being significantly more effective than mancozeb and

Table 1

Effect of seven fungicides on cane spot and yield of the raspberry cultivar Malling Jewel in 1968 and 1969

	Oz a.i./ac per application	1968 No. of spots/ top 12 inches fruiting cane	1968 No. of spots/ young cane	1968 Yield cwt/ac	1969 No. of spots/ young cane	1969 Yield cwt/ac
Captafol	25.6	10.9***	3.0***	71.2*	1.8***	75.2
Dichlofluanid	25.6	13.2***	9.5***	83.8**	5.5***	63.9
Dithianon	18.0	13.7***	1.2***	61.5	11.6*	79.8
Dodine	5.2	37.4***	20.5***	64.5	10.2**	76.1
Mancozeb	38.4	22.9***	7.1***	66.4	11.1**	70.6
Maneb	38.4	30.3***	21.0***	81.0**	12.9*	67.3
Thiram	51.2	20.3***	3.4***	74.8*	4.8***	94.5
Control		68.0	47.3	54.6	25.0	91.4
S.E. of treatment means (df = 21)		5.4	4.7	5.6	3.4	9.9

* Significantly different from control at 5.0%
** " " " " " 1.0%
*** " " " " " 0.1%

thiram (Table 2). Spur blight was severe only in the Co. Longford experiments. None of the treatments gave any reduction in the disease; on the contrary, dichlofluanid and mancozeb increased the disease rating significantly over the control in Experiment I (Table 3).

Table 2

Effects of four fungicides on cane spot of raspberries at three centres in 1968 and 1969

	Oz a.i. per ac per application	Gorey	Co. Longford		
			Experiment I		Experiment II
		1968	1968	1969	1969
Dichlofluanid	25.6	-	-	10.6***	18.7
Dithianon	18.0	10.7***	7.1***	-	-
Mancozeb	38.4	34.1**	26.3	29.7***	20.7
Thiram	51.2	30.7**	22.9*	29.7***	22.4
Control	-	49.9	35.8	56.1	32.5
S.E. of treatment means		3.3	3.2	3.8	5.2
df		9	12		15

* Significantly different from control at 5.0%
** " " " " " 1.0%
*** " " " " " 0.1%

Table 3

Effects of three fungicides on spur blight index of the raspberry cultivar Malling Notable in Co. Longford

	Longford I	Longford II
Dichlofluanid	1.92**	1.75
Mancozeb	1.88**	2.03
Thiram	1.40	1.77
Control	0.92	1.77
S.E. of treatment means	0.22	0.16
df	12	15

** Significantly different from control at 1%

DISCUSSION

Cane spot is more serious than spur blight under Irish conditions and it is evident from the present experiments that considerable control of the former can be obtained with fungicides. In particular some of the newer fungicides, which apparently have not been previously tested for cane spot control, gave promising results and merit further investigation. Dichlofluanid, captafol and dithianon, in the Clonroche experiment gave the same order of control as thiram. In the extension experiments dichlofluanid and dithianon gave better results than thiram and mancozeb. Of these fungicides dichlofluanid is the most useful as it will also control Botrytis fruit rot (Freeman and Pepin, 1967). Significant increases in yields were obtained in 1968 with captafol, dichlofluanid, maneb and thiram. These increases probably resulted from the considerably reduced cane spot on the fruiting canes of the sprayed plots. Another factor contributing to these higher yields may have been control of Botrytis fruit rot by dichlofluanid and thiram. In the very dry season of 1969 there was very little cane spot on the fruiting canes. The apparently contradictory yields in this season must be viewed in the light of the high variation in the figures, none of the yields being significantly different.

An observation trial was carried out at Clonroche using benomyl, at 8.0 oz a.i. per acre, on plots adjacent to the above experiment. These had a mean cane spot count of 0.7 spots per cane, indicating that benomyl is a promising fungicide for control of this disease as well as fruit rot (Freeman and Pepin, 1967).

Johnson (1966) obtained a reduction in spur blight with a number of fungicides different from those tested here. However, in the present experiments no control was obtained. In fact, spraying with dichlofluanid and mancozeb increased the disease rating in one of the Co. Longford experiments. Further work on the control of both these diseases is necessary.

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BREEDING POTATOES RESISTANT TO CYST-NEMATODE

H. W. Howard
Plant Breeding Institute, Trumpington, Cambridge

Summary The first sources of resistance used in breeding potatoes resistant to potato cyst-nematode, Heterodera rostochiensis, were the Andigena clones, C.P.C.'s 1673, 1685 and 1690. These clones have a dominant gene, H_1, which gives resistance to pathotype A only of the nematode. A second source of resistance is the wild, diploid potato, Solanum multidissectum, which has a dominant gene, H_2, giving resistance to pathotype B. Potatoes with genes H_1 and H_2 are resistant to both pathotypes A and B but susceptible to pathotype C (E). Other wild potato species, including S. vernei, have resistance to pathotype C, and breeding from them is difficult but has made some progress. Resistance to populations which are not pathotype A has now been found in Andigena clones but the value of this resistance will not be known until they have been tested with more non-pathotype A nematode populations.

INTRODUCTION

The breeding of potatoes resistant to cyst-nematode (root eelworm), Heterodera rostochiensis, was started by the discovery of Ellenby (1952) that a small number of potatoes in the Commonwealth Potato Collection of Central and S. American potatoes had few or no cysts on their roots when grown in a nematode-infested soil. Four of these potatoes (C.P.C.'s 1673, 1685, 1690 and 1962) were Andigena clones, another was a triploid and the sixth was the wild, diploid species, S. vernei.

BREEDING FROM ANDIGENA

Because the Andigena potatoes belong to the same species, S. tuberosum, as the potato varieties cultivated all over the world of which they are the ancestors, and because they are cultivated, not wild, potatoes, they were obviously the easiest source of resistance to use in breeding. It was found that the resistance of C.P.C.'s 1673, 1685 and 1690 is due to a single dominant gene, H_1; the resistance of C.P.C. 1692, which has not been used by breeders, may be due to polygenes. This made breeding for resistance easy as the cross of resistant x susceptible gave about 50 per cent of resistant seedlings.

The Andigena group of potatoes differ from the Tuberosum group (the cultivated potatoes of most parts of the world) in requiring short days for tuberisation. F_1 Andigena x Tuberosum gives fair yields of tubers in long days and in the first backcross, (Andigena x Tuberosum) x Tuberosum, it is possible to select seedlings which give high yields. Both Maris Piper and Ulster Glade, the two nematode-resistant varieties now available in the United Kingdom in some quantity, are first backcrosses.

The main difficulty in breeding from the Andigenas was susceptibility to blight. Blight did not occur in S. America until comparatively recently and the Andigena potatoes are very susceptible, particularly in the tubers. Ulster Glade is rather susceptible to blight but Maris Piper is not too susceptible, being not as resistant as Majestic but probably more resistant than King Edward. The main defects of Maris Piper are its susceptibility to common scab and to slugs. Two further varieties with gene $\underline{H}_1$, Pentland Javelin and Pentland Lustre, have now been introduced and more clones are in trial or being selected for trials.

Resistant varieties with the gene $\underline{H}_1$ produce a root diffusate with a hatching power similar to that produced by the standard susceptible varieties. Their roots are invaded by the larvae but the larvae are not able to develop into mature females, although mature males are produced. No giant cells are formed and hence there is little damage to the secondary xylem (Cole and Howard, 1958) so that under moderate infestations good yields can be obtained. More important, however, is the fact that, because larvae are hatched out and new cysts are not produced, the growing of the resistant varieties reduces the nematode population more than does a non-host crop.

DISCOVERY OF PATHOTYPE B

The first discovery of a nematode population which could produce many cysts on potatoes with gene $\underline{H}_1$ was made by Dunnett (1957). He found a population at Duddingston, near Edinburgh, which produced as many cysts on clones with gene $\underline{H}_1$ as it did on standard susceptible varieties. Dunnett (1961) also found that the wild, diploid potato, S. multidissectum had a dominant gene, $\underline{H}_2$, which gave resistance to the Duddingston population but no resistance to the Boghall population. It is now usual in the United Kingdom to refer to the Boghall and similar populations which produce few, or no cysts, on potatoes with gene $\underline{H}_1$ and many cysts on potatoes with gene $\underline{H}_2$ as pathotype A and to populations similar to the Duddingston population (many cysts on $\underline{H}_1$, no cysts on $\underline{H}_2$) as pathotype B (Cole and Howard, 1966). Pathotypes A and B can be distinguished by the colour changes undergone by cysts during their development (Guile, 1967).

Table 1

Pathotypes of potato cyst-nematode

Pathotype	Population	Cysts per root-ball on Home Guard	Cysts per root-ball as percentage of Home Guard: U. Glade H_1	P55/7 H_2	K4/13 H_1H_2	K5/26 H_1H_2
A	Strabane	310	0	42	0	0
	Ballyvoy	245	0	49	0	0
B	Dummining	160	78	0	0	1
	Glaryford	145	90	0	0	3
B + C	Carmacmoi	215	107	17	40	62
	Rostrevor	225	78	15	21	39

Results obtained by Dr. R. D. Winslow, Nematology Laboratory, Newtownabbey, Co. Antrim, N. Ireland.

BREEDING FROM S. MULTIDISSECTUM

From crosses of S. multidissectum it has been possible to breed potatoes of about commercial standard which have either gene H_2 or genes H_1 and H_2. Tests of nematode populations using such potatoes together with potatoes with gene H_1 only (see Table 1) have shown that populations more or less pure for pathotype B are rare and that most populations which are not pathotype A usually contain a pathotype which can form many cysts on potatoes with gene H_1, gene H_2 or genes H_1 plus H_2. This pathotype can be called C, but is also often called E. Its existence means that potatoes with genes H_1 and H_2 are of limited value.

BREEDING FROM S. VERNEI

The discovery that many nematode populations contained pathotypes that can form many cysts on the Andigena-bred potatoes with genes H_1 stimulated attempts to breed from the wild, diploid species, S. vernei. This was done by first producing autotetraploid S. vernei by colchicine treatment and crossing it with Tuberosum varieties to give tetraploid F_1 hybrids. These were resistant to all, or nearly all, nematode populations and could be backcrossed by Tuberosum varieties. In the first backcross generation there were some resistant seedlings but the inheritance of resistance seemed to be complicated and there was often not a clear distinction between resistance and susceptibility. It was difficult to give a genetical interpretation of the results and the resistance of S. vernei has been suggested variously to be due to a number of major genes, to polygenes, or to major dominant genes plus recessive genes. Breeding from a wild species must consist of a number of backcrosses by cultivated Tuberosum varieties and the apparently complicated nature of the inheritance of the resistance of S. vernei has made the task very difficult. Considerable progress has, however, been made and there do exist resistant clones bred from S. vernei which are almost of commercial standard.

Table 2

Breeding from Solanum vernei at the diploid level by using dihaploid Tuberosum

L3 = Solanum vernei x dihaploid Tuberosum
H100 = L3/10 x dihaploid Tuberosum

Seedling	Cysts per root-ball: Feltwell	Cysts per root-ball: Changed Little Ouse
L3/10	0	3
H100/1	5	2
2	128	24
3	1	15
4	-	444
5	-	185
6	1,101	443
7	111	99
8	369	424
9	111	99
10	-	399
11	582	522
12	642	349

It would be much easier to understand the inheritance of resistance derived from S. vernei if the breeding was carried out at the diploid instead of the tetraploid level. This it is now possible to do using dihaploid Tuberosum. Results (Table 2) suggest that the resistance of S. vernei to two populations, Feltwell (pathotype A) and Changed Little Ouse (pathotypes B + C?), is due to two complementary dominant genes, both of which must be present to give resistance (Table 2). There is, however, some suggestion also of modifier genes, e.g. H100/2, /7 and /9 which have an intermediate number of cysts.

BREEDING FROM OTHER WILD SPECIES

Resistance is also found in a number of other wild species (Ross, 1966). These include S. sanctae-rosae, S. kurtzianum, S. spegazinii, S. oplocense and S. sparsipilum. The species have been studied in Germany and Holland and some progress has been made in breeding from them. Like breeding from S. vernei, progress is difficult and the genetical situation appears to be complicated.

FURTHER SOURCES OF RESISTANCE IN THE ANDIGENA POTATOES

At Cambridge it was decided that there was the possibility that there might be in the Andigena potatoes genes other than H_1 which would give resistance to pathotypes other than A. Accordingly screening of some 600 Andigena stocks has been carried out. As the C.P.C. had been put into true seed, it was necessary to test about 5 plants of each line, i.e. there were some 3,000 plants to test. The first tests were carried out using the Duddingston population (pathotype B) but later tests have used a Nocton population (pathotypes B + C?, see Guile, 1967), and the Changed Little Ouse population (also pathotypes B + C?, see Cole and Howard, 1966).

Table 3

Andigena family (K81) with possible resistance to pathotypes B and C

(a) Tested with Changed Little Ouse population in 1968, 15 resistant : 24 susceptible
(b) Tests of some of the resistant seedlings from (a) in 1969

	Number of cysts per two root-balls on seedling K81/										
Population	8	9	14	22	25	27	28	29	33	36	39
Changed L. Ouse	14	10	20	20	12	17	33	3	33	4	9
Feltwell	13	20	22	18	253	293	15	7	331	184	254

Changed Little Ouse, 282 cysts per 2 root-balls on Maris Page
Feltwell, 460 cysts per 2 root-balls on Maris Page

The present position is that resistance to pathotypes B and C may exist in not more than four stocks which trace back to only three Andigena varieties. Rather surprisingly (see Table 3), one of these Andigena varieties seems to have two genes, one giving resistance to the Feltwell population (pathotype A) and another to the Changed Little Ouse population (pathotypes B + C?). These Andigena stocks are therefore promising as a source of resistance to pathotypes other than A, but until further tests have been made using many non-pathotype A populations and until further work has been done on the inheritance of their resistance, it would be premature to conclude that they are going to be as valuable for resistance to pathotypes B and C as were C.P.C.'s 1673, 1685 and 1690 as sources of resistance to pathotype A. On the other hand they are cultivated potatoes and they should be very much easier to use in breeding for commercial characters than are wild species such as S. vernei.

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CEREAL VARIETIES RESISTANT TO HETERODERA AVENAE AND DITYLENCHUS DIPSACI

J. Cotten*
Welsh Plant Breeding Station, Plas Gogerddan, Nr. Aberystwyth

Summary The introduction of resistance to the stem nematode, (*Ditylenchus dipsaci*), derived from the old land race oat Grey Winter, into spring and winter oat cultivars, has proved an effective means of controlling this pest.

Resistance to the cereal cyst nematode, (*Heterodera avenae*) is being introduced into spring barley and into spring and winter oat cultivars. Resistance in spring barley is effective not only in reducing cereal cyst nematode infestations, but also in producing higher yields of grain on infested land.

INTRODUCTION

Heterodera avenae, the cereal cyst nematode, and *Ditylenchus dipsaci*, the stem nematode are two soil-borne pests known to be capable of causing considerable yield losses in cereals.

The cereal cyst nematode attacks all three major cereals, oats being the most severely damaged, followed by wheat, while barley apparently shows some tolerance to attack. The second stage larvae of the nematode invade the roots of the host plant behind the root tip and typically, infected plants have shallow but profusely branched and somewhat galled root systems.

The stem nematode attacks both spring and winter oats, the larvae and adults being found at the base of the stem in the ensheathing portions of the leaves. Typically, attacked plants show so called 'tulip root' symptoms, a swelling at the base of the stem resulting from cell hypertrophy and separation.

Both these pests can be controlled effectively by incorporation of resistance into the host.

SOURCES OF RESISTANCE

Resistance to the stem nematode in most spring and winter oat cultivars probably derives initially from the old land race oat Grey Winter, with resistance controlled by a single dominant gene (Griffiths, Holden and Jones, 1957).

Selection of breeding material at the Welsh Plant Breeding Station for resistance to the stem nematode has been carried out exclusively in the field, and is based on the absence of tulip root symptoms in comparison with known susceptible genotypes.

In breeding cultivars resistant to the cereal cyst nematode the absence or near absence of adult females (cysts) on the roots of the host has been used as the

* Present address: Plant Pathology Laboratory, Hatching Green, Harpenden, Herts.

criterion of resistance. Attention has so far been confined to barley and oats, although resistance in wheat is also known. In barley resistance has been derived from the unadapted genotype Cb 824 (= No. 191). This genotype has a single dominant gene Ha (Cotten and Hayes, in press) effective against races 1 and 2 of the nematode, the most prevalent races in Britain, as well as against a wide range of European races (Table 1).

Table 1.

Reaction of barley genotypes to British (B), Danish (D)[1] and Dutch (N)[2] races of *Heterodera avenae*

R = resistant. S = susceptible. SR = semi-resistant.

	Nematode races								
	B 1	N a	D 1	B 2	N c	D 2	B 3	N b	N d
Genotype									
Cb 545 (Rika)	S	-	-	S	-	-	S	-	-
Herta	-	S	S	-	S	S	-	R	S
Drost/Fero	R	R	R	S	S	S	-	R	R
Cb 824/No. 191	R	R	R	R	R	R	S	S	R
Cb 1033/Harlan 43	SR	S	-	SR	SR	-	R	-	R

[1]Andersen (1961)
[2]Kort, Dantuma and van Essen (1964) and Kort (personal communication)

Resistance in oats to the cereal cyst nematode is derived from Cc 4658 *Avena sterilis*. This genotype, although not completely cyst-free, has good resistance to all the races of the nematode so far encountered in Britain. Preliminary investigations on the inheritance of resistance in this genotype indicate that resistance is controlled by two major genes, with resistance incompletely dominant.

MECHANISM OF RESISTANCE

Controlled inoculation experiments by Blake (1962a) showed that, although the rate of invasion by the stem nematode did not differ for resistant and susceptible oat genotypes, the rate of development and reproduction of the nematode was subsequently faster in susceptible genotypes. Cell hypertrophy and separation following nematode invasion was considerably less in resistant genotypes (Blake 1962b).

