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PRELIMINARY OBSERVATIONS ON SAFETY IN ULV SPRAYING

P. Fuller Lewis
Turbair Limited, Maidenhead, Berkshire.

Summary Numerous observations were made on the safety aspects of the ultra low volume application of dilute oil-based pesticides by means of specially developed hand-held spraying machines incorporating rotary atomisers. Droplet spectra, spray distribution and pesticide residues were examined.

Droplet sizes were relatively uniform and lay largely within the band 70 - 110 micron v.m.d. (volume median diameter). Distribution conformed approximately to a 'solid cone', exhibiting fairly sharp peripheral 'cut-off', and gave good overall plant cover. Efficiency as measured by leaf deposit of pesticide was considerably higher than with conventional spraying. Residues at harvest were well within the accepted safe tolerance levels.

The system of 'waterless' spraying examined is likely in use to present less hazard to the operator, result in better plant cover and present no greater residue problems than conventional hydraulic nozzle/water-carrier spraying. It is also probable that environmental contamination from excess pesticide would be reduced, as lower rates of active ingredient per acre gave equivalent leaf deposits.

INTRODUCTION

Safety in pesticide spraying depends on:-

1. The toxicity of the active ingredient.
2. The concentration of active ingredient.
3. The formulation.
4. The method of application including the type of carrier liquid, size and distribution of droplets etc.

These factors all contribute to the following hazards:-

1. Operator exposure to toxicant through contact and inhalation.
2. Contamination of neighbouring crops and the general environment.
3. Residues remaining on the crop at harvest.

This paper sets out to show that the use of ULV spraying techniques can reduce these hazards.

Early attempts at reduced volume spraying often involved the application of spray concentrates-undiluted pesticide formulations or dilutions containing more than 50% of formulated product in water. This was done in order to apply the same dosage of active ingredient per acre as was recommended for conventional medium or high volume applications. The sprayers or mist-blowers used incorporated a venturi (airblast nozzle) or air-shear (high speed air jet) atomiser and produced a high pressure low volume air-blast to carry the droplets to the target area. They all suffered to a varying degree from the following limitations:-

1. Poor droplet spectrum with a considerable number of droplets in the 'driftable' band.
2. Variable crop cover often dependent on changing environmental factors.
3. Liability to blockage of the pesticide feed and/or nozzle coupled with the frequent inability to handle suspensions.

The inhalation hazard of very small droplets precluded the safe use of toxic pesticides and drift prevented the application of products harmful to neighbouring crops. Pest and disease control was variable, but in general insecticides performed better than fungicides. Many workers, while acknowledging the attractions of reduced volume spraying, felt that the limitations coupled with the hazards involved, would prevent its widespread acceptance.

The system of ULV waterless spraying examined evolved from a concerted study of both application equipment and pesticide formulations. Dilute oil-based pesticides were developed alongside the application equipment. As this equipment was designed to apply 1 to 4 l/ha it was commercially practicable to market ready-to-use dilute formulations thus eliminating the need at any time for the operator to handle concentrates. During development work and biological evaluation it was decided to examine various aspects of safety under the following headings:-

1. Droplet Spectra. Droplet size in this system was primarily chosen for reasons of biological efficiency. The capacity of the equipment for consistently producing droplets of the required size was examined as this was important for both efficiency and safety.
2. Spray Distribution. Again the system was designed to maximise crop cover using the minimum volume, without producing droplets of a size that would constitute a drift or inhalation hazard. Swath patterns were analysed as a guide to spraying techniques and safety margins.
3. Residues. Examination of leaf deposits of pesticides showed these to be much higher than those achieved by equivalent doses of a.i. per acre applied conventionally. Residue determinations on harvested crops were carried out to ensure that levels did not exceed those from conventional spraying.

The results given in this paper are confined to work done with a range of machines and oil-based formulations currently available. In the case of droplet analyses, a water carrier was also used to allow standard analytical techniques to be followed.

METHODS

Machines.

Unless specifically mentioned otherwise all work was done using a commercially available light weight hand-held sprayer, engine driven having the following characteristics:-

Effective spraying range: $3\frac{1}{2}$ to $4\frac{1}{2}$ m (12 to 15 ft) approx.

Pesticide feed: Gravity at 1 ml per second using standard formulations.