Nematode counts from root samples taken from plots of oats and barley, both resistant and susceptible to cereal cyst nematode, grown on a cereal cyst nematode infested site at Ruthin, Denbighshire showed that similar numbers of larvae were found in both resistant and susceptible genotypes (Table 2). The higher proportion of stage 2 larvae in resistant genotypes indicated that development of the nematode was slower compared with that in susceptible genotypes, and whereas large numbers of adult females were found on the roots of susceptible oats and barley, very few adult females occurred on resistant genotypes.

Stem nematode resistant spring and winter oat varieties developed at Aberystwyth and elsewhere such as S. 225 (Milford), S. 235 (Manod), S. 172, S. 238 (Peniarth) and Maris Quest, have been successful in controlling this pest. There have been no substantiated cases where resistant varieties have succumbed in the field to attack by more virulent races of this pest, by contrast to crop varieties having resistance to foliar pathogens. However, a small number of British populations of the cereal cyst nematode (Cotten, 1967), and unpublished data of the N.A.A.S. Cereal Nematodes Working Party), and some Dutch populations (Kort, Dantuma and van Essen, 1964), are known to carry a proportion of individuals capable of overcoming the resistance conferred by the gene Ha (Table 1). At the moment, such populations seem to occur infrequently in Britain, but it is possible that the continued use of resistant varieties on such sites would lead to an increase in the numbers of resistance breaking individuals, and further work is clearly needed on this aspect.

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CHEMICAL CONTROL OF THE CEREAL CYST NEMATODE - CAN IT BE ECONOMIC?

T. D. Williams
Rothamsted Experimental Station, Harpenden, Herts

Summary Various soil sterilants used in fields infested with the cereal cyst nematode (Heterodera avenae) have increased yields of barley and wheat. Such increases may reflect the control of the nematode, take-all (Ophiobolus graminis) or other pathogens, and the increased mineralisation of soil nitrogen. However, the current prices of the chemicals makes them uneconomic, but if cheaper ones are produced, or smaller amounts used, or they give beneficial residual effects in succeeding crops their use might become profitable.

INTRODUCTION

In the United Kingdom, cereals are grown on 9½ million acres, about 30% of the total area occupied by grass and all crops. There are about:

	6 million acres of barley	yielding about	9¼ million tons of grain,	
	2¼ " " " wheat	" "	3¾ " " " "	
and	1 " " " oats	" "	1¼ " " " "	

The cereal cyst nematode (Heterodera avenae) attacks and reproduces freely on all three crops. It is indigenous and widespread in England and Wales. Crop losses are widespread (Fig 1) and considerable, but there are no firm estimates for Britain. Stapel (1953) estimated that crop losses in Denmark amounted to some £2½ million annually. Dixon (1968) showed that, on sandy soils in Lancashire and the Vale of York, every increase of 10 eggs/g soil of H. avenae results in a loss of about 3 cwt/ac of oats, 1.5 cwt/ac of wheat, and 0.6 cwt/ac of barley.

The results of field trials, using several soil sterilants, made on nematode-infested sandy loam soil at Woburn (Beds) Experimental Station from 1964 to 1969, are referred to in this paper.

METHODS, MATERIALS AND RESULTS

In 1964, the application of formalin (38% formaldehyde solution at 266 gal/ac) during winter 1963/4, doubled yields of spring wheat grain and straw (Table 1). In treated plots, only 8 H. avenae larvae/g of root were found compared with 110/g in control plots. Take-all was also effectively controlled in the treated plots.

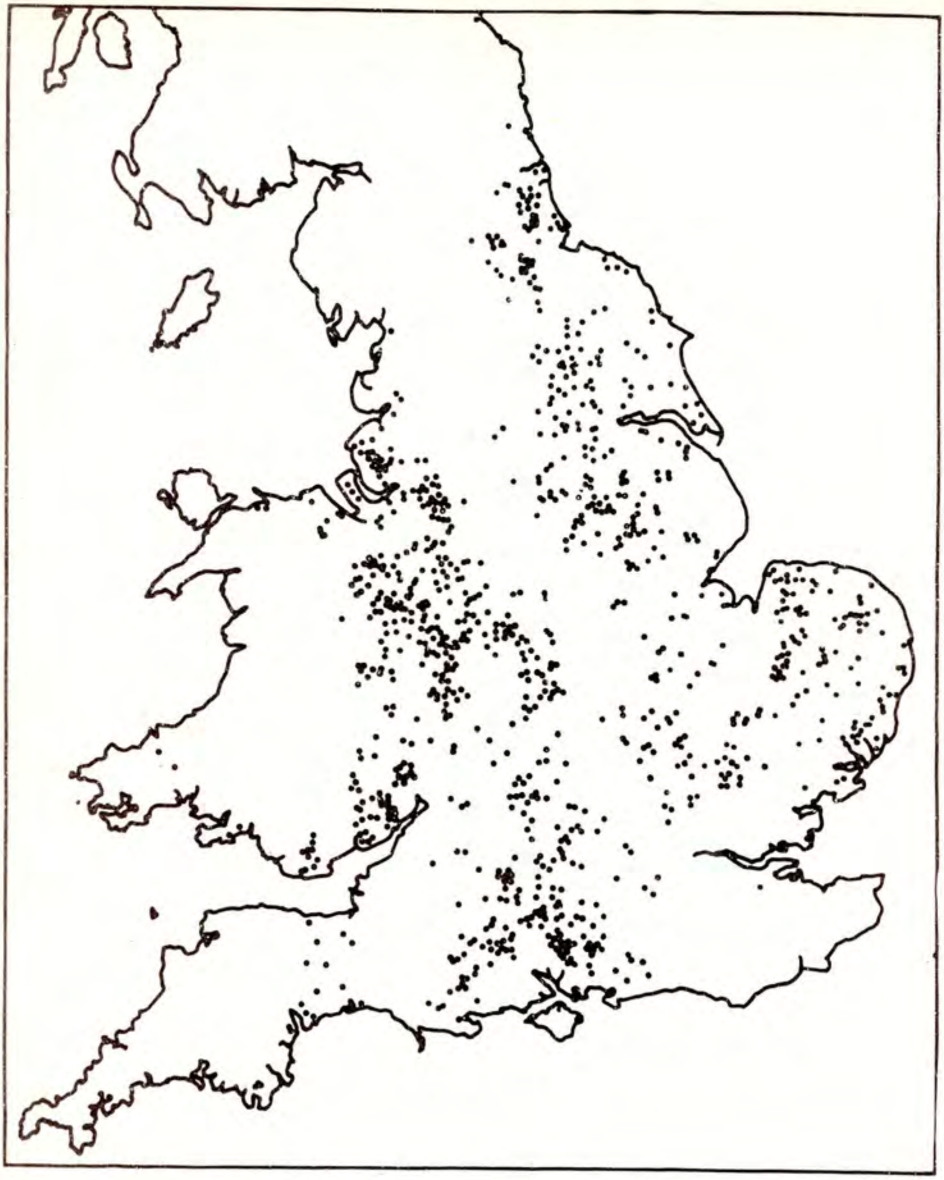

Fig. 1. Occurrences of cereal crop damage attributed to <u>Heterodera avenae</u>. Map prepared by Dr. F. G. W. Jones from Ministry of Agriculture, Fisheries and Food Monthly Summaries of Insect and Allied Pests occurring in England and Wales. (Up to 1960)

Table 1

Grain yield (cwt/ac) spring wheat, Woburn, 1964
(After Widdowson & Penny 1965)

		No formalin, irrigated	Formalin, irrigated
Nitrogen	0.6 cwt/ac	11.6	29.9
	1.2 cwt/ac	18.3	37.2
	1.8 cwt/ac	23.4	35.8
	Mean	17.8	34.3

During the next two years, various sequences of formalin treatments were established and had complex effects on the nematode and take-all fungus (*Ophiobolus graminis*) (Williams, 1969; Slope, 1966). Despite substantial yield increases, nematode populations were increased by applying formalin annually (Table 2), whereas without formalin, nematode populations remained almost constant.

Table 2

Accumulated grain yields of Spring Wheat. Woburn 1964-66

Treatment	Grain (cwt/ac)	*H. avenae* eggs/g soil (after harvest 1966
Formalin 1964/65/66	82.8	37
No Formalin 1964/65/66	44.4	5

A second experiment, using various amounts of D-D (dichloropropene-dichloropropane) and Dazomet (dimethyltetrahydro-thiodiazinethione), began in 1966, the effects of Dazomet are shown in Table 3.

In the second year of this experiment (1967), plots were split to compare the effects of single (1966) with cumulative (1966 and 1967) treatments. The largest yields (55 and 57 cwt grain/ac) were from plots given 1 cwt nitrogen/ac and 200 lb or 400 lb Dazomet/ac respectively in both years, untreated plots yielded 52 cwt/ac. The plots treated with Dazomet in 1966 only, and given 0.5 cwt N/ac, yielded 26 cwt/ac compared with 38 cwt/ac from untreated plots. Considerable mineralisation of nitrogen followed the application of D-D and Dazomet (Fig 2). Whereas Dazomet applied in both years decreased take-all to 3%, compared with 26% on untreated plots, residual Dazomet doubled or trebled the incidence of take-all. D-D, especially in the second year produced an unusual result. The crop grew well at first but later produced malformed heads. This effect

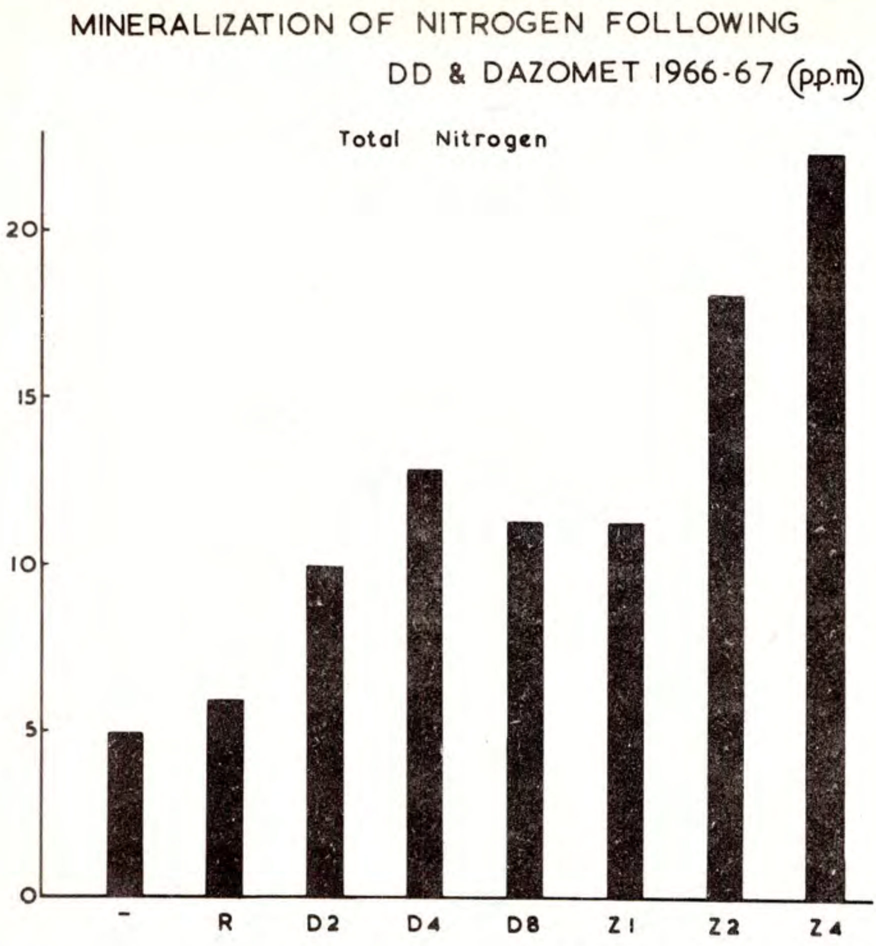

Fig. 2. Total mineralised nitrogen (mostly NH_4^+) in field soil, Woburn, three months after treatment with D-D and Dazomet. 1 ppm N = 2 units N (in a 6 in. furrow slice). Part of the nitrogen after Dazomet may come from the Dazomet molecule itself.

Key

- untreated	D2, D4, D8, - 200, 400 and 800 lb D-D/ac
R rotavated only	Z1, Z2, Z4, - 100, 200 and 400 lb Dazomet

Table 3

Effect of Dazomet on spring wheat (Kloka) and H. avenae 1966

(Williams, with Salt & Ebbels 1967)

	Untreated	Rotated only	Rotavated + Dazomet (lb/ac) 100	200	400
Grain, cwt/ac	36.6	36.9	39.7*	44.1***	44.3***
H. avenae/g root	42	39	10	4**	0***

* Significantly different from untreated 5%
** Significantly different from untreated 1%
*** Significantly different from untreated 0.1%

increased with increasing amounts of D-D and nitrogen, and 46% of heads were affected by 800 lb/ac D-D and 1.5 cwt/ac N. At 400 lb D-D/ac and 1 cwt N/ac 23% of the heads were deformed. This damage again occurred on the Rothamsted clay in 1967 and 1968 and on the lighter Woburn soil in 1967. No satisfactory explanation is yet forthcoming for the damage, which in some ways resembles frost damage (Ebbels, 1969).

A third experiment, also started in 1966, was on a site at Woburn lightly infested with H. avenae which was planted with oats; part of the crop area was grown to harvest to increase the nematode population, part was rotavated during May 1966 as a 'trap-crop' for H. avenae, and part was rotavated and then treated with D-D at 400 lb/ac. In 1967 and 1968 spring wheat and spring barley were grown to assess how the treatments affected nematode numbers and yield (Table 4).

Yields of spring wheat were increased more than those of barley by the treatments, perhaps because (a) it is less tolerant of H. avenae invasion, (b) responds better to nitrogen mineralised after D-D treatment, (c) more affected by take-all .

Residual effects from D-D applied in 1966 were still measurable in 1969 when a barley resistant to H. avenae (kindly supplied by the Welsh Plant Breeding Station) was grown. This is a variety, the roots of which can be invaded by H. avenae but in which the nematode does not multiply. However, it seems improbable that nematode attack was severe enough to account for the significant differences in yield between the fumigated and unfumigated plots, so the significant yield increase (Table 5) from D-D applied 3 years earlier may have come from some other cause, such as the control of other soil-borne pathogen or continued increase in nitrogen mineralised in the soil. The barley may have responded more in 1969 than in the two previous years because it did not lodge in 1969 whereas it lodged badly in the other years.

Table 4

Yields of spring wheat and spring barley (grain, cwt/ac) and nematode numbers after 1966 oat crop treatments

	Treatment		
	A	B	C
	Oats to harvest 1966	Oats rotavated May 1966	Oats rotavated + DD 1966
1967 Wheat	34.7	36.9	41.1*
Barley	34.1	36.5	37.3
1968 Wheat	32.8	35.1	36.6
Barley	32.1	33.7	37.3
Wheat, *H. avenae*/g root 1968	139	48**	20***
Wheat, post crop *H. avenae*, eggs/g soil 1968	5.3	2.5***	1.1***
Barley, *H. avenae*/g root 1968	179	78***	23***
Barley, post crop *H. avenae*, eggs/g soil 1968	6.2	2.4***	1.2***

* Significantly different from A (5%)
** Significantly different from A (1%)
*** Significantly different from A (0.1%)

Table 5

Yields of nematode resistant barley, Woburn 1969 after 1966 treatments

	Treatments 1966		
	Oats to harvest 1966	Oats rotavated 1966	Oats rotavated + DD 1966
1969			
Barley after wheat (grain, cwt/ac)	35.2	36.7	39.9**
Barley after barley (grain, cwt/ac)	32.2	32.7	37.9**

** Significantly different from treatment A at 1%

In an other experiment (Williams and Salt, 1966, 1967, 1968), D-D, methyl bromide, chloropicrin, Dazomet and formalin were applied before sowing spring crops of wheat and barley. D-D, methyl bromide, chloropicrin and Dazomet all increased yield substantially and decreased H. avenae. Formalin, although it at first increased yield, eventually decreased it, because H. avenae and take-all both increased. In the third, residual, year of this experiment, the best barley grain yields were 34.1 cwt/ac after one application of methyl bromide (1 lb/100 sq ft) in the first year, and 32.4 cwt/ac after D-D (800 lb/ac) in both preceding years. Formalin (first year only) gave 18.9 cwt/ac, after both years 19.6 cwt/ac. Untreated plots, in the third year, yielded 23.4 cwt/ac. Straw yields followed the same pattern.

DISCUSSION

The amounts and costs (in 1967) of the chemicals used in these tests, given in Table 6, show that the return in extra grain fell far short of paying for these treatments. Hence, unless the chemicals become cheaper or methods can be developed whereby similar improvements can be obtained with much less of the chemical, there is little hope of using them economically simply to maintain cereal yields. However, where cereals are grown in rotation with other crops, such as potatoes or sugar beet on soil infested with cyst nematodes or the ectoparasitic nematodes that cause Docking disorder, treatment with D-D may well prove worthwhile because it will increase the yield of all these crops.

Table 6

Sterilant costs (materials only) 1967

Sterilant	Dose/ac	Cost/ac
D-D	400 lb	£47 (£34 in 1969)
Formalin	266 gal	£64
Methyl bromide	400 lb	£110
Dazomet	400 lb	£136
Chloropicrin	400 lb	£149

Acknowledgements

Many of the experiments described were jointly sponsored by the Chemistry and Plant Pathology Departments at Rothamsted. Appropriate acknowledgement is made in the Text. Fig. 1 was prepared by Dr. F. G. W. Jones from information contained in the M.A.F.F. Monthly Summaries of Insect and Allied Pests occurring in England and Wales.

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CONTROL OF LONGIDORUS AND XIPHINEMA

C. E. Taylor
Scottish Horticultural Research Institute, Invergowrie, Dundee

Summary In field and laboratory experiment D-D, dazomet and quintozene gave good control of *Longidorus elongatus* and *Xiphinema diversicaudatum* and largely prevented virus transmission by them. Methomyl had little effect on nematode populations but prevented virus transmission, probably by preventing the nematodes from feeding. Individual treatments were equally successful at 7, 14.5 or 22°C.

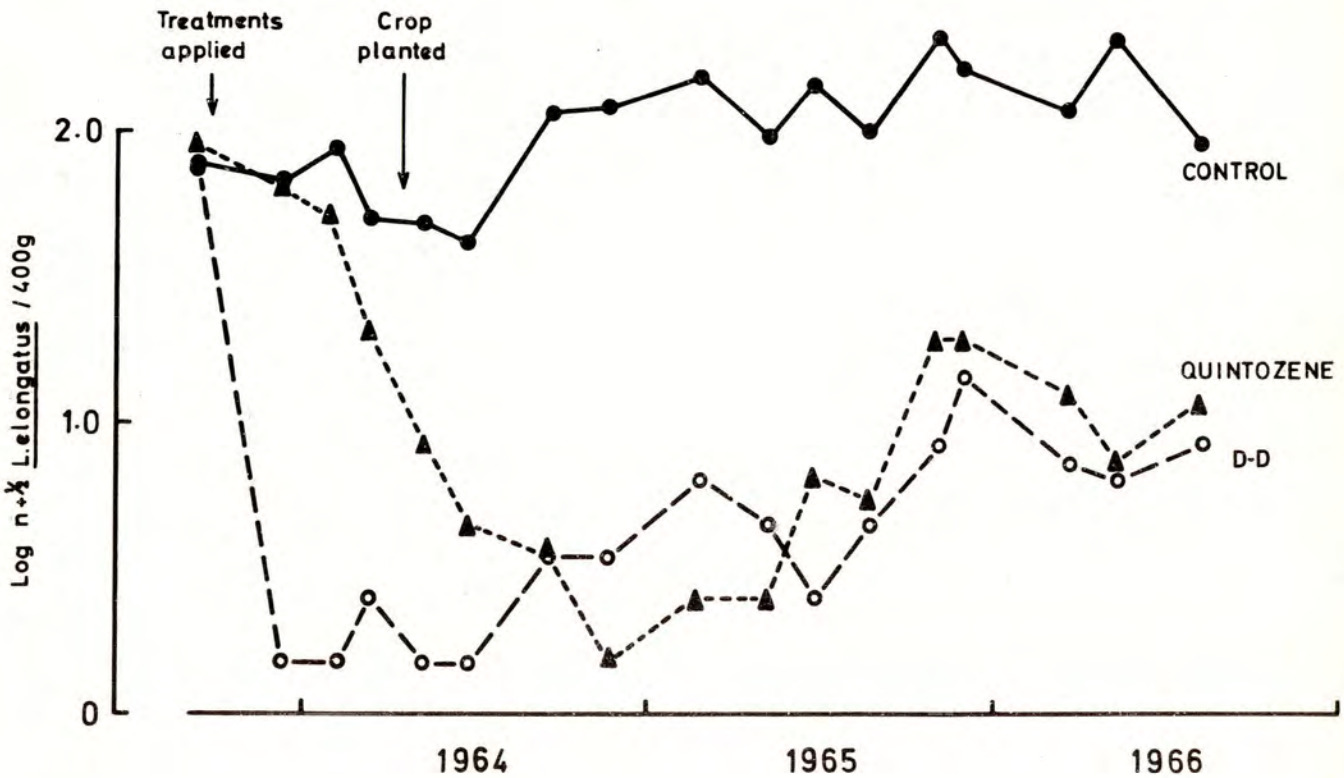
INTRODUCTION

The biology of *Xiphinema* and *Longidorus* species present several features which influence the choice of methods for their control. In addition to direct damage caused by their feeding at the root tips, several species are vectors of plant viruses and because of the wide host range among crop and weed plants of both viruses and vectors crop rotation has little effect as a control measure. Even a fallow soil results in only a slight and gradual decrease in the numbers of *Xiphinema* and *Longidorus* because most, if not all, species can survive for long periods without food. Moreover, although the vector species may lose their virus infectivity during a long fallow, reservoirs of infection remain in virus-infected weed seeds and in root pieces remaining from a previously infected crop. On the other hand, most *Xiphinema* and *Longidorus* species have a life cycle from egg to adult of at least a year and this, together with their low rate of multiplication, restricts their increase in numbers even on favourable hosts. Once populations have been reduced to low levels by chemical or other means of control, it may be several years before they are sufficiently large to be of economic importance in causing direct damage; low populations may, however, remain important in terms of virus infection.

With long-term crops such as grapevines, stone-fruits and raspberry, the planting of disease-escaping or virus-immune cultivars offers an attractive solution to the problem of nematode-transmitted virus infection, but in general nematicidal treatment of the soil has so far proved the most satisfactory way of controlling *Xiphinema* and *Longidorus* and preventing the spread of the viruses they transmit.

In the stony, shallow soils of Cote d'Or vineyards, Vuittenez (1961) obtained good control of *X. index*, vector of grapevine fanleaf virus, with D-D (dichloropropane-dichloropropene), carbon bisulphide and methyl bromide. In California, *X. index* in vineyard soils survived treatment with

Fig. 1. Control of *Longidorus elongatus* and virus transmission with D-D (400 lb/ac) or quintozene (60 lb a.i./ac)



D-D, EDB (ethylene dibromide), chloropicrin and methyl bromide, but this was because some of the nematodes survived at depths below 1 m where the chemicals did not penetrate (Hewitt, W. B. et al, 1962); nevertheless, Raski and Schmitt (1964) obtained significant increases in yields of Tokay grapevines by applications of DBCP (dibromochloropropane) metered into irrigation water and the beneficial effect of treatment was apparent for three years.

In England, treatment of glasshouse soils with D-D or DBCP controlled X. diversicaudatum and reduced the extent of galling on rose roots (Peachey and Brown, 1965; Peachey, J. E. et al, 1965) and in field experiments, applications of D-D or methyl bromide killed over 99% of X. diversicaudatum to a depth of 28 in and largely prevented infection of strawberry crops with arabis mosaic virus (Harrison, B. D. et al, 1963). D-D has also been used successfully in Scotland to prevent infection of strawberry crops by viruses transmitted by L. elongatus (Murant and Taylor, 1965; Taylor and Murant, 1968). On valuable crops such as strawberry and raspberry, where nematode-transmitted viruses can result in much reduced yields, large doses of nematicides are economically justifiable. On grain crops and sugar beet, where nematodes cause a reduction in yield by their feeding but where virus transmission is unimportant, it has been shown that the cost of treatment with D-D can be reduced by applying small doses in the rows; 6½ gal D-D/ac applied in this way significantly increased the yield of sugar beet where "Docking disorder" was prevalent (Whitehead and Tite, 1967; 1969).

The use of quintozene (pentachloronitrobenzene, PCNB) as a nematicide was first reported at the third British Insecticide and Fungicide Conference (Taylor and Murant, 1966). Since then it has been used successfully in further experiments for the control of L. elongatus and X. diversicaudatum, and on commercial holdings where there was a history of nematode-transmitted virus diseases in strawberry and raspberry crops. However, one of the features of its use in the field is that it does not quickly kill the nematodes, as does D-D, possibly because of the effect of the low winter and spring temperatures of eastern Scotland. This possibility was examined in experiments in which quintozene was compared with D-D and some newer nematicidal chemicals.

RESULTS

In a field experiment in eastern Scotland, treatment of soil in autumn with 300 lb/ac 20% quintozene or 400 lb/ac D-D killed most of the L. elongatus and largely prevented transmission of raspberry ringspot virus to Redgauntlet strawberry planted the following spring. Fig. 1 illustrates the level of control attained and also the slow rate of increase of L. elongatus on strawberry, considered as one of the most favourable host plants for the nematode. In 1965 and 1966, yields (tons/ac) from the treatments were respectively 0.2 and 0.3 from untreated, 1.2 and 2.6 from D-D, and 0.7 and 2.8 from quintozene plots. By June 1966, all plants in untreated plots were infected with raspberry ringspot virus, 6% were infected in D-D treated and 10% were infected in quintozene-treated plots.

Table 1.

Effect of temperature and period of fallow on the chemical control of *Longidorus elongatus* and virus transmission

Treatment[1]	Temp °C	No. *L. elongatus*/200 g[2] Fallow (wks) 3	6	12	Virus infectivity[3] 3 RRV:TBRV	6 RRV:TBRV	12 RRV:TBRV
Untreated	7.0	78	42	30	2 : 3	2 : 2	0 : 2
	14.5	85	58	58	4 : 2	5 : 4	0 : 1
	22.0	101	20	7	2 : 2	3 : 3	0 : 1
D-D (400)	7.0	5	5	6	0 : 0	1 : 0	0 : 0
	14.5	19	12	6	4 : 2	1 : 3	0 : 0
	22.0	0	1	0	0 : 1	0 : 1	0 : 0
Quintozene (120)	7.0	30	2	2	0 : 0	0 : 0	0 : 0
	14.5	23	2	1	1 : 1	0 : 0	0 : 0
	22.0	33	1	1	0 : 0	0 : 0	0 : 0
Dazomet (250)	7.0	1	1	1	1 : 1	0 : 0	0 : 0
	14.5	2	3	2	0 : 0	1 : 0	0 : 0
	22.0	0	1	1	1 : 0	1 : 0	0 : 0
Methomyl (13)	7.0	40	37	10	0 : 0	0 : 0	0 : 0
	14.5	66	18	11	0 : 0	0 : 0	0 : 0
	22.0	22	9	3	0 : 0	0 : 0	0 : 0

[1]Figures in brackets are equivalent rates of application a.i. lb/ac

[2]Initial population 140/200 g soil

[3]Infectivity assessed out of 5 plants tested; RRV = raspberry ringspot virus, TBRV = tomato black ring virus

Table 2.

Effect of temperature and period of fallow on the chemical control of *Xiphinema diversicaudatum* and virus transmission

Treatment[1]	Temp °C	No. *X. diversicaudatum*/200 g[2] Fallow (wks) 3	6	12	Virus infectivity[3] 3 AMV:SLRV	6 AMV:SLRV
Untreated	7.0	15	11	5	1 : 0	0 : 0
	14.5	16	15	5	2 : 2	1 : 0
	22.0	17	6	5	2 : 1	0 : 0
D-D	7.0	1	0	0	0 : 0	0 : 0
	14.5	2	4	1	3 : 1	1 : 0
	22.0	1	0	0	0 : 0	0 : 0
Quintozene	7.0	2	1	0	0 : 0	0 : 0
	14.5	3	1	0	0 : 0	0 : 0
	22.0	3	0	0	0 : 0	0 : 1
Dazomet	7.0	0	1	0	0 : 0	0 : 0
	14.5	1	1	0	0 : 0	0 : 0
	22.0	0	1	0	0 : 0	0 : 0
Methomyl	7.0	12	8	4	0 : 0	0 : 0
	14.5	8	10	2	0 : 0	0 : 0
	22.0	3	3	0	0 : 0	0 : 0

[1] Rates of application as shown in Table 1

[2] Initial population 16/200 g soil

[3] Infectivity assessed out of 5 plants tested; AMV = arabis mosaic virus, SLRV = strawberry latent ringspot virus. Assessment discontinued at 6 weeks because of low infectivity in control pots.

The effect of soil temperature on the nematicidal action of quintozene, D-D, dazomet and methomyl (Du Pont "Lannate"; Shell WL 18236) was examined in pot experiments, using L. elongatus and X. diversicaudatum infested soils. Pots of treated soil were maintained at 7, 14.5 or 22°C for periods of 3, 6 or 12 weeks. Nematode populations were assessed by taking 200 g soil from each of the pots and virus infectivity was assessed by planting Stellaria media bait seedlings in each pot and after 4 weeks' growth inoculating Chenopodium quinoa test plants with sap from the macerated roots. Nematode populations were again assessed at the end of the 4 week period with S. media.

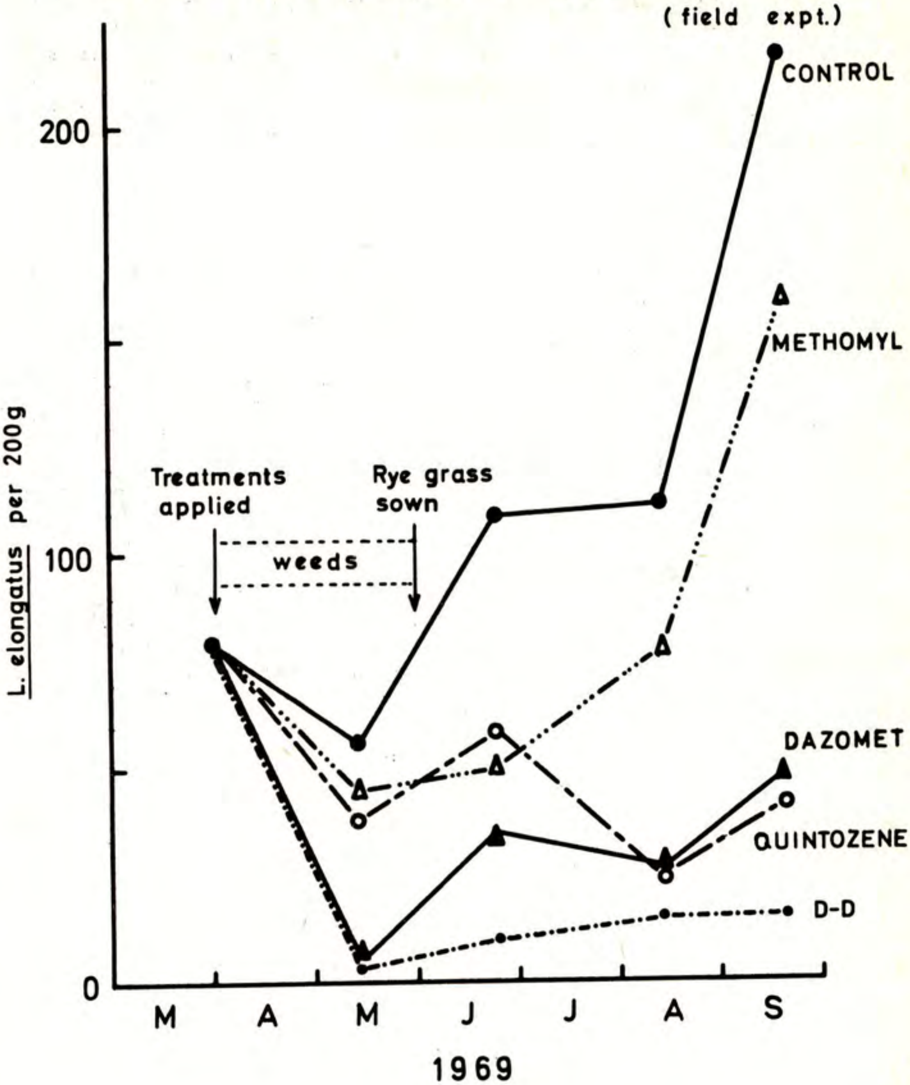
At all temperatures D-D and dazomet gave good control of L. elongatus (Table 1). Quintozene produced a similar effect at all temperatures, with nematode populations reaching the level of D-D treatment after 6 weeks, but methomyl caused only a slight reduction in nematode numbers in fallow soil. However, the most successful treatment in terms of virus control was methomyl, in which no transmission of raspberry ringspot or tomato black ring viruses was detected at any time during the experiment. D-D, dazomet and quintozene reduced the incidence of virus infection but did not eliminate it.

In a similar experiment with X. diversicaudatum (Table 2) D-D, dazomet and quintozene were efficient nematicides at all three temperatures. Methomyl again killed few nematodes but prevented transmission of arabis mosaic or strawberry latent ringspot viruses to S. media bait seedlings.

In these two experiments methomyl persisted in fallow soil for at least 6 weeks but although it was only slightly toxic to the nematodes it apparently prevented them from feeding on, and hence transmitting virus to, S. media bait seedlings when these were planted. After 4 weeks' growth of the bait plants, the numbers of nematodes in methomyl-treated pots had decreased further but in D-D- or dazomet-treated pots had increased at rates similar to those in untreated pots.

Methomyl was further compared with dazomet, quintozene and D-D in a field experiment. Treatments were applied to L. elongatus-infested soil on 31 March, 1969 and rye grass was sown on 31 May; there was a general weed cover on all plots during the intervening period. D-D and dazomet caused a quick decline in numbers of L. elongatus, but populations in these treatments began to increase from about June onwards (Fig. 2). Nematode numbers in quintozene-treated plots showed a more or less steady and continuing decline from the start of the experiment through to August. Methomyl killed few L. elongatus and by mid-summer they were almost as abundant as in untreated plots. Soil samples in June showed that the incidence of tomato black ring virus had been reduced in D-D-, dazomet- and quintozene-treated plots and eliminated from methomyl-treated plots. In August, virus infectivity in methomyl-treated plots was similar to that in untreated plots, but remained low in D-D-, dazomet- and quintozene-treated plots. The relatively short period during which methomyl prevents nematodes from feeding may nevertheless allow many annual crops to escape early virus infection and serious nematode injury. In perennial crops methomyl is unlikely to give a sufficiently long protection against virus infection but it could be used in combination with the

Fig. 2. Chemical control of *Longidorus elongatus* (field expt.)



Rates of application

METHOMYL	13 lb a.i./ac	}	surface application with rotary cultivation to depth of 9in.
DAZOMET	250 lb a.i./ac		
QUINTOZENE	120 lb a.i./ac		
D-D	400 lb /ac	—	applied by soil injector

persistent and slow-acting quintozene, to provide a more effective treatm
than either chemical alone.

In these and other experiments in the United Kingdom, D-D remain one of the most effective nematicides for controlling Xiphinema and Longidorus, but requires specialized equipment for its application. Many nematicides in granular form are easily incorporated into the soil and are more specific and more persistent; these characteristics are of particular value for controlling Xiphinema and Longidorus.

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THE CONTROL OF NEMATODES IN MUSHROOM COMPOST

J.J. Hesling and R.J. Kempton
Glasshouse Crops Research Institute, Littlehampton

Summary It is difficult to use nematicides in mushroom growing because of (1) the quick growth of the crop, (2) the physical difficulties of incorporating chemicals into huge volumes of compost in stacks or closely packed boxes, (3) the sensitivity of mushroom to chemicals and (4) the special risks to consumers and growers. Thionazin seems to be the only non-fungitoxic nematicide useable. It is effective at low concentrations when mixed into compost at spawning; "Spot" treatment of compost with thionazin is ineffective. In successful treatments using initially 20 p.p.m. a.i. in compost, no residues were detectable in mushrooms first picked four weeks later.