Atomiser: Rotary 3-disc type, 6.35 cm ($3\frac{1}{2}$ in) diameter, rotating at 6,500 to 7,000 r.p.m.

Air blast: 70.79 m^3/min (2,500 cu. ft./min.)

Some tests were done using an ultra-light weight hand-held sprayer, battery operated, with the following specifications:-

Effective swath width: 1 m (3 ft); may also be used as a 'drift' sprayer.

Pesticide feed: Gravity, at 0.5 ml per sec using standard formulations.

Atomiser: Rotary 2-disc, 6.35 cm ($3\frac{1}{2}$ in) diameter with serrated edge, driven at 3,000 to 9,000 r.p.m. according to input voltage.

Formulations.
These were all based on oils belonging to the general group of paraffins and iso-paraffins, having a viscosity of about 2.0 centistokes at 20°C, Concentration of a.i. varied from 1 to 5% according to activity and residual effect. Rates of application were from 2 to 6 l/ha (1.5 to 4.5 pints/ac) according to the leaf and plant area per acre.

Droplet Spectra.
Considerable variations occurred between analyses obtained by different methods. Techniques suitable for measuring water droplets were not suitable for oils and vice versa. Fairly consistent results for oils were obtained using shallow 2.5 cm diameter circular trays coated with a thick layer of freshly prepared MgO. The standard method for measuring water droplets was to spray 1% w/v nigrosine in water on to clean prepared glass slides. This technique also allowed quantitative determination. A third method was to spray 1% waxoline red in a solvent oil on to special heavy semi-gloss drawing paper. In each case spread factors had to be calculated using a vibrating needle or calibrated rotary atomiser.

Spray Distribution.
Two techniques were used. For the examination of the distribution of droplets on the plant or target surface, spraying was done using a 1-2% w/v suspension of an ultra violet (U.V.) tracer in oil - Lumogen U.V. yellow/orange (Code No. LK.7138 ex BASF) in a non-phytotoxic refined paraffinic oil. The resulting deposit could be examined in situ after dark using a portable U.V. lamp. For a more permanent record and easy assessment, a special reactant was sprayed on to heat sensitive paper (plasticiser free).

Residues.
Standard analytical techniques were used and the work was divided into three phases:-

1. Leaf deposit. Leaves were collected after various intervals following spraying and deposits were compared with those obtained by conventional application at the same rate of a.i. per acre.

2. Rain fastness of leaf deposits. The sprayed foliage was subjected to continuous heavy irrigation and samples were taken at intervals. Two different carrier oils were compared for their 'sticking' properties.
3. Residues at harvest. The crop was divided into plots and sprayed at regular intervals so that all levels from unsprayed control up to 4 applications could be examined.

RESULTS AND DISCUSSION

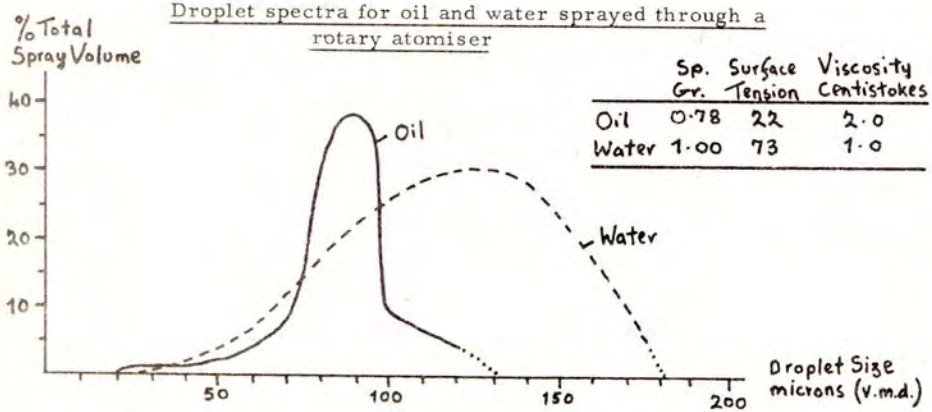
Some typical results obtained in the preliminary investigations are described, and the work is still in progress.

Droplet Spectra.

From a theoretical calculation the atomiser used should produce droplets of approximately 70 micron v.m.d. (1). Results of two trials using a paraffinic oil (Mg O crater technique) and water (nigrosine in water/glass slide technique) are shown in Fig. 1.

Fig 1

Droplet spectra for oil and water sprayed through a rotary atomiser



The results clearly show the superiority of oil over water as a carrier for ULV spraying and illustrate the effect of specific gravity (oil = 0.78), surface tension and other factors on droplet sizes. The water test was done indoors under near ideal conditions.

Table 1 shows how droplet size can easily be varied using a rotary atomiser; also the relationship of droplet size to deposit when the feed rate is constant. Within limits, droplet sizes could be chosen to suit particular application problems. Tests were done using waxoline red in oil with the sprayer held 1 m above horizontally exposed targets and carried at 0.9 m per sec. (2 m.p.h.).

Table 1

Mean Droplet Spectrum Ultra-light weight handheld sprayer

RPM of Atomiser	Droplet V.m.d. microns	Deposit droplets/ cm^2
9,000	50	349
* 7,000	68	150 (Av.)
5,500	65	148
4,500	120	44
3,100	250	14

* Using heavy aromatic naptha. Vertical targets 0.5 to 2.0 m high at 1.35 to 4.05 m from moving sprayer (2)

The variability of results obtained by different methods makes difficult the determination of the absolute size of a droplet, but any one method used consistently will provide comparative data.

Operator hazard: Current opinion is that a droplet of less than 25 micron v.m.d. may be inhaled and would allow the deposition of pesticide on the nasal mucosa. Tests were done by the Ministry of Agriculture using 1% w/v nigrosine in water. Assuming that the spray swath was directed at a person breathing at 20 l per min, so as to result in maximum exposure - that is, at a distance of 122 cm (4 ft) from the unit where the spray deposit on a vertically exposed target was 40 droplets/cm^2- that person would have inhaled 0.0014% of the total volume sprayed. Substituting toxicant for nigrosine this would represent a maximum conceivable inhalation rate of 0.35 microgrammes/l and would be less than the acceptable concentration for many hazardous materials. In practice exposure would obviously be far less in the majority of circumstances and when using oil-based formulations.

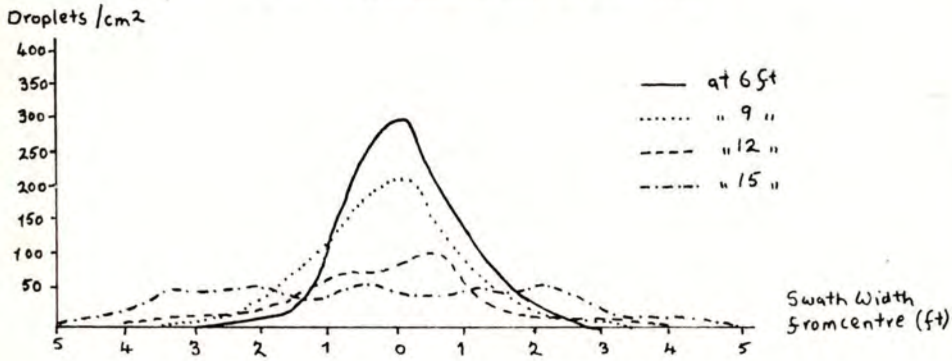
Drift: The practical implications of droplet size in relation to drift are less well understood and most reports relate to aerial application. It seems generally accepted for ground application that droplets of less than 80 micron v.m.d. have some drift potential and those of less than 40 micron v.md. may present some drift hazard. Trials showed that considerable drift resulted when spraying water under near still conditions whereas very little drift occurred when spraying oil in cross-winds of up to 8 k.p.h. (5 m.p.h.). These effects were assessed when spray distribution was studied.

Spray Distribution.

Fig. 2 shows results obtained by spraying bands of heat sensitive paper suspended horizontally to present a vertical target. Tall crops were also sprayed with U.V. tracer and this resulted in a widening and flattening of the curves particularly marked at the closer distances. An unimpeded spray swath followed the pattern of a trumpet-shaped 'solid cone' and consisted of low pressure turbulent air currents.

Fig 2

Spray Distribution and Swathe Pattern of a Rotary Atomiser with Fan-assisted Air Dispersal of Droplets



Impaction of droplets was completely satisfactory at 366 cm (12 ft). Using water, however, considerable 'fall-out' occurred, resulting in a maximum deposit of 40 droplets/cm^2 on vertical targets at only 122 cm (4 ft) whereas the same deposit was found on a horizontal ground target at 244 cm (8 ft).