INTRODUCTION

Some of the difficulties encountered in the chemical control of mushroom nematodes are common to all pest control, but others are emphasised or are unique because of mushroom growing methods and the nature of the crop and its eelworm pests.

Difficulties common to pest control in general

There must be no toxic hazard to the consumer or grower, there must be no adverse effect on the crop (fungitoxicity), the best time and site must be found for the chemical's application, and the treatment must be economic.

Difficulties emphasised or unique in mushroom growing

Cropping is continuous for 6-8 weeks and the mushrooms are harvested within a few days of appearing on the beds. Therefore any chemical applied in this time must be non-toxic or of very short persistence.

On most farms, machinery prepares and handles compost. Nevertheless, growers and others are frequently in contact with compost and its containers, and some man-handling is necessary. This work is arduous and is often done speedily because piece-work payment is common, and to avoid compost exposure to air-borne pests and diseases. The addition of chemicals to compost creates a risk to operatives, and any process or practice (such as wearing protective clothing) that lowers work output, and hence wages, is most unpopular. Once compost is filled into boxes and put into pasteurisation rooms or growing rooms treatment with nematicides is difficult because the boxes are densely packed, and once it has been spawned, compost should not be disturbed.

Agaricus bisporus is sensitive to chemicals, and the sporophore is sometimes more sensitive than its mycelium. Thus, chemicals applied to the surface of mushroom beds or incorporated in the "casing" may induce abnormal and unsaleable mushrooms, and the application of some chemicals must be limited to compost only (Hussey, 1967).

A well-prepared compost contains about 70% by weight of moisture, and only a slight deviation from this is permissible; nematicidal drenches must not add more than two per cent of moisture. Mushroom mycelium is stimulated to produce sporophores by micro-organisms in the "casing" (Eger, 1963, Hayes, Randle and Last 1969). If these micro-organisms were affected by nematicides there might be an adverse effect on mushroom yield.

Difficulties peculiar to the control of mushroom nematodes

On a "field" scale it is impossible to completely control any nematodes, there are always some survivors. The speed of re-occurrence of nematode damage after control treatment depends on the number of survivors and on their fecundity. This is especially so with mushroom nematodes, for many breed rapidly and some are parthenogenetic so that even an isolated larva can give rise to millions in a few weeks. Outbreaks of mushroom nematodes usually arise from few nematodes scattered in several foci of infestation. Peak eelworm populations may be 5,000/g compost (harmful fungal-feeders) and 40,000-50,000 g (saprophagous species). Many mushroom nematodes are readily spread, and recontamination of treated compost is inevitable. Once established in mushroom houses nematodes persist in crevices where some seem to survive despite the most extreme physical (heat) or chemical treatments that can be practically applied. Survivors cause chronic nematode problems where there is no effective "cook-out" after cropping. When nematodes destroy the mushroom mycelium, the immediately-subsequent microbial activity makes the infested compost quite unsuitable for recolonisation by mycelium.

The role of a mushroom nematicide

The mammalian and fungal toxicities of currently-used nematicides make them unsuitable for use in mushroom-growing. Assuming that a suitable substance were found what should be its role? It can only be to protect the mycelium and the crop by its persistence. A short-lived eradicant would be unsuitable because of recontamination and the nematodes' enormous potential for survival and increase; a curative treatment would be too late because by the time of its application the compost would be unsuitable for further mycelial growth. A protective chemical need not be a direct quick killer - although this seems always preferable - it may be successful if it drastically lowers the eelworm reproductive rate, for example, by interfering with reproductive physiology or behaviour.

Mushroom nematicides and practicality of application

All mushroom nematodes (saprophagous as well as fungal-feeding forms) are liable to be killed by a contact nematicide in compost moisture. Saprophagous eelworms may also be killed by ingesting poisonous particles or liquids, but spear-bearing fungal-feeders are less likely to be killed by ingesting poisons from compost moisture, and may only be susceptible to those ingested poisons that they suck from fungal cells - i.e. fungal-systemic poisons.

For effective control of relatively immobile and minute eelworms the "contact-killer" or "ingestion-killer" must be well dispersed and soluble in compost moisture. Water solubility seems to be a necessary property of mushroom nematicides because, to avoid over-wetting compost, the chemical may have to be applied at low volume-high concentration and, after mixing with compost, be left to disperse itself to the required concentration in the compost moisture. On some mushroom farms this would involve the mechanical mixing of 100 tons of compost - a lengthy and power-demanding process. The applied concentration of the chemical may be dangerous and then there must be a delay before spawning until the chemical has diluted itself to a safe level. Such a delay would be unpopular, because composting and growing schedules are often precisely timed to fit into an established routine.

A nematicide that is systemic in mycelium seemingly needs less elaborate methods of application for, theoretically, the mycelium itself may be relied upon to carry the poison to every corner of the compost. Such a substance, however, might be ineffective against saprophagous eelworms (suspect vectors of pathogenic bacteria), which are not believed to pierce and eat mycelial cells.

Thionazin as a mushroom nematicide

The previous chapters suggest that, on grounds of toxicity alone, there is no place in mushroom-growing for any currently-used nematicide. One substance however, THIONAZIN, is non-fungitoxic as the e.c. formulation (to mycelium only) at concentrations of 80 ppm in mushroom compost, and is effective against harmful fungal-feeding nematodes at low concentrations (< 4 ppm) (Oliff, 1965). It is, however, very toxic (acute oral L.D. 50 in rats 11-16 mg/Kg) and there is considerable risk in its use because it needs to be applied at high concentration to avoid over-wetting compost. Fortunately, the sequence of operations in mushroom cultivation (Table 1) provides a convenient point - "spawning" - at which this chemical may be applied with minimum risk and little delay.

Table 1

Sequence of Mushroom Cultivation

Operation	Duration; remarks
composting	Usually 1-2 weeks, sometimes longer.
"peak-heat"	1-5 days at 135-140°F. Often much NH_3 evolved.
spawning	The seeding of finished compost with mushroom spawn. Thionazin incorporation convenient at this stage.
spawn run	14 days at 70-75°F.
casing	Covering beds with 1 in layer of peat and chalk.
incubation	15-20 days at 65°F.
cropping	6-8 weeks.

Spawning methods vary but their basis is the even admixture - usually by machine of mushroom spawn into pasteurised compost. This is known as "through" spawning. This stage is a logical input-point for thionazin because the spawning machinery will mix it into the compost, and there is no hold-up of production. Also, spawning is followed by a fourteen-day "spawn-run" when compost is not disturbed and a further 10-12 weeks when disturbance is most unlikely. It is vital to take every care and use suitable protective clothing during the treatment process and during the handling of treated boxes of compost. The outside of the box should not be contaminated. During spawn-run the thionazin becomes diluted in the compost, and in practice an acceptably even (though far from perfect!) distribution is achieved; in experiments there was little difficulty in achieving final target concentrations of up to 80 ppm by manual mixing when the concentrated chemical was applied at 2 pints/cwt compost.

RESULTS

In trials, thionazin (e.c.) gave protection from the fungal-feeding Aphelenchoides composticola and Ditylenchus myceliophagus for at least five weeks' cropping (Hesling, 1966). No residues were detected in picked mushrooms, but at that time analytical facilities (thin-layer chromatography) were inadequate to detect concentrations of less than 0.2 ppm. These results showed the potential usefulness of thionazin and stimulated further work on the persistence and residues of thionazin in compost and picked mushrooms. At the same time a safer method of application was sought, and others (Wyatt, 1969) investigated its use as a compost insecticide.

In later work, using gas-liquid chromatography, the "half-life" of thionazin in compost was found to be about fourteen days. In one experiment where compost contained initially 20 ppm thionazin the highest concentration after twelve weeks was 0.06 ppm, and no thionazin was detected in any mushrooms (limit of detection 0.01 ppm).

Thionazin is systemic in higher plants and possibly in fungi; it seemed that this could be exploited to make application safer. Thus, "spot" placement of the chemical in mushroom compost might be as effective as "through" treatment if the thionazin became systemically distributed in the mycelium. This seemed to offer a simpler, safer, method than "through" treatment because the grower would only need to apply small doses of thionazin at convenient spacing in beds and trays. The granular formulation of thionazin seems less hazardous than the e.c. but granules have had little, if any, use against mushroom eelworms. An experiment was done to compare "through" treatment with "spot" treatment using e.c. and granular thionazin at two dose rates-5 and 20 ppm-in compost artificially infested with one *D. myceliophagus*/g. compost. The "spot" treatment entailed the application of a measured dose of thionazin or granules about 1 in deep in the centre of 4 Kg compost in boxes 30 cm square.

The results confirmed the effectiveness of "through" treatment with e.c. formulation at 20 ppm. "Through" treatment with granules was not as good, but even so nematode control and mushroom yield were acceptable, and nematode control was maintained for at least five weeks. "Spot" treatments were unsatisfactory; eelworm control was poor, with much mycelial damage and low mushroom yield. No abnormal mushrooms were produced with any treatment.

"Through" treatment of compost using the e.c. formulation still seems the best method of protecting mushroom mycelium from fungal-feeding eelworms, and "spot" treatment, which promised to be safer, is ineffective. This may indicate that thionazin is not as systemic in mushroom as was hoped. Further investigations on the usefulness of the granular formulation seem worthwhile.

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THE PRINCIPLES OF AND NEW DEVELOPMENTS IN ULTRA LOW VOLUME SPRAYING

E. J. Bals
Micron Sprayers Limited, 1, Phillips Street, Birmingham 6.

Summary Recent experience in ultra low volume spraying, with non-evaporating carrier liquids with even sized droplets, has shown that a very much greater percentage of the chemical applied is collected by the target surface than with conventional spraying. Critical examination should be done to show whether with this method recommended dosage rates can be drastically cut and whether ultra low volume spraying can, in future, be synonymous with ultra low dosage spraying.

I am greatly honoured to have been asked to read this paper at this scientific conference, in spite of my non-scientific background. I will, therefore, limit myself to the purely technical and logical aspects of this question, leaving it to more qualified persons to prove or disprove my assertions, which are based on primitive common sense, hunches, and some practical experience gained over the last 20 years. This paper should, therefore, be treated as a challenge to investigate rather than a statement of facts.

The techniques of actually applying insecticides or fungicides to the target have, in my opinion, been sadly neglected since the advent of the modern, highly effective pesticides. For example, the recommended dosage rate of a pesticide is still given as so many ounces per acre, or grammes per hectare, irrespective of either the leaf surface to be covered, or the total weight of the crop to be treated with a systemic insecticide to achieve a contamination of the plant to such an extent that it is lethal to the insect to be destroyed.

Furthermore, the dosage rate per area does not specify how it should be distributed over the area, save that it should be diluted with a certain amount of water or other diluent.

Because it is obvious that, if the recommended dose of pesticide, diluted or undiluted, were to be dumped on one spot in the middle of the area to be treated, no beneficial results could be expected, we have come to assume that we should distribute the material uniformly over a target. It is, however, much less obvious that spraying a crop with droplets of indiscriminate size can be nearly as wasteful. The droplet spectrum from an ordinary pressure nozzle consists of droplets varying from 20 to 400 micron in diameter. This constitutes a variation in dosage between the smallest droplets, containing one unit of chemical, and the largest ones of 20^3 or 8000 units of chemical. If this were a contact insecticide and the 20 micron droplet contained enough active ingredient to kill the insect, the 400 micron droplet would kill it 8000 times or, alternatively, leave a residue 8000 times in excess of what should have been used for scientific pest control. Exactly the same logic applies to the spraying of fungicides.

It is, therefore, absolutely essential to have as near as possible even sized droplets to achieve the maximum benefit in insect destruction from the chemical applied, leaving a minimum of residue on the crop meant for human or animal consumption. Another aspect which has been given little consideration in pesticide application is the advantage of depositing the pesticide on the target area only without contaminating surfaces, which will not contribute to the destruction of th pest to be controlled and only helps in the contamination of the general environme

In spraying against cotton bollworm, for example, the target is the cotton bo and any spray deposited on the leaves constitutes a waste. In this instance, as many others, it will not be feasible to achieve this ideal but, all the same, it still remains desirable.

Another example of this, which springs to my mind, has been the defoliation programme of forests in Vietnam. Had droplets smaller than 20 micron been used t herbicide would have only been able to impact on the stems of leaves with only min mum deposit on the leaves themselves, and a wonderful penetration right to ground level would have been achieved. The destruction of the stems would have automati cally destroyed the leaves and, as a very rough and ready estimate, less than 1% o the active ingredient and less than 1% of the total liquid would have achieved the same results, i.e. the rapid growth of a secondary, much more impenetrable, jungle

In my view, the efficiency of a spraying machine is inversely proportional to the range of droplets it emits, whilst the suitability for a specific problem depends on the actual size of the droplets emitted. Everyone knows that a tree will give an excellent shelter against a heavy downpour, as large droplets are collected on the outside of the tree without penetrating it, whilst the same tree will give no protection against a scotch mist or light drizzle. On the contrary, apart from getting wetted by the scotch mist, the inside of the tree collects it t and drips it mercilessly on your head. We are, therefore, faced with the problem of producing even sized droplets of the chemical, small enough to give maximum coverage and penetration, without being filtered out by the first obstacle they encounter. On the other hand, they must be large enough to impact on the target surfaces.

Spray collection depends mainly on two factors: the terminal velocity of the droplets; and the prevailing air movement or wind. The terminal velocity depend on the droplet size and the specific gravity of the liquid. In the case of a 70 micron droplet with a specific gravity of one, this is approximately 6" or 15 cm. per second (⅓ mile, or ½ km. per hour). From experience, we know that such a droplet in still air will sediment on all horizontal surfaces, large or small. An air movement will ensure the impact of such a droplet on surfaces normal to the droplet path. As the micro climate inside the crop contains forces of this type impaction can, and does, occur on the leeward sides of target areas.

This statement about vertical and leeward impaction needs, of course, considerable qualifications. A droplet impacts only through its own momentum which must be in excess of the forces (wind or air movement) trying to carry it around such surfaces. By necessity these small droplets have very little momentum of their own, save their terminal velocity and the velocity with which an air movemen carries them in relation to the stationary target. If the target, due to its sma size, causes minimal diversion of the moving air, small horizontal velocities will make it impact. The larger the obstacle the greater the horizontal velocity has be to impart enough momentum to the droplet to make it impact on the large surface without being taken around it by the air.

The impaction on leeward surfaces can be enhanced by providing a further forc in the form of an air blast, emitted by the spraying machine, having a different angle to the prevailing natural air movement. This force, compared to the natura forces, is puny and quickly dissipated even using massive power units. This is b illustrated by observing the force of penetration achieved by the 70,000 horse pow produced by the four jet engines of a VC 10 aircraft against a prevailing wind of 5 m.p.h. at a distance of 100 yards, which is practically nil.

Recent work by Himel, The University of Georgia, U.S.A., has shown that, both in spruce budworm control as well as in cotton spraying, about 95% of all insects collected their lethal dose from droplets of less than 30 micron. This is not surprising in spruce budworm control, where the coniferous plants make an ideal collecting area for small droplets providing stomach poisoning, and the hairy surface of the spruce budworm an even better target for contact kill. It was, however, an eye-opener in the case of cotton spraying. As far as I understand, the operations were carried out with a rather indiscriminate droplet spectrum varying from 10 to 300 micron. This means that, with much less than 1% of the recommended dosage rate, 95% of the kill was achieved.

We have aimed, in our machines, rather arbitrarily at a 70 micron droplet size as we found that, in practice under varying conditions, we not only obtained a very good recovery rate of the total liquid emitted in the target area but, also, a kill of insects and a protection against fungus attacks far in excess of our expectations. Results were better than with 100 or 150 micron droplets, which were advocated only a short time ago.

Various considerations decided our arbitrary choice of 70 micron, the first being very mundane ones, namely, the availability of power sources, the speed of rotation available from them, their power output, and the physical need to have a disc, cup or gauze on the rotary atomiser, which has enough issuing surface for the droplets to be formed and is large enough to be physically fed at an even rate, yet small enough to consume the minimum of power. With the disc size chosen by us, which fulfils these conditions, the droplet size in micron produced with an average oil is, as a very rough and ready guide, 500,000 divided by the r.p.m. of the atomiser.

The second consideration was that reasonable spraying machines are needed now. The scientific work involved to determine the ideal droplet size for each purpose involves many thousands of permutations - wind speeds, thermal convections, eddies, plant surfaces to be covered and their size, specific gravity of the spray liquid, its vapour pressure, surface tension and viscosity, the size and surface of the insect to be destroyed either by contact and/or stomach action, and whether this insect is stationary, moving, or actually flying and thereby collecting very efficiently small droplets out of a spray cloud, have all to be taken into consideration - a lifetime task for a new generation of scientists and computers, to be completed sometime in the 21st century. Once this task is accomplished, a small computer on each spraying machine, provided that it is fed with the right information, will tell the farmer what to do.

In the meantime, we have to work on a "suck and see" basis. With rotary atomisation we have, however, the advantage that, by changing the rotational speed of the atomiser, we can change the droplet size. This should not be left for the man in the field who, in all probability, will make the wrong choice and is better off with a unit which, under average conditions, will give reasonable results. But it might be, and can be, done for experimental purposes and we might find that, with 35 micron droplets, better results are achieved considering that eight times the number of droplets are available from the same amount of liquid as are available from 70 micron droplets. For herbicide spraying, on the other hand, we want a droplet in the region of 350 micron which is practically only settling with the force of its own terminal velocity and, therefore, represents no drift hazard. Both of these extremes can be achieved with a rotary atomiser.

A very interesting experiment, recently carried out by CIBA, showed that 500 millilitres per acre of Dimecron 100, sprayed with a battery operated rotating disc sprayer, with a volume median diameter of 70 micron, left a contamination of the sprayed rice at 120 parts per million whilst the same amount of active ingredient, sprayed with a knapsack sprayer at 100 gallons per acre in water, produced only 4 parts per million contamination which, incidentally, was not nearly as evenly distributed over the whole plant surface as when applied at ultra low volume rates. This observation, and similar ones by other scientists, bears out my own collected over the last 20 years on a non-scientific basis and helps to account for the successes achieved with concentrate spraying with even sized droplets.