The effects of cross winds of up to 8 k.p.h. (5 m.p.h.) on the swath pattern were overcome by the initial velocity imparted to the droplets by the air blast from the fan. The resultant distribution of droplets on a target crop 366 cm (12 ft) from the sprayer was similar to that shown in Fig. 2 but was displaced downwind approximately 60 cm (2 ft).

Residues.

Several workers have reported higher leaf deposits of pesticide when using ULV techniques. Typical results are shown in Table 2.

Table 2 (3)

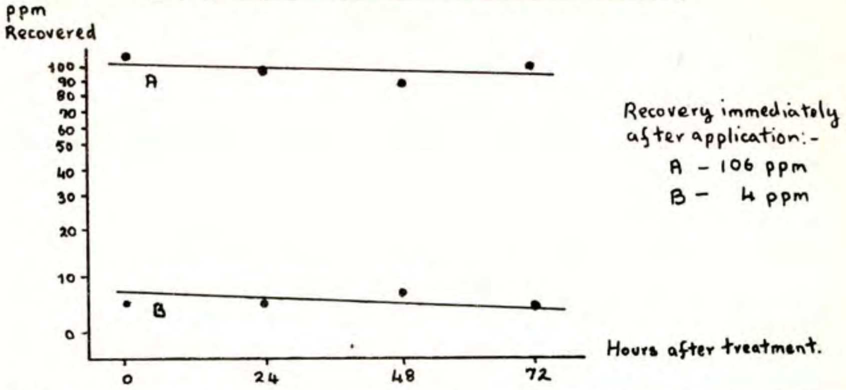
Leaf Deposits on coffee, sprayed aerially with malathion

	Conventional	ULV
Immediate post-treatment	147 ppm	612 ppm
After 3 days	7.5 ppm	22.3 ppm

This tendency is also true for ground application and results are shown in Fig. 3.

Fig 3

Leaf deposits on potatoes sprayed with Copper



B - 1 lb copper per ac applied as oxychloride in water using a knapsack sprayer

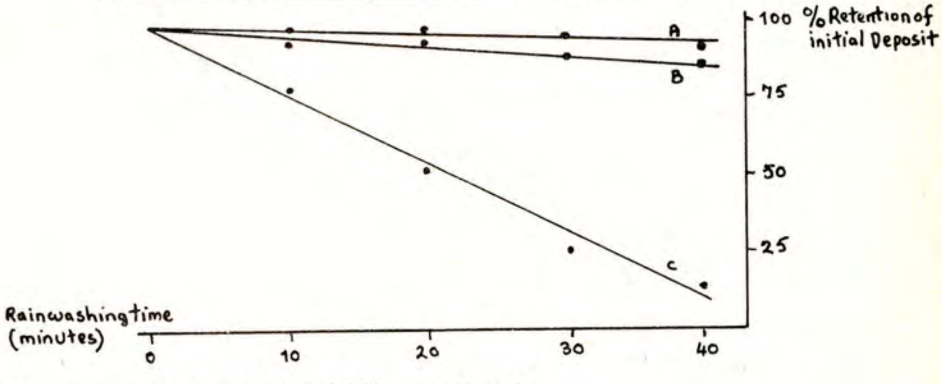
A - 1 lb copper per ac applied as oxychloride in oil using a ULV sprayer

The implication is that ULV spraying can be up to 25 times more efficient than conventional application, and a high proportion of the total spray volume must deposit on the plant. This is probably the main reason why the reduced dosages applied with this ULV system give satisfactory control of pests and diseases.

The rainfastness of oil deposits compared with conventional spraying is shown in Fig. 4. Oil formulations were in all cases markedly superior to conventionally applied water, although it is likely that the controlled size of small droplets in ULV spraying also contributed to improved retention (4).

Fig 4

Rainfastness test - Copper deposit on Chrysanthemum leaves



A - Copper oxychloride in oil 'A' applied ULV
B - Copper oxychloride in oil 'B' applied ULV
C - Conventional copper oxychloride in water applied LV

Less loss through drift and run-off coupled with reduced dosages of a.i. per acre could lead to a worthwhile reduction in the general environmental contamination with pesticides.