We coined in 1950 the expression "ultra low volume" spraying and, a few years later, went over to using the word "concentrate" spraying to conform with the vocabulary then used by Potts and other workers in the U.S.A. However, as we realised that, with dilute sprays applied at ultra low volume rates, we obtained equally good, and very often better, results without massive overdosing and contamination of the environment, we quickly changed back to the rather ungainly expression "ultra low volume" spraying. I feel that the time has come to investigate very carefully the concept of "ultra low dosage" spraying.

If, as was shown in the Dimecron 100 trials, 30 times the amount of active ingredient is collected by the target area than is actually needed for control, it is surely nonsensical to apply the dosage rate hitherto recommended when 3% of the active ingredient will achieve the desired result. This, however, does not necessarily mean that we can reduce the total amount of liquid applied to 3% of 500 millilitres or 15 c.c. per acre.

With droplets of 70 micron a theoretical coverage of 60 droplets per square cm. is achieved when distributing 1 litre on 1 hectare surface. Assuming 3 hectare leaf surface to 1 hectare ground surface, an average deposit of 20 droplets per square cm. or 120 droplets per square inch, can be expected. Therefore, for purely physical reasons, the total amount of liquid cannot be reduced below a certain point without losing the required density distribution over the target area. It goes without saying that all these deliberations are based on waterless spraying, i.e. the carrier liquid should be oil or another non-evaporating liquid, ensuring that the droplets arrive at the target the same size as emitted from the machine.

These small amounts of total liquid needed and the low concentration of active ingredient incorporated in them can and, in my opinion, will revolutionise the whole concept of pest control. Instead of leaving the final formulation of the pesticide to be applied to a, perhaps, illiterate farmer using water as a diluent of an unknown PH value, which might cause serious deterioration of the chemical to be applied, ready formulated and securely packed chemicals can be supplied. All Micron sprayers are constructed so that these containers are screwed onto them and any unused liquid remains in the bottle, properly labelled for instant use when required at a later date. No handling and mixing of concentrated chemicals with its inherent danger, no washing out of tanks and disposal of unused dilute chemical with its contamination problem, is required. Exactly as in all other spray operations the container in which the pesticide has been delivered has to be safely disposed of but, in the case of ultra low dosage pesticides, any residue in the container is a dilute rather than a concentrated poison. I hope to see the day that the oil content of such chemicals will be so great that vomiting occurs before the insecticide has acted on a person accidentally drinking such a mixture.

One very strong argument used against ultra low volume spraying is the risk of drift and we must face the fact that, whatever spray method we are using, drift is liable to occur. If, however, we are using a non-evaporating droplet of 70 micron, this will remain of the same size and will, if it has a specific gravity of 1, fall at a rate of 15 cm. or 6" per second and will, therefore, sooner or later make contact with an obstacle, i.e. the plant to be sprayed, to be filtered out and collected by it. A water based droplet of the same size containing 0.1% active ingredient will, however, within a matter of seconds become a 7 micron droplet of highly concentrated chemical, which has much less chance of impacting on anything as its terminal velocity is 2 millimetres per second, or 7 metres per hour. This means that such a droplet will drift 75 times further than a 70 micron droplet, with much less chance of impacting even when inside a crop. A 0.1% water based spray means 1 pint of active ingredient in 125 gallons of water.

Unless, therefore, we use in high volume water based spraying only droplets of such a size that they will land on the target area without any appreciable loss due to evaporation, the drift hazard is, in my opinion, very much greater with water based sprays than with ultra low volume spraying with a non-evaporating carrier.

There are many other advantages associated with using waterless non-evaporating spray liquids. I do hope that some of these aspects will be covered in other papers read in this session. I will, therefore, mention only a few without going into details:

1. Due to non-evaporation during the flight of the droplet from the machine to the target a very much better overlapping of spray paths is achieved. The droplets deposited at different times are liable to encounter varying micro climatic conditions and are, therefore, evening out any deficiencies of spray pattern.
2. Insects over thousands of years have developed a defence against water whilst oil as a carrier very often ensures a rapid penetration of the insecticide to the nerve centre of the insect, i.e. the real target at which we are aiming.
3. Many target areas (pea leaves, etc.) are hydrophobic whilst oil will adhere perfectly.
4. Small oil based droplets offer great resistance to removal from the foliage by rain or dew.

I would like to say a few words about rotary atomisers. They are simple devices as simple as an ordinary water tap. Each droplet falling off a water tap is of the same diameter as the next; their size is determined by gravity overcoming the surface tension in the liquid. On a rotating disc the centrifugal forces are enormous and the liquid arriving at the edge, influenced by many thousand times G, is thrown off in relatively even sized, small droplets. With the same disc diameter, specific gravity, and surface tension of the liquid, the droplet size is only determined in an inverse proportion to the angular velocity of the disc. Therefore, a rotary atomiser lends itself extremely well for producing a desired droplet spectrum both with regard to the evenness of droplets and the choice of their size.

Droplet sizes are very often expressed either in number median diameter or volume median diameter. Both of these measurements do not necessarily give the right impression of the efficiency of the spray pattern. The real importance lies in the relationship between number median diameter and volume median diameter of the spray pattern. If this relationship is 1:1 we have completely even sized droplets; the nearer it comes to this relationship of 1:1 the more efficient the spray pattern will be.

The total amount of spray liquid needed to give an efficient coverage of the target area can physically be determined by the size of droplets produced by a machine, the total of the collecting surface to be protected and the density of coverage required to control the pest encountered.

A considerable amount of work, however, still needs to be done to determine the amount of active ingredient necessary to provide lethal doses to the pest we are fighting, without contaminating the environment more than is absolutely essential for efficient plant protection.

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THE ULTRA LOW VOLUME GROUND APPLICATION OF DILUTE OIL BASED FORMULATIONS

E. D. Heath
Turbair Limited, Maidenhead, Berkshire.

Summary For the purposes of this report ultra low volume spraying refers to the application from the ground of oil-based formulations at 2 to 8 pints per acre. Application was through rotary atomisers and the formulations contained from 1 to 5% of active ingredient.

Most published work on ULV relates to "concentrate" spraying, i.e. the application of a formulation containing 25 to 100% of active ingredient. The object of concentrate spraying is to apply approximately the same amount of active ingredient per acre as with conventional spraying. The trials reported here show that with improved application techniques it is possible to reduce the usual dose rate by 20 to 95% depending upon the activity of the pesticide.

It is widely held that ULV spraying techniques are unsuited to the application of contact fungicides. This report details trials on three economic crop diseases using three common fungicides, each of which gave good disease control when applied by ULV techniques. An insecticide trial is also reported.

INTRODUCTION

The definition of Ultra Low Volume varies from country to country. For example in the U.S.A. it is defined as "less than 4 pints per acre undiluted" whereas in France more recently it has been defined as merely "application at less than 5 litres/hectare".

During the 1950's the term "concentrate spraying" was widely used and was generally synonymous with "ULV". Most of the data so far published on ULV spraying in fact relates to the application - usually from the air - of concentrated pesticides consisting largely of active ingredient with a small amount of diluent to give the liquid satisfactory physical properties.

The use of oils as the diluent or carrier is now quite common for the ULV application of pesticides and various types of aerial, tractor mounted and portable equipment are available, specifically designed and developed for this purpose. However, the author wishes to distinguish between the ULV application of 'concentrate' and 'dilute' materials and the line is drawn at the 10% level of active ingredient. Thus the ULV application of a formulation containing more than 10% active ingredient is regarded as concentrate spraying.

It is believed that only about five manufacturing companies at present have a commercial interest in the ULV application of "dilute" oil-based pesticides for crop protection but it is known that many more are engaged in research and development in this field and very much wider use of the techniques is foreseen in the near future because it appears likely that legislation may prohibit the use of pesticides at rates higher than those necessary for satisfactory pest control.

This report is concerned solely with the application from the ground of oil-based formulations containing from 1 to 5% of active ingredient applied at 2 to 8 pints per acre (2.8 to 11.2 litres/ha.), conventional water-based formulations of course being used as standards for comparison. All the oil-based pesticides used were formulated to conform as closely as possible to a standard viscosity and surface tension as a means of achieving a constant flow rate and droplet size.

The ULV spray equipment used was a commercially available type feeding liquid by gravity through a metering orifice to a constant speed rotary atomiser with fan-assisted dispersal of the atomised liquid. The standard water formulations were applied by means of hydraulic jet equipment.

TRIAL 1

Crop:	Majestic potatoes
Disease:	Blight (Phytophthora infestans)
Location:	Kingsley, Hampshire
Plot size:	½ acre
Replication:	Three times
Treatment dates:	19 July, 28 July, 12 August 1967
Assessment dates:	Disease - 21 August 1967 Yield - 28 October 1967
Method of assessment:	Disease - % leaves showing one or more lesions. 300 leaves/plot. Yield - 2 rows, each 240 yds long, harvested from each plot.

Table 1.

Comparison of ULV copper with standard fungicides for control of Potato Blight

Treatment	Blight assessment (% leaves infected)	Yield in tons per acre of clean ware
	(means of three replications)	
Mancozeb @ 19.2 oz in 20 gal/ac	12.2	15.4
Fentin acetate @ 12 oz plus maneb @ 4 oz in 20 gal/ac	13.3	13.4
Isophthalonitrile @ 20 oz in 20 gal/ac	6.1	17.2
Copper (as oxychloride) @ 1.4 oz in 2.8 pints/ac	2.9	16.6
Untreated	68.4	9.9
S.D. @ 5%	3.4	2.9

TRIAL 2

Crop: Apples
Location: Surrey
Disease: Scab (Venturia inaequalis)
Plot size: 4 trees
Replication: Twice
Treatment dates: 9 applications, bud-burst to mid-July at 7 to 10 day intervals
Method of assessment: N.A.A.S. standard method

Table 2.

Comparison of LV and ULV sprays for the control of Apple Scab

Treatment	Variety (% Scab infection)				
	L. Superb	Cox	Worcester*	Bramley	Newton*
Captan @ 2.5 lb a.i. in 30 gal/ac LV	0.1	0.1	0.1	0.5	0.01
Maneb @ 6 oz a.i. in 6½ pints/ac ULV	0.1	1.0	0.1	0.5	0.1
'Daconil' @ 3.25 oz in 6½ pints/ac ULV	0.01	0.1	0.01	0.01	0.1
Untreated	5.0	25.0	10.0	25.0	10.0

* Leaf assessment due to insufficient fruit

TRIAL 3

Crop: Roses
Disease: Powdery mildew (Sphaerotheca pannosa)
Location: College of Agriculture, Surrey
Plot size: 60 bushes
Replication: 40 varieties
Treatment dates: 10.8.67 21.8.67 8.9.67
Assessment dates: 24.8.67 18.9.67
Method of assessment: 10 units per variety scored for disease (0=nil 5=severe) Max 50

Table 3 (part 1)

Comparison of HV and ULV sprays for the control of Rose Powdery Mildew

Treatment	Score for disease on 24.8.67 (10 shoots per variety)			Mean
	Uncle Walter	Christian Dior	Mr. Lincoln	
Dinocap @ 2 oz a.i. in 100 gal HV	8	17	9	11.3
Dinocap @ 0.7 oz a.i. in 3.5 pints/ac ULV	4	6	5	5.0
Copper @ 1.75 oz a.i. in 3.5 pints/ac ULV	9	14	14	12.3
Untreated	16	20	24	20.0

Table 3 (part 2)

Treatment	Score for disease on 18.9.67 (10 peduncles per variety)			Mean
	Miss France	Message	Hawaii	
Dinocap @ 2 oz a.i. in 100 gal HV	17	22	13	17.3
Dinocap @ 0.7 oz a.i. in 3.5 pints/ac ULV	6	4	5	5.0
Copper @ 1.75 oz a.i. in 3.5 pints/ac ULV	17	16	14	15.6
Untreated	25	34	25	28.0

TRIAL 4

Crop: Roses
Pest: Aphids - various
Location: College of Agriculture, Surrey
Plot size: 90 bushes
Replication: Three times
Treatment date: 19.6.67
Assessment dates: 20.6.67 26.6.67 3.7.67
Method of assessment: 2 shoots on each of 10 bushes scored
0 = no aphids 3 = many

Table 4

Comparison of LV and ULV application of a Systemic Insecticide for Aphid Control

Treatment	Aphid score on 20 shoots (mean of 3 reps) pre-treatment	after 1 day	after 7 days	after 14 days
Dimethoate @ 5 oz a.i. in 20 gal/ac LV	15.3	0.0	1.3	8.3
Dimethoate @ 0.56 oz a.i. in 2.8 pints/ac ULV	24.0	0.0	0.0	0.6
Untreated	24.3	25.3	24.3	31.0

DISCUSSION

The fungicide trials reported here show that with ULV application methods reduced dosage can give at least as good control of diseases as normal dosage applied by normal methods.

"Redistribution", or the relocation of toxicant on the target by rainfall, is sometimes considered to play an important part in fungicidal effectiveness. It can only be important however if the original distribution of toxicant is inadequate. Further, the ability of a deposit to be redistributed implies also the ability to be completely removed by rain. Very little redistribution takes place from small oil droplets but the high degree of rainfastness and resistance to weathering together with the much better distribution and retention of spray over the target more than compensates for this.

Quantitative analysis of spray residues has indicated that a very much greater proportion of applied pesticide is retained on foliage after ULV application than after normal application. Application of reduced dosages by ULV techniques therefore does not necessarily mean lower deposits of pesticide per unit area of target surface.

Trial 4 comparing LV and ULV application of a systemic aphicide shows that not only does reduced dosage result in an equally quick kill of aphids as normal dosage but that in this particular instance persistence, as measured by reinfestation, was slightly longer. As persistence of a systemic insecticide is largely dependent on initial "dose rate" the implication is that a greater amount of toxicant was deposited on the target by ULV application than by LV application, in spite of the considerably reduced "dose rate". There is therefore a need to distinguish between "applied dose rate" and "target dose rate" and a need for greater emphasis on the latter.

Acknowledgements

The author wishes to thank the Principal and Staff of the Surrey College of Agriculture, Mr. C. Howard Jones of Kingsley Fruit Farms Ltd. and Marshall Brothers, Malthouse Farm, Bordon for the kind provision of trials facilities.

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ULTRA-LOW VOLUME SPRAY APPLICATION TO FRUIT CROPS

H. R. Mapother and N. G. Morgan
Long Ashton Research Station

Summary A preliminary trial of ULV spraying of apples with undiluted malathion and malathion in oil using a hand-held fan-assisted spinning disc sprayer and a large experimental hydraulically-driven mist-blower has demonstrated the feasability of this spraying technique. Virtually complete control of apple aphids and sucker was obtained by the application of approximately 2 gal/acre, but poor control was obtained on large heavily-infested trees.

INTRODUCTION

Ultra-low volume (ULV) spraying can be defined as crop protection operations in which the total volume of liquid applied amounts to a few pints/acre, in contrast to the use of large volumes, tens or hundreds of gallons/acre, in conventional spraying. The crop protection chemical is usually either undiluted or formulated in oil and ULV applications have so far been made mainly in aircraft spraying where the small volumes and the less volatile liquids offer obvious operational advantages.

The recent introduction of the hand-held spinning disc sprayer, employing a droplet-generating and dispersing system similar to that used on some aircraft, has revived interest in the ULV technique for ground application, as also has the use of modified motorised knapsack sprayers.

The present paper reports preliminary trials of ULV spraying in fruit crops with a large experimental tractor-mounted mist-blower and with a small proprietary hand-directed spinning-disc sprayer.

MATERIALS AND METHODS

A trial of ULV was carried out on apple in 1969 for the control of Apple-grass aphid *Rhopalosiphum insertum*, and apple sucker, *Psylla mali*, at the green cluster-pink bud stage. The materials were:-

95 % technical malathion, undiluted	applied once by the ULV technique. (2 methods)	
5 % " " in oil		
0.5% " " " "		
0.125% malathion emulsion in water	applied once by conventional large volume spraying. 250 gal/acre.	

The two methods of ULV spraying were:-

(a) the spinning disc sprayer, hand-directed at each quarter of each tree for 7.5 seconds (= 30 ml/tree or approximately 2½ gal/acre);

(b) a hydraulically-driven mist-blower delivering 30,000 c.f.m., specially fitted for ULV spraying to apply 2 gal/acre at 2½ m.p.h. with the 38 in. dia. axial flow fan directed at 50° to one side of each tree row at each pass.

The trees used for the trial were 17-year old Cox's Orange Pippin and Cheddar Cross planted at 15 ft x 9 ft. The Cox's were 8 - 10 ft high, and the much denser Cheddar Cross 10 - 15 ft high.

Four- and five-tree plots of each variety were used for the hand-directed applications of each material. The mist-blower applications were done on 24-tree plots of Cheddar Cross and were repeated on 48-tree plots of Cox's Orange Pippin.

Shoots on which almost all the blossom was infested with aphid and sucker were labelled on each plot before spraying. Spraying dates were:-

Spinning disc sprayer : 22 April (late green cluster)
Hydraulically driven mist-blower : 5 May (early pink bud)

The effects of the treatments on insect control were determined by recording the % number of flower trusses remaining infested a few days after spraying.

Levels of malathion deposited on the targets by the different treatments were determined by gas chromatography.

RESULTS

Effects of the treatments on insect control are shown in Table 1.

Infestations by both aphid and sucker were heavier on Cheddar Cross than on Cox. On the latter variety, all the ULV treatments with 95% and 5% malathion gave virtually complete control, but both spinning disc sprayer and mist-blower applications of 0.5% malathion failed to do so, although some dead aphids were found with live ones on the blossom trusses. On the larger and more heavily infested Cheddar Cross the insect control was less complete than on Cox.

Levels of malathion deposits are expressed in Table 2 as ug/cm^2 of rosette leaves and as ug/blossom cluster.

As expected, more malathion was found on the trusses sprayed with 95% material than the 5%, although not in proportion to the concentration. The amounts of 5% malathion deposited by the two methods were of the same order but the hydraulic blower deposited more 95% malathion than did the disc sprayer.

Table 1
Insect control with ULV spraying

Method and Malathion concentration	Variety	% clusters remaining infested with Aphid	Sucker
Unsprayed	Cox's Orange Pippin	22.0	21.0
	Cheddar Cross	56.0	41.6
95% with mist-blower	Cox's Orange Pippin	0.2	0.6
	Cheddar Cross	6.6	17.5
95% with disc sprayer	Cox's Orange Pippin	0.0	0.0
	Cheddar Cross	22.2	15.0
5% with mist-blower	Cox's Orange Pippin	1.2	0.4
	Cheddar Cross	11.0	22.6
5% with disc sprayer	Cox's Orange Pippin	0.0	0.0
	Cheddar Cross	10.0	10.0
Unsprayed	Cox's Orange Pippin	56.0	-
0.5% with mist-blower	Cox's Orange Pippin	42.5	-
0.5% with disc sprayer	Cox's Orange Pippin	9.5	-
0.125% with high volume automatic sprayer	Cox's Orange Pippin	1.1	-

Table 2

Malathion deposits with ULV spraying

Method and Malathion concentration	Variety	Sample site*	Malathion deposits/blossom truss ug/cm^2 rosette leaves	ug/blossom cluster
95% with mist-blower	Cox's Orange Pippin	Top	10.2	192.0
		Middle	3.9	146.2
		Base	4.8	545.2
95% with disc sprayer	Cox's Orange Pippin	Top	5.1	129.5
		Middle	5.2	110.0
		Base	2.8	26.4
5% with mist-blower	Cox's Orange Pippin	Top	0.5	8.1
		Middle	0.8	32.9
		Base	0.7	23.5
5% with disc sprayer	Cox's Orange Pippin	Top	0.8	16.3
		Middle	1.0	16.7
		Base	0.6	8.6

* Approximate height : Top 8 feet
Middle 5 feet
Base below 4 feet

DISCUSSION

The preliminary trial has demonstrated the feasability of insect control in fruit crops by ULV application of malathion on a practical scale, although insect control was poor on heavily-infested large trees.

The time of spraying an acre of fruit with the tractor-mounted mist-blower was 13 minutes with one side spraying and 6½ minutes double side spraying, the time for spraying the same area with the hand-held disc sprayer would be at least 2¾ hours.

The trial has indicated that at these low rates of application initial cover of the target is incomplete and that control depends on the mode of action of the spray deposits of concentrated material. Although this effect is apparent when the malathion concentration was increased from 0.5% to 5% in oil, no increase in control was obtained by increasing the concentration to 95%.

Acknowledgements

Grateful thanks are due to Miss P. Herrington, Mr. B. Cooke for valued assistance with biological and chemical assessments, and to Mr. K. Jones for assistance with the experimental spraying apparatus.

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THE EFFECT OF METEOROLOGICAL CONDITIONS ON THE SPRAY DISTRIBUTION OF A COARSE AEROSOL

H. H. Coutts*
Tropical Pesticides Research Institute, Arusha, Tanzania

Summary The use of ultra-low volume (ULV) spraying has given very variable results both in recovery and biological effectiveness. Many factors interact to produce a poor application, but meteorological conditions become more important as the volume median diameter (VMD) of the spray decreases.

Most ground machines designed for ULV applications atomise the liquid, by air blast or rotary discs and cages, to give a drop spectrum with a VMD of between 80 and 120 μm. Such a sprayer, using a rotary disc atomiser and producing droplets with a VMD of 80 μm, was used to measure recovery under different meteorological conditions, over short grass and in coffee trees.

There was a significant difference in droplet density and distribution between applications carried out under temperature inversions and those with a superadiabatic lapse rate.

INTRODUCTION

Meteorological conditions have an increasing effect on the recovery and distribution of pesticides as the volume median diameter of the spray decreases. Ultra-low volume applications use sprays with a lower VMD than in conventional applications to obtain a greater penetration within a crop and a more even distribution of the pesticide. Many ULV applications by aircraft use a spray with a VMD above 120 μm, as this is about the lower limit of the equipment used; but ground machines specifically designed for ULV applications atomise the liquid to give a VMD from 80-120 μm, by the use of rotary discs or by emission into an air blast. The effect of stable and turbulent conditions on the distribution of a coarse aerosol with a VMD of 80 μm, produced by a small rotary disc sprayer, was investigated. Assessments were carried out over a short grass surface and in coffee trees.

Description of Sprayer

The sprayer head consisted of two plastic discs, 9 cm in diameter and 1 mm apart, rotated at 7,000 rpm by a direct drive from a 12 volt electric motor. The pesticide was supplied in 1 litre capacity plastic bottles which were screwed into the spraying head. The head was fixed to a metal tube, 1.25 m in length, which acted as a handle and also carried the flex from the electric motor to the 12 volt dry cell battery. The battery was carried in a sling over the operator's shoulder. To commence spraying, the handle was rotated through 180°C to bring the bottle above the spraying head; the pesticide was then gravity fed between the rotating discs.

Assessment layout

Trials were carried out over a short grass surface and in coffee trees, under two meteorological conditions. The plan of the layout is shown in Fig. 1. Target posts, 2 m high, were placed in line downwind; five between coffee trees, and five in the open, at 2.7 m spacings, this being the distance apart of the coffee trees. Each target post had four arms, 15 cm long, at right angles to the post, fixed at 0.5, 1.0, 1.5 and 2.0 m above the ground. Horizontal and vertical targets of glossy paper were fixed to these arms, the vertical targets, 3 x 6 cm, faced upwind. The

* Now at Shell Research Limited,
Woodstock Agricultural Research Centre,
Sittingbourne, Kent.

horizontal targets, 12 x 3 cm, were folded in half to give a 6 x 3 cm glossy surface on the upper and lower sides, and fitted into a slot at the end of the arm. Similarly folded targets were stapled to coffee leaves, to sample the deposits representative of the upper and lower surfaces of the coffee leaves. Targets in the coffee trees were placed at the same heights as the arms on the target posts, on outer leaves and 20 cm from the main stem, at the four quadrants, in line and at right angles to the wind direction. Targets were stapled in five trees in line downwind and adjacent to the target posts. Targets were also placed on the ground at the base of and between posts.

Meteorological Instrumentation

Meteorological measurements were made using a 2 m mast with shielded thermistor probes at 1 and 2 m. Temperature measurement was made by connecting the probes to one arm of a Wheatstone bridge incorporated in a Tele-Thermometer made by the YS Instrument Co. Inc. The instrument used has several overlapping narrow ranges of temperature scales to obtain a greater accuracy in reading, and also to produce a more linear output voltage for recording. Wind speed was measured at 1.5 m, with a Casella sensitive anemometer of the cup type. The mast was placed in the open, upwind of the assessment layout during spraying, and was moved into the coffee immediately after spraying. The meteorological data in the open and in the coffee trees are given in Table 1.

Spraying procedure

Heavy aromatic naphtha (HAN) dyed with 1% w/v Waxoline Red was sprayed at a mean emission rate of 60 ml/min. Two trials were carried out in wind speed of 1.0 m/sec in the open, but with different vertical temperature profiles. The first, under turbulent conditions, with the temperature profile greater than the adiabatic lapse rate, and the second under an inversion. The operator moved across wind between the coffee trees and out into the open, past the two assessment lines, at a speed of 0.9 m/sec.

Preliminary trials indicated that the most effective spraying height under turbulent conditions was between 1 and 1.5; above this height much of the spray cloud passed over the target array. However, under a temperature inversion it was necessary to spray at 2 m, the level of the top of the coffee trees; below this height the maximum deposit occurred before the first target post had been reached.

After spraying, the glossy paper targets were allowed to dry, and removed from the posts and trees. When the droplet density on the target was adequate, the droplets were sized and counted, and the drop spectrum obtained.

RESULTS

The mean drop spectrum for the vertical targets is given in Fig 2. The VMD was 80 μm with a 50% range from 60 to 100 μm. Under superadiabatic lapse conditions the VMD varied from 60 μm at 2 m to 100 μm at 0.5 m on the first target post downwind, and between 60-70 μm at all heights by the third post. As the droplet range was narrow the data have been presented as droplet numbers per sq. cm and isopleths of droplet numbers have been drawn. Figs 3 (a) and (b) give the pattern from the vertical and horizontal targets in superadiabatic conditions, over the grass and within the coffee. Fig 4 gives similar details under a temperature inversion for the upper surface of the horizontal targets. There was little or no deposit on the vertical targets or the underside of horizontal targets in inversion conditions. Fig 5 demonstrates the difference in distribution within the first coffee tree downwind. The maximum droplet density on the second tree downwind was less than 25 drops/cm^2 in both trials.

DISCUSSION

The axis of the 'ridge' in the isopleths gives an indication of the direction of movement of the median sized droplets, and thus of the air movement. Under superadiabatic conditions there was a general upwind movement out of the target array and the coffee trees, with a loss of the spray out of the target area. The dotted lines in Fig 4 indicate the plane above which the deposit on the underside of the targets was greater than on the upper side.

Under inversion conditions there was little or no deposit on vertical targets and the direction of the droplets was downward with the maximum density on the ground displaced to between 4 and 6 metres in the open as compared with 2 to 4 metres in the coffee due to the higher wind speed in the open.

Penetration into the coffee trees was limited as shown in Fig 5. In superadiabatic conditions the deposit was mainly on the upwind side between 0.75 and 1.5 m. Under a temperature inversion, droplet density was greatest on the upper leaf surfaces above 1 m. Movement of the sprayer up and down, whilst moving along the spray line, would improve the vertical spread but probably not the penetration to the lee side of the tree. However, the droplet distribution over the grass surface indicated that this sprayer could be used to give a satisfactory deposit on shorter and less dense crops, with the spraying head close to the top of the crop under superadiabatic lapse conditions and as high as possible under a temperature inversion.

Table 1

Meteorological Data

Trial	Time	Position	Ambient Temp.°C	Temp. Diff. °C 2m - 1m	Wind speed m/sec
1	11.30	Open	22.0	- 0.8	1.0
		Coffee	20.0	- 0.6	0.8
II	18.30	Open	16.4	+ 0.2	1.0
		Coffee	16.0	+ 0.2	0.5

When a dry atmosphere is in a state of neutral equilibrium the temperature decreases with height 1°C per 100 m and this is known as the adiabatic lapse rate. A more rapid decrease of temperature with height, i.e. superadiabatic, is an unstable condition and convection takes place. In stable conditions the temperature lapse rate is less than the adiabatic and an inversion occurs when temperature increases with height. Under these conditions the upward movement of air is inhibited.

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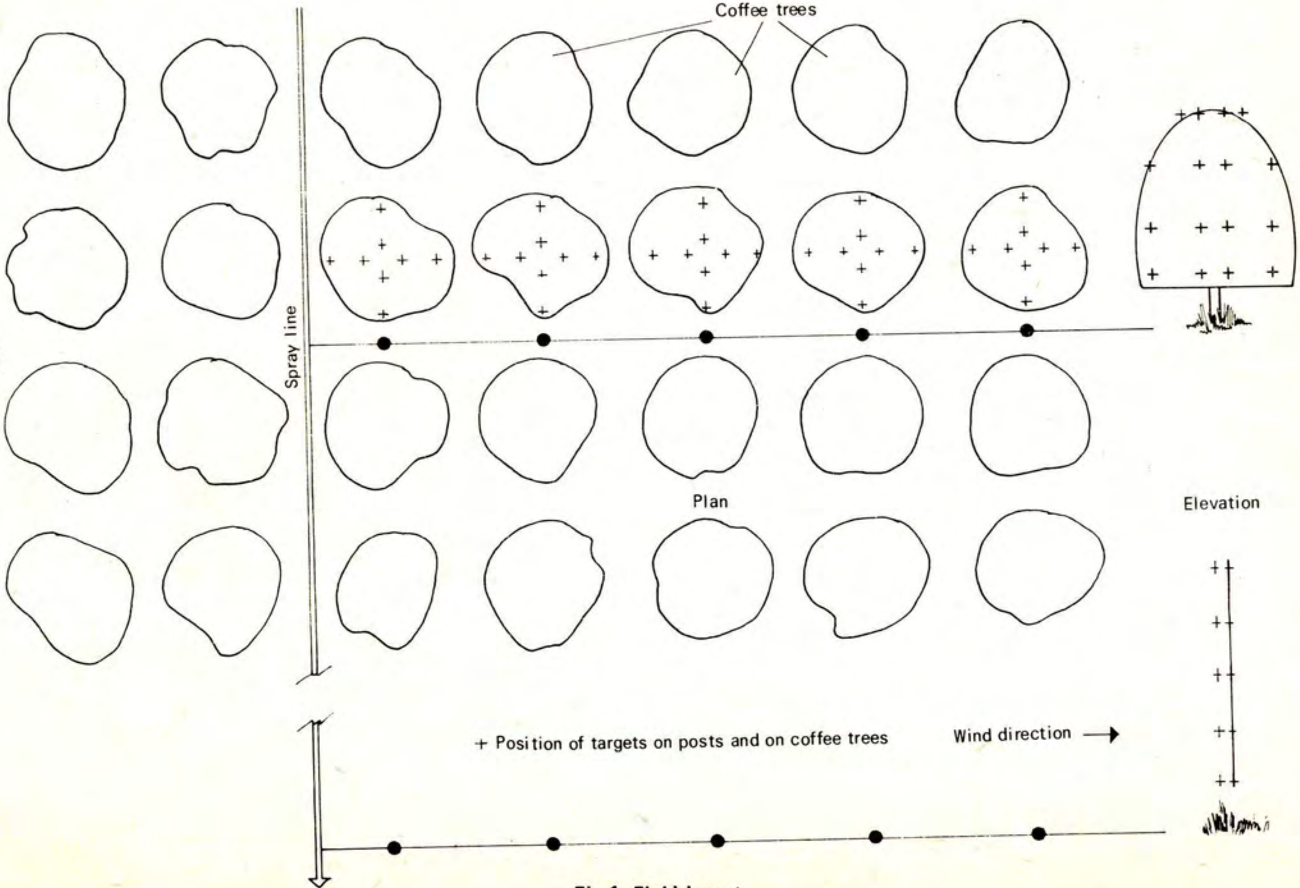

Fig 1 Field layout

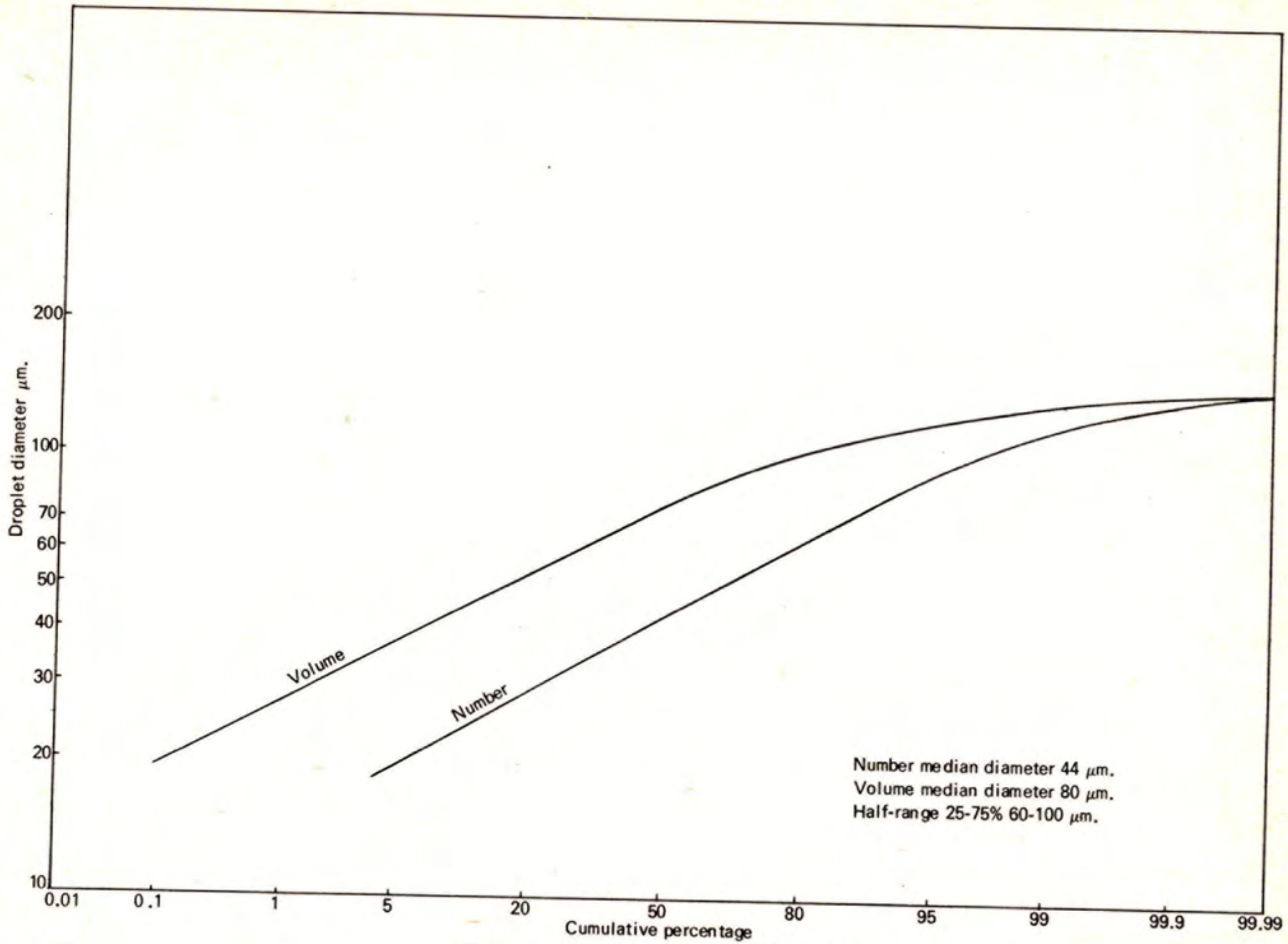

Fig 2 Droplet spectrum from rotary atomiser

(Mean of all vertical targets)