Table 3 shows residues on tomatoes sprayed with 4.3% copper oxychloride in oil applied at 5.6 l/ha (4 pints/ac). Repeated applications appeared to have no significant cumulative effect, and the results also indicated that normal degradation processes were not altered.

Table 3

Copper residues at harvest in glasshouse Tomatoes sprayed with ULV copper in oil

Harvest date: 26.6.69.

Times sprayed	Dates of treatment				Residue in p.p.m. *
0	-	-	-	-	0.67
1	-	-	-	20.6	1.55
2	-	-	12.6	20.6	0.51
3	-	6.6	12.6	20.6	0.73
4	30.5	6.6	12.6	20.6	1.26

* Figures corrected for recovery, found to be 140% at 1 to 2 ppm.

Residues on random samples purchased from local shops (3 x 1 lb samples)	0.14 1.36 4.21

CONCLUSIONS

Indications are that the system of ULV spraying examined is at least as safe and in many ways safer than conventional methods. Critical features are the droplet size and spectrum, the spray swathe and pattern, and the type of dilute oil-based pesticides used. Further confirmatory work would be needed with any scaling-up of equipment or modification of pesticide formulations.

Acknowledgements

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CABBAGE ROOT FLY DAMAGE TO CAULIFLOWERS AND BRUSSELS SPROUTS IN THE WEST MIDLANDS

K. J. Coghill
National Agricultural Advisory Service, Westbury-on-Trym, Bristol

Summary Fields of early summer cauliflower were examined for damage by cabbage root fly (Erioischia brassicae) at the end of harvest in the three years 1967-69. Organochlorine drenches of dieldrin or lindane gave no protection against attack by resistant flies, whereas organophosphorus granules containing either diazinon or chlorfenvinphos gave a satisfactory control. Granular formulations of parathion, phorate or thionazin were only slightly effective. The amount of root damage on both treated and untreated crops increased between 1967 and 1969 yet crops were generally satisfactory probably because the weather, particularly the rain in May, encouraged good growth.

Brussels sprout fields were examined in January at the end of harvest in 1967 and in 1969. Dieldrin dips gave no protection against attack by later generations while both diazinon and chlorfenvinphos granules continued to give some protection.

Organophosphorus granules had been applied to more than half the fields visited, but nearly a quarter of the crops examined had not been treated in any way.

INTRODUCTION

Prior to 1963, the prevention of damage by the larva of the cabbage root fly (Erioischia brassicae) to brassicas grown for human consumption in Worcestershire, Warwickshire and Gloucestershire was successfully based on the use of organochlorine insecticides. Early summer cauliflower plants, over-wintered under glass in small pots, were watered with a dilute solution of either aldrin, dieldrin or lindane a few days before planting out in the fields during March. Sufficient insecticide persisted in the soil-ball to prevent injury by larvae emerging from eggs laid during May. The roots of young Brussels sprout plants were dipped in aldrin or dieldrin solutions immediately before being transplanted in April and May and sufficient insecticide remained on the tap-root to prevent much injury during the early, critical stages of plant establishment. The methods (Wright, 1954; Wright and Buxton, 1956) were easy to apply, effective and cheap.

However, in 1963 resistance to these organochlorines was first reported at Great Rollright, Oxfordshire, within twenty miles of the Worcestershire boundary (Coaker, T.H. et al, 1963). In 1964, a few cases of root fly damage were seen in the Vale of Evesham, despite use of the customary organochlorine insecticides, and many more occurred in the following year. Laboratory tests confirmed that dieldrin-resistant flies were present in Worcestershire from 1964 onwards (Gostick and Baker, 1968) and thus, by 1966, growers had to use new materials and new methods of application to prevent cabbage root fly damage. The new materials were all organophosphorus compounds and, although some were formulated as wettable powders or emulsifiable concentrates, none could be applied to summer cauliflowers before planting out or used as root dips on Brussels sprouts because they were either not sufficiently persistent, or they were phytotoxic. All were available, however, as granules and the small quantity needed, between 2 to 10 lb of formulated product/ac of Brussels sprouts, together with the availability of small hand applicators to meter out the correct amount for each plant, were added inducements for growers to change from the traditional methods. Subsequently, tractor-mounted machines became available to deliver granules automatically to the base of each plant or apply a continuous band along the rows but these methods have not been widely adopted in the area and brassicas continue to be treated against cabbage root fly mainly by hand.