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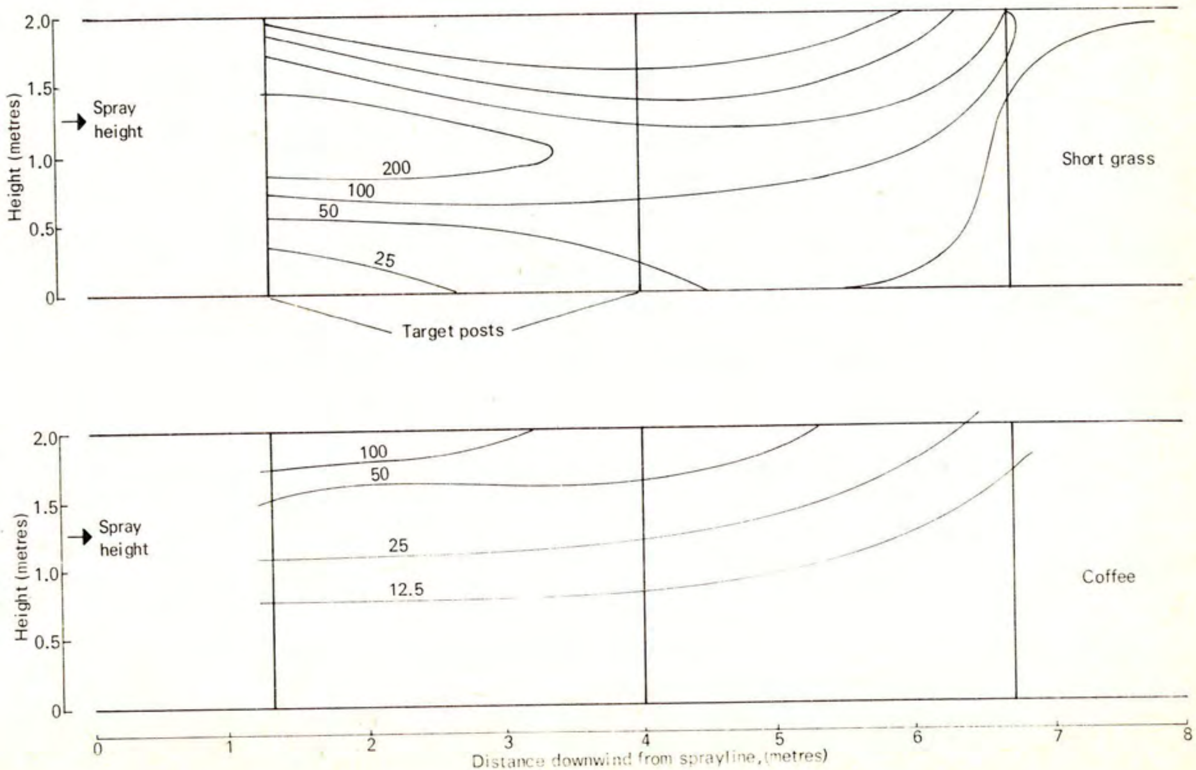

Fig 3 (a) Isopleths of droplet no/cm² on vertical targets- Superadiabatic lapse rate

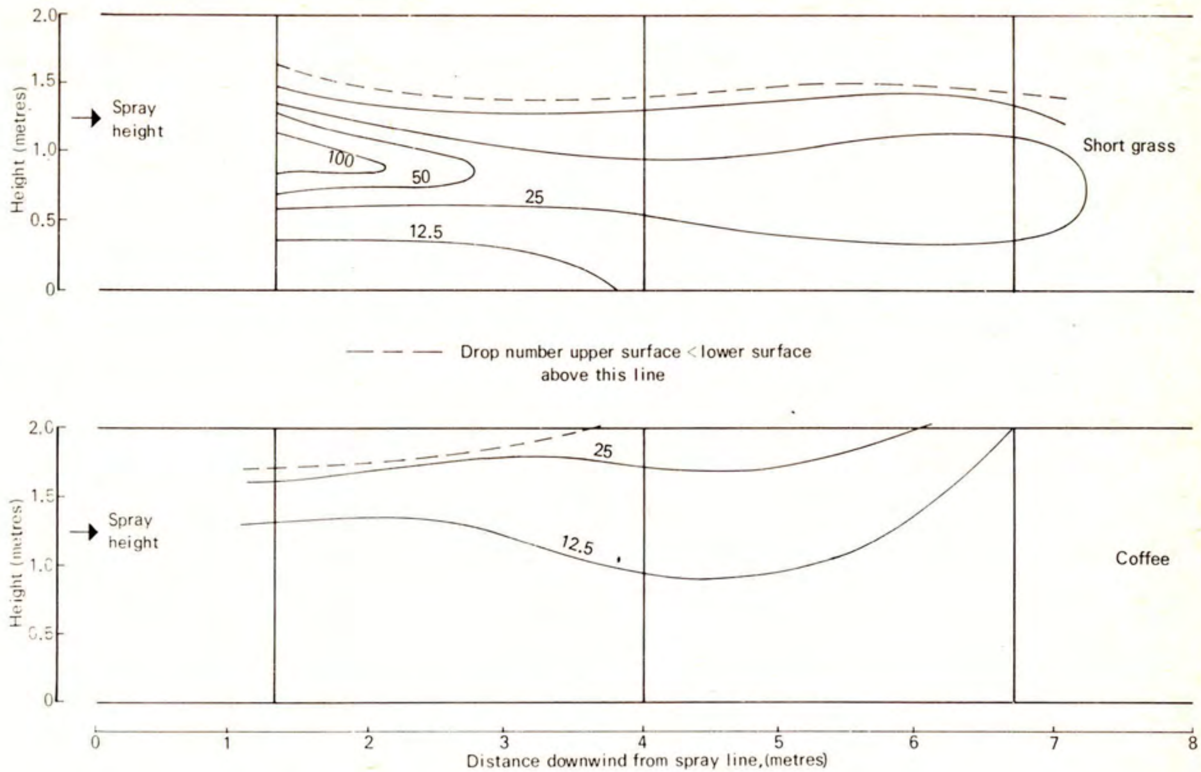

Fig 3(b) Isopleths of droplet no/cm^2 on upper surfaces horizontal targets - Superadiabatic lapse rate

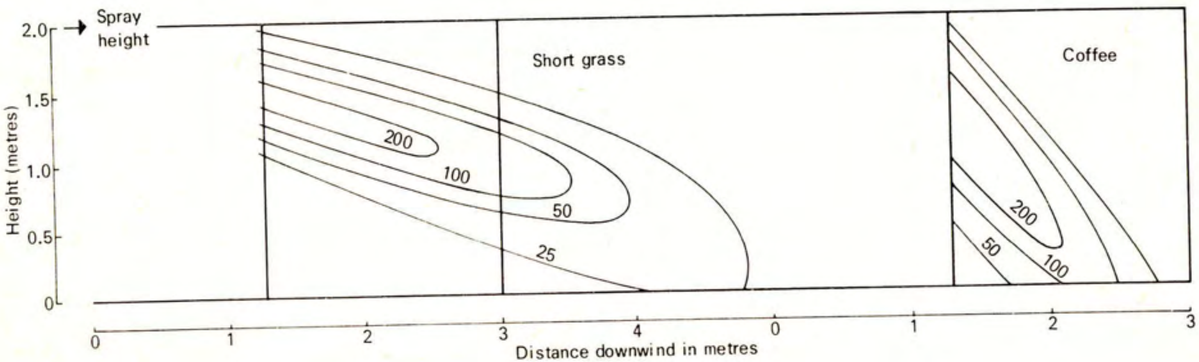

Fig 4 Isopleths of droplet no/cm^2 on horizontal targets - Temp. inversion

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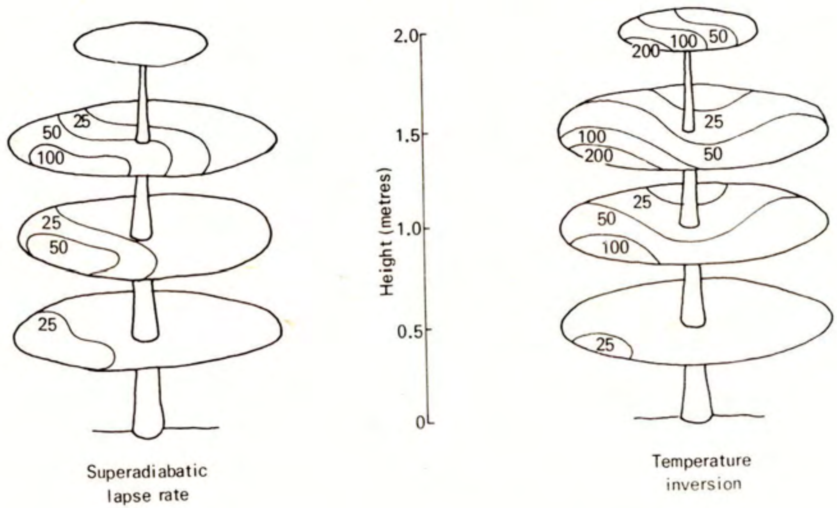

Fig 5 Droplet distribution within the first coffee tree downwind

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CONTROL OF SOME PESTS OF CITRUS, DATE PALM, WHEAT AND COTTON WITH ULV SPRAYS

C.D. Lindley
Cyanamid International Corporation, Zurich, Switzerland

Summary Data from field experiments in the Mid-East and Africa with ultra-low-volume (ULV) applications of malathion and fenitrothion are reviewed. Aerial ULV bait sprays of malathion/protein hydrolysate bait have given very effective control of Mediterranean fruit fly (*Ceratitis capitata*) on citrus and of olive fly (*Dacus oleae*) at a total volume of 1.0 to 1.5 l/h. Both application and insecticide costs are reduced compared to conventional treatment. ULV malathion/bait sprays have been used exclusively in Israel for Medfly control during the 1968 and 1969 seasons. In Iraq and Iran ULV applications of 1.8 kg a.i./h (1.5 l/h MALATHION* ULV Concentrate) have controlled "Dubas" bug (*Ommatissus binotatus*) on date palm. Sunn pest (*Eurygaster integriceps*) on wheat was not controlled in Iran by ULV application of malathion, but ULV fenitrothion at 1.0 to 1.4 kg a.i./h (0.8 to 1.1 l/h ACCOTHION* ULV Concentrate insecticide) gave effective control of adults and nymphs. On cotton in Turkey, Iran, Sudan and Kenya ULV applications of malathion have given effective control of aphids (*Aphis* spp.), thrips (*Thrips* spp.), whitefly (*Bemisia tabaci*), jassids (*Empoasca lybica*), stainers (*Dysdercus* spp.) and Old World bollworm (*Heliothis armigera*), but not of mites (*Tetranychus* spp.). Dosage rates ranges from 1.1 to 2.4 kg a.i./h.

INTRODUCTION

Considerable interest in the technique of ultra-low-volume (ULV) spraying of agricultural and horticultural crops has arisen in the last few years. Many scientific papers have been published during this period, particularly based on work carried ouf in North America.

Important developments in ULV spraying have taken place in the Mid-East and Africa in recent years, and some application on citrus, olives, date palm, wheat and cotton for control of certain specific pests are reviewed in this paper.

CITRUS

The use of aerially or ground applied dilute sprays of malathion formulations (w.p. or e.c.) with protein hydrolysate bait became a standard treatment for control of the Mditerranean fruit fly (*Ceratitis capitata*) during the 1950's. Steiner and his colleagues pioneered this bait spraying technique in Hawaii with sprays applied when the number of adults, found in attractant traps, reached the economic threshold.

The first use of ULV sprays for Mediterranean fruit fly control was reported from Texas in 1966 (Stephenson and McClung, 1966). An eradication campaign was carried out following the discovery of adult *C. capitata* in the Rio Grande Valley. Weekly applications of malathion ULV bait sprays were made on 5200 h

*Trademark of American Cyanamid Company

at a total volume of 0.87 l/h. These bait sprays were made by mixing one part MALATHION ULV Concentrate with four parts protein hydrolysate bait. Eradication was declared complete after 16 applications.

Bioassay tests, using Mexican fruit fly (Anastrepha ludens) as test insect showed that foliar deposits of a single application of malathion ULV bait spray gave complete mortality of adults for 9 days (Hart et al, 1967).

In the Mediterranean area the first trials with this new ULV bait spraying technique were carried out in 1966 in Israel for Medfly control and in Greece for olive fly control.

In Israel ULV bait sprays consisting of one part malathion and three parts protein hydrolysate bait were aerially applied using four nozzles with D8 discs and core No. 45 (D8/45) at a dosage of 1 l/h for control of medfly on citrus. Swath width was 40 to 50 m. Sprays were timed according to data from the adult medfly traps. Fruit from 250 h sprayed in 1966 during the whole season and from 4000 h of Valencia oranges sprayed at the end of the season was completely free of medfly infestation (Cohen and Cohen, 1967). Approximately one third of the total Israel citrus acreage was ULV bait sprayed in 1967 and the whole area in 1968 and 1969. Results based on adult trapping data and % infested fruit were very satisfactory. A considerable saving has resulted from this ULV bait spraying in Israel from reduced application cost as well as reduced insecticide cost. The insecticide rate, which was formerly 0.5 kg a.i./h with conventional malathion e.c., has been reduced to 0.3 kg a.i./h with the ULV bait technique.

Following these trials, an experiment was conducted in Tunisia in 1967 (Yana and Stancic, 1967). Table 1 gives details of the four treatments which were applied to 50-h plots and the application equipment used.

Table 1

Medfly Control on Citrus - Tunisia 1967

Treatment no. Insecticide	1* Malathion	2* Malathion	3* Trichlorfon	4* Dimethoate
Rate kg a.i./h	0.35	0.59	1.2	0.3
Rate bait l/h	1.2	0	0	0
Spray volume l/h	1.5	0.5	25	25
Application equipment (no.)	D8/45 nozzles (4)	Turbaero* (2)	D8/45 nozzles(42)	D8/45 nozzles(42)

*Spray dates Sept. 23, Oct. 7 and 25, Nov. 11

Two ULV treatments (malathion and malathion plus bait) were compared with conventional cover sprays of dimethoate and trichlorfon. Turbaero rotary atomizers, used for ULV malathion application, gave the desired small, uniform droplets, whilst D8/45 nozzles, used for ULV malathion plus bait, gave the required spectrum of large droplets.

Assessments, made by trapping adults, showed from 2 to 5/trap/day before the first treatment. Treatment 1 kept numbers below 0.5 during the season. Treatments 2, 3 and 4 were less effective, with up to 2 adults/trap being recorded 10 to 12 days after spraying, showing that shorter intervals between sprays were required.

*Trademark of Edward Bals (Sprayers) Ltd.

Additional trials and commercial usage of aerial ULV bait spraying with malathion for Mediterranean fruit fly control were made in Tunisia, Libya and Spain during 1968 and 1969. 20,000 h of table vines in the Alicante area of Spain were aerially treated in 1969 with malathion ULV bait sprays (1:4 ratio) at a volume of 1.5 to 2.0 l/h.

A ratio of one part MALATHION ULV Concentrate to three or four parts protein bait applied at between 1 and 1.5 l/h (0.3 to 0.35 kg malathion/h) seems optimal for control. Large droplets (200 to 300 μ) are recommended in contrast to the normal small ULV droplets (80 to 100 μ) because they remain attractive to the adults for up to two weeks.

The protein bait should be strained through a 32-mesh screen before mixing with the malathion to prevent nozzle blockage. Normal by-pass agitation should be used during application.

OLIVES

Less extensive trials have been carried out on olives.

Orphanidis and Pelekassis (1968) have published results of their ULV trials for olive fly (Dacus oleae) control in Greece. ULV bait sprays were aerially applied in 1966 using one part malathion ULV and seven parts bait at a rate of approximately 1 l/h (0.15 kg malathion/h). The control of D. oleae, based on data of knock-down of adult flies and counts of damaged fruits, was similar to that given by conventional dimethoate bait sprays applied at 10 l/h volume. Residues of malathion in olive oil were $<$ 0.15 ppm.

Following further large-scale trials in 1967 and 1968, malathion ULV bait sprays (1:7 ratio) are being commercially applied to several thousand hectares of olives in Greece during the 1969 season.

Trials are currently being carried out in Cyprus by the Plant Protection Department using a 1:4 ratio malathion bait spray at 1 l/h (0.24 kg malathion/h) applied by a Piper Pawnee equipped with four D8/45 nozzles. Preliminary results are encouraging.

DATE PALM

"Dubas" bug (Ommatissus binotatus) is a trophiduchid which damages date palms. It is a particularly serious pest in Iraq. The copious production of honey dew affects the leaves and fruit.

Because of the great height ot the trees, only aerial application is practical. Ministry of Agriculture aircraft carry out spraying each year in Iraq and Iran. In recent years sprays of dichlorvos e.c. have given excellent results (Anon, 1969).

ULV sprays of malathion were first tested in Iraq in October 1965, using 80015 nozzles on a Piper PA-18A; 1.77 kg a.i./h (1.5 l/h) gave good control. A second trial was carried out near Baghdad in May 1968, using 8001 nozzle tips and applying between 1.65 and 1.89 kg malathion/h. Pretreatment infestations of 25 Dubas bugs per leaf were reduced to nil when assessed 3 days after treatment (Haidari, 1968).

Evas and Salehi (1968a) carried out a trial in May 1968 in Mehrjan, Iran, on 18 hectares of severely infested date palms. ULV application of 1.3 l/h malathion using 80015 nozzles on a Piper PA-18A was made with a swath width of 20 to 25 m. Results from counts made on 15 leaves from 4 plots are shown in Table 2.

Table 2

Dubas bug Control on Date palm - Iran 1968

Treatment	Dosage (kg a.i./h)	Mean no. nymphs/leaf Days before/after spraying - 1	+ 3	+ 5
Malathion ULV Concentrate	1.53	197.2	1.9	0.5
Control	-	234.3	251.3	519.5

The population was reduced by 99.0% 3 days after treatment and by 99.7 % after 5 days.

These trials have demonstrated that ULV spraying of malathion at 1.3 to 1.5 l/h will effectively control Dubas bug. Further data are required on its effectiveness on other date palm pests, such as Batrachedra amydraula and mites.

WHEAT

The Sunn pest (Eurygaster integriceps) is a pentatomid which causes serious damage to wheat (and to a lesser extent barley and oats) in S.E.Europe and parts of Asia by feeding on the developing grains and on the stems. Adults hibernate during the winter and fly to the wheat fields in the spring. There is only one generation per year. Control measures are carried out by Plant Protection Departments in several countries since the infested area is too large for individual farmers to treat and because of the extensive yield losses. Aircraft application is most frequently used. The overwintering adults, after migrating and before breeding, have traditionally been controlled with DDT at up to 4 kg a.i./h and control of nymphs has been made with fenthion, trichlorphon and other insecticides.

ULV sprays were first tested in Iran in 1965 for Sunn pest control (Wilson, 1966). Malathion at 2.4 kg a.i./h (2.0 l/h) gave only a 5 % reduction of population.

In 1967 the Plant Pest and Disease Institute initiated trials with several ULV formulations. Fenitrothion gave very promising results at the relatively high dosage of 2.24 kg a.i./h (1.8 l ACCOTHION ULV Concentrate insecticide) on adults and nymphs. (Evas, 1968a).

In May 1968, a Piper PA-18A equipped with 8001 nozzles treated 20 h of wheat near Isfahan with 1.0 kg a.i./h fenitrothion (Evas and Salehi, 1968b). Counts of the population, which consisted of migrated adults, showed high mortality within 24 hours (Table 3).

Table 3

Sunn pest Control on Wheat - Iran 1968

Treatment	Dosage (kg a.i./h	No adults / 5 m2 .... days before/after spraying - 1	+ 1	+ 3	+ 5
Fenitrothion ULV CONCENTRATE	1.0	19.2	0	0	0
Control	-	19.3	22.3	24.0	17.7

Field trials carried out in Diyarbakir, Turkey, in 1969 with a ULV spray of fenitrothion at 1.37 kg a.i./h (1.1 l/h) gave promising control of 4th to 5th instar nymphs. Results will be published at a later date.

In conclusion, these preliminary trials have shown that the Sunn pest can be effectively controlled by ULV fenitrothion sprays. Further tests are required to clarify the dosage required for control of adults and of the different larval instars.

The ULV technique is ideally suited for control of this pest because of the extensive areas infested each spring and the necessity for timely application to prevent damage.

COTTON

ULV cotton trials were initiated in several Mid-East and African countries in 1965. Since the cotton pest complex differs from country to country, differs by locality within each country, and differs in degree from year to year, it was necessary to continue trials for several years. Results are reviewed by yountry.

Turkey

In 1965 a trial was carried out by Cyanamid entomologists with ULV application of malathion in the Adana area. A Piper PA-18A equipped with 80015 nozzles made two applications at 1.53 kg a.i./h (1.3 l/h) to 27 h of Delta Pine cotton for control of several pests.

Table 4

Cotton insect control with Malathion ULV applications in Turkey 1965

Assessment date	Bollworm Eggs	Larvae	% plants infested with Aphids	Mites	Thrips
July 20	12	12	24	8	4
21	APPLICATION				
22	16	4	30	8	0
23	12	3	9	18	0
24	12	6	6	24	0
26	22	2	18	40	0
27	APPLICATION				
28	28	3	3	45	0
29	22	4	4	42	0
30	36	0	0	32	0

Old World bollworm (Heliothis armigera) counts showed heavy egg laying during the trial, and larval numbers were reduced by the treatments. Aphids (Aphis spp.) and thrips (Thrips spp.) were controlled, but mite (Tetranychus spp.) numbers increased.

In 1967, one ULV application of malathion at 1.77 kg a.i./h gave effective control of Egyptian cotton leafworm (Spodoptera littoralis) 1st to 4th instar larvae. One application of malathion/DDT ULV Concentrate in 1969 at 3 l/h (1.0 kg malathion/ 1.0 kg DDT/h) was made with a Piper Pawnee C fitted with 8001 nozzles. The mean reduction of 1st to 6th instar Egyptian leafworm larvae was 76 % after two days and 83 % after seven days. Twelve days after application numbers of 1st and 2nd instar larvae remained low indicating comparatively long residual effectiveness. Further trials are planned for 1970.

Sudan

ULV applications of malathion gave effective control of jassid (Empoasca lybica) whitefly (Bemisia tabaci) and aphids at 1.12 kg a.i./h (1.0 l/h) in a trial in 1965 - 66. In 1966 - 67 four applications of 1.4 kg a.i./h gave effective control of jassid, whitefly and Old World bollworm, and there was no significant difference in cotton yield between malathion and DDT/dimethoate conventional sprays (Hussein, 1966 and 1967).

Iran

ULV trials were carried out in 1967 and 1968 in the Gorgon area (near Caspian Sea). The major pests are Old World bollworm, aphids and mites, with spiny bollworm infestation sometimes causing extensive damage close to harvest (as in 1966).

In 1967, three and, in 1968, four or five ULV applications of malathion at 2.1 kg a.i./h (1.75 l/h) were made using 8001 nozzles on a Piper PA-18A. A 50 % mean reduction of Old World bollworm larvae, based on counts 1,3, 7 and 15 days after application was obtained in 1967. However, the application intervals of 16 and 18 days were too long for optimum control (Evas, 1968b).

In 1968, the mean reduction was 80 % and 85 % in two trials based on counts 3, 7 and 10 days after application. The intervals between applications were shorter (11 to 16 days) than in 1967. ULV malathion was highly effective on 1st, 2nd and 3rd instar bollworm larvae, but less effective on 4th and 5th instar larvae. Persistence against newly hatched larvae was from 7 to 10 days. This highlights the need for correctly timed sprays.

Control of aphids was good, but the mite infestation necessitated conventional over-spraying with dimethoate.

Data on spiny bollworm (Earias insulana) control from the two year trials was limited due to a low infestation, and further trials were scheduled for 1969. (Evas and Salehi, 1968c).

Kenya

In a ground application trial carried out in 1969 near Meru, four ULV treatments applied with a Ulva* were compared with the standard knapsack sprayer-applied DDT/Carbaryl. Six sprays were applied at 10 day intervals, and counts of stainers (Dysdercus cardinalis and D. nigrofasciatus), Old World bollworm and spiny bollworm were made 3 and 9 days after each spray.

Populations of Old World and spiny bollworms averaged approximately 2 and 0.5 larvae respectively per 100 plants on all treatments in the post application counts. The percentage of flared squares was approximately 10 % during the trial. Data on the control of stainers are given in Table 5.

*Trademark of Micron Sprayers Ltd.

Table 5

Cotton stainer control - Kenya 1969

Treatment	Volume l/h	Dosage (kg a.i./h)	Mean no. stainers / 100 plants Pretreatment	Post 1st and 2nd sprays*
Malathion ULV/Concentrate	1.5	1.77	8.9	0
" " "	2.0	2.36	9.8	0.9
Malathion/DDT "	1.5	0.5/0.5	10.7	1.3
" " "	2.5	0.84/0.84	7.1	0.2
DDT/Carbaryl	80	1.12/1.12	7.1	1.6

*1st spray April 5; 2nd spray April 15. Counts April 8, 12, 18 and 24.

All the ULV treatments gave very effective control of stainers.

These preliminary results with a malathion/DDT ULV Concentrage warrant further experimentation on cotton pests.

Conclusions

ULV applications of malathion at 1.12 kg have given effective control of aphids, whiteflies and jassids, and of thrips at 1.53, and of stainers at 1.77 kg a.i./h. The dosage for Old World bollworm control was related to the interval between sprays with 1.53 kg a.i./h being effective in Turkey at 6-day intervals, but up to 2.1 kg was required in Iran where a 12- to 16-day interval was used. For optimum Old World bollworm control, applications should be timed according to egg and larval size so that the larvae are controlled before they reach the more damaging 4th to 5th instar size.

Mites were not controlled, and further data are required on the control of spiny bollworm and Egyptian cotton leafworm with ULV malathion, particularly in view of promising results in Spain and U.A.R. of the latter pest with 3.5 kg a.i./h.

DISCUSSION

As with any revolutionary new application technique, several problems were encountered in field experiments with ULV aerial application in the Mid-East.

Aircraft equipped with rotary atomisers (such as Micronair equipment) were not initially available in these countries and it was necessary to use 8001 or 80015 nozzles, which do not give a satisfactory droplet spectrum (Sayer, 1969). Therefore, insect control, particularly of cotton pests, was not optimal and blockage of nozzles interfered with desired application rates.

Experimental design was complicated because of the need for relatively large plots to avoid drift problems. This difficulty was only satisfactorily overcome in the Sudan where the cotton fields happen to be ideal for aerial spraying. Comparison with conventional standard treatments and evaluation of more than one or two ULV rates proved difficult. ULV application with ground equipment requires a high degree of skill and ideal weather conditions for best results.

The need for large plots is particularly important in experiments with bait sprays on citrus and olives because of the flight range of the trypetid flies. However, since large droplets were specified, there were not the same difficulties with ULV modifications to the aircraft spraying system as in the case of cotton.

With experience gained from many different countries since 1965, the ULV application concept is now gaining in acceptance in specific pest control situations. Medfly, olive fly, Dubas bug, Sunn pest and grasshoppers are particularly amenable to ULV application because of the extensive affected areas in many countries, and the overall efficiency dictated by shortage of aircraft and finance. The reduced costs of ULV application are particularly attractive to Governments that undertake control of these pests. ULV control of cotton pests will expand where fields are suitably laid out (as in the Sudan and N. Iran) and where formulations are available to control the whole pest complex. The latter point needs particularly close attention and further work in the future is planned with malathion/DDT ULV concentrate.

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RECENT DEVELOPMENTS IN ULV SPRAYING

R. J. V. Joyce
CIBA-Pilatus Aerial Spraying Co. Ltd., 8750 Glarus, Spielhof 3, Switzerland.

Summary Ultra-low-volume spraying is defined as the distribution of pesticides at rates of less than 5 litres per hectare and emphasis is placed on the importance of control of droplet size to secure the required distribution of pesticide on the target surface.

The relationship of ULV and concentrate spraying is discussed and is shown to be one between independent but connected concepts.

Recent work on spraying at ULV rates from the air in Java and from the ground in various countries using spinning disc atomizers is described.

INTRODUCTION

The concept of ultra low volume spraying, originally indicating the application to crops of very small volumes of spray (that is less than 5 litres per hectare), has become confounded with concentrate spraying as if the latter is an inevitable consequence of the former. This natural but unnecessary conjunction of two separate processes is now resulting in avoidable confusion and impeding the acceptance of a logical and analytical approach to pest control problems.

The conventional empirical approach to pesticide application in agriculture has been to seek to obtain an "even cover" of spray over a crop. Where the pest problems required a "good cover", high volume rates of application were recommended (100 - 1,000 litres/ha), or even very high volume rates (over 1,000 litres/ha), but some pests, particularly mobile ones, could be controlled by low volume rates (5 - 100 litres/ha). The biological activity of the pesticide is commonly determined in terms of "minimum lethal concentration" (LD 50 level, for example), and the minimum application rate of the pesticide (erroneously termed "dosage rate") could be established and maintained for any volume rate of application of spray.

This same process of thought has accompanied the development of ULV spraying so as to attain the goal of applying the pure chemical undiluted at the same "dosage" as was applied in low or high volume sprays.

The exacting nature of the task of distributing very small volumes of liquid over large surfaces has, however, demanded a deeper study of the objectives of pesticide application and the processes which are involved.

The objective of pesticide application is to secure pest control by conveying a pesticide to its site of action within the pest. As far as sprays are concerned, this involves the following processes:

- atomisation: breaking down to suitable dosage units.
- transmission: of these dosage units from the atomiser to a target surface.
- collection: of dosage units on the target surfaces.
- translocation: of dosage units from the target surface to the site of action.

These processes can be described in quantitative terms only when there is available precise knowledge of the biological activity of the pesticide to the pest concerned (in terms of lethal dosages - LD 50 for example) and of the nature of the target surface. Application at ULV rates then at once generates an analytical approach to pest control problems and directs attention to questions previously largely ignored, such as:

- How much pesticide must be collected by the target surface to provide the required biological result (i.e. dose in terms of micrograms per unit area) and how must this be distributed? (i.e. dosage distribution in terms of droplets per unit area).
- What is the most efficient way to achieve the target dose on the target surface?
- How can efficiency, in terms of the percentage of pesticide emitted which contributes to the target dose, be maximised?

These questions leave no room for "spraying" in general terms, so that pesticide application problems must be considered as ones involving specific pests and specific targets, and requiring investigation of the specific biological, bio-chemical, chemical, physical and mechanical aspects of conveying the pesticide to a specific site of action.

It is this analytical approach to pest control problems that the ULV concept has generated and encouraged and the object of this paper is to describe by two examples from the field of entomology results recently achieved.

RECENT EXAMPLES IN ULV SPRAYING

Control of Paddy Pests in Java

The control of insect pests must take into consideration the characteristic of insects that they can disperse. That is to say, crop protection programmes are most economic when based on the scale dictated by the pest rather than by the artificial standard of field boundaries. The target must, therefore, be defined so as to provide maximum economy in crop protection. In recent operations in Java, where we sought to protect the paddy crop against attack by stemborers, we were able to introduce by means of light traps a system of synoptic survey, by which the pest situation in regions consisting of hundreds of thousands of hectares could be appreciated at one time, and a system of synchronised control by which the pest was destroyed within a few days over a large part of its concurrent distribution area. Such a system of synchronous control could be achieved only by aerial spraying, and by aerial spraying only if the aircraft was permitted to carry the maximum number of toxic doses and to disperse these efficiently to the target surfaces.

In this particular instance, we had decided that the target surface was that upon which moths laid their egg masses - namely the paddy leaves. The target dose (in terms of quantity and distribution) had been determined experimentally. It was found that larvae hatching from eggs laid on paddy leaves contaminated with phosphamidon at 2 ppm died before penetrating the leaf tissue. It was also found experimentally that this dose could be most efficiently achieved when DIMECRON 100 was applied in droplets of 80 - 120 microns in diameter. Indeed, it took 2 - 10 times more phosphamidon to provide 2 ppm contamination if the chemical were applied in water in larger droplets. It was also found experimentally that when DIMECRON 100 droplets of this size were dispersed over paddy at rates as low as 350 ml per hectare. all leaves were contaminated to this level and some considerably in excess of this level. Knowing the half-life of the chemical in paddy leaves and the cost of application, it was a matter of calculation to determine whether to apply a low dose more frequently, or a high dose less frequently, in order to achieve the maximum overall economy.

Control of Hemlock Looper in Newfoundland

Several species of forest pests, including the Hemlock looper and the Spruce budworm, have been successfully controlled by spraying pure phosphamidon at ULV rates (250 - 300 ml/ha), and it was considered that the greatest contribution to control came through direct hits on the larvae, particularly when they were suspended on their silken threads. Moreover, Himel L.M. et al (1965) showed that 93% of the spray droplets collected by such larvae measured less than 50 microns in diameter. Clearly in this case the chances of hitting such larvae will be a function of the number of suitable droplets made available and the time these droplets are airborne. Since the quantity of active ingredient (4 oz/acre) is evidently adequate to give control in the field, the question arises, can this quantity be reduced if the other two requirements are better satisfied. Thus, better control of the drop spectrum by eliminating droplets above 50 and below about 30 diameter will increase the available droplets by several orders of magnitude; moreover, such droplets will remain air-borne longer. The number of these droplets may also be doubled by maintaining the same volume rate (250 - 300 ml/ha), but reducing the concentration of phosphamidon to 50%. Both approaches are being investigated, but preliminary results indicate that the same control can be achieved by half the quantity of phosphamidon, provided it is adequately atomised. The results, however, suggest that control can be improved by increasing the number of droplets, i.e. reducing the concentration, thus providing an example of application at ULV rates of pesticides in a non-concentrated form.

DISCUSSION

These two examples have been selected from our own experience to illustrate several concepts:

- The target is a biological concept which must take into consideration the scale on which control action must be executed synchronously to achieve maximum economy in pest control.
- The target surface is a biological concept and must be selected for essentially biological reasons.
- The lethal dose must be defined in terms of quantity and distribution.
- The target dose (a collection of lethal doses) is a bio-chemical concept determined by the biology of the target and the half-life of the pesticide.
- The efficiency of spraying can be measured best in terms of deposit (per unit area of target surface) per unit emission. (DUE of Courshee, R.J., 1959).

These concepts, generated by the analytical approach encouraged by applying pesticides at ULV rates, are common to all problems of chemical control of pests. Synchronous control demands the high speed of work which is available only from ULV rates. ULV rates, moreover, by reducing the cost of application to a fraction of the cost of the chemical, provide flexibility in the selection of the level of the target dose. At the same time, since the target surface is a biological concept, its extent and accessibility will be factors determining the level of the target dose and hence the application rate. Not all target doses on all target surfaces can be capable of achievement at ULV rates. What is fundamental is that the target dose must be defined in terms of quantity and distribution, and both requirements can be achieved efficiently only if droplet size range can be accurately controlled. In practice, we have found that accurate control of droplet size results in achieving the target dose with a smaller quantity of active ingredient and a smaller volume rate of application, giving rise to ULV rates of application of sprays which are not necessarily concentrated.

Moreover, in practice, we have found that water is a most unsuitable material for all the processes of pesticide application, namely:

- <u>atomisation</u>, because of its surface tension and adherence to surfaces;
- <u>transmission</u>, because of its volatility;
- <u>collection</u>, because most target surfaces are hydrophobic;

translocation, because of insect and plant cuticular barriers.

We have, therefore, developed the concept of waterless spraying which, by eliminating water from the formulation, provides new opportunities of improving the efficiency, economy and safety of pesticide application without commitment to rate of application or concentration of active ingredient.

Waterless spraying, we consider, stimulates the analytical approach to pest control problems by which alone progress can be ordered and planned. We have found that many pest problems are capable of solution by the application of waterless sprays at ULV rates.

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