In 1966 some fields of early summer cauliflowers were examined to assess the effectiveness of diazinon watered onto the pots before planting out. The method proved to be of value and so it was decided to survey a larger number of crops in subsequent years to compare the efficiencies of commercial applications of different materials.

METHOD

Twenty roots per field were dug up at random along a single diagonal. Depending on the stickiness of the soil, they were either washed or had the soil carefully removed so that they could be scored in the laboratory for root damage caused by cabbage root fly larvae. Wardlow and Winfield (1967) have compared two methods for scoring root damage and one of these methods, that devised by workers at the National Vegetable Research Station (Wright, 1953), was always used to obtain the percentage root damage index for each crop (Rolfe, 1969). To avoid objections by growers, roots of early summer cauliflowers were sampled between the end of June and early July after the crop had been harvested. Brussels sprouts were examined in January when harvesting of the crop in the Worcestershire area was nearly finished.

Crops were not selected at random, growers being chosen from those in the main brassica-growing areas who had previously sought advice on any pest. If a particular grower was not available, or had ploughed-in his crop, then a neighbour was visited. In no case was it known beforehand what treatment, if any, had been applied (Table 1). The majority (78%) of the fields of cauliflowers and sprouts examined were in Worcestershire, a further 16% were in Warwickshire and the remainder, mostly cauliflowers, were in the Mickleton area of Gloucestershire.

Table 1.

Some insecticide treatments used commercially for cabbage root fly control

Treatment	Dose of formulated product
Spot application 10% chlorfenvinphos granules	2 lb for 5,000 plants
5% diazinon granules	10 lb " " "
10% parathion granules	5 lb " " "
10% thionazin granules	2 lb " " "
Band application 10% phorate granules	20 lb per acre for 36-inch rows
	30 lb " " " 21-inch "
Pre-planting liquid drench 0.028% dieldrin	1/16th pint per plant in pot
0.019% lindane	1/16th pint " " " "
Root dip 0.047% dieldrin	1 gal for approximately 3,000 plants

RESULTS

Early summer cauliflower Although relatively few fields were surveyed, the results were similar in each of the three years (Table 2). Untreated plants had the greatest amount of root damage, the level of which increased between 1967 and 1969. Where dieldrin or lindane had been applied as pre-planting drenches, the damage differed little from that on untreated plants, confirming the presence of dieldrin-resistant flies during this period. Both chlorfenvinphos and diazinon granules applied between mid-April and early May to individual plants, before the eggs were laid in early May, gave good control in 1967 and 1968 although the results in 1969 were less satisfactory. The control given by the other organophosphorus materials was generally negligible, although thionazin seemed to be moderately effective in 1968.

Table 2.

Comparisons of mean root damage index from commercial applications of insecticides for cabbage root fly control on early summer cauliflowers

Treatment	Root damage index 1967	1968	1969
Chlorfenvinphos granules	2	11	15
Diazinon granules	1	7	22
Other organophosphorus granules (parathion, phorate or thionazin)	8	33	48
Organochlorine liquid drench (dieldrin or lindane)	23	40	43
No treatment	30	39	55
Total number of fields examined	18	28	29

During the three-year period, twelve fields of summer cabbage were also examined. The levels of root damage on treated and untreated plants were comparable with those found on summer cauliflower.

Brussels sprouts Roots of early summer cauliflowers show damage caused by larvae hatching from eggs laid from early May onwards, but sprout roots examined in the following January show damage from the later generations. Thus, while it is reasonable to suppose that the relative control of the early attack on sprouts would be similar to that on cauliflowers, this does not necessarily follow for the control of the later generations. However, the results for sprouts (Table 3) were found to be comparable with those for the cauliflowers, dieldrin root dips having given no control while both chlorfenvinphos and diazinon granules had continued to reduce damage either by directly killing the later larvae or, indirectly, by reducing the number of larvae of the early generation and hence limiting the root fly populations in the subsequent generations. As with cauliflowers, there was an increase in the degree of infestation between 1966 and 1968 but, unfortunately, crops planted in 1967 could not be examined because of restrictions arising from the serious foot and mouth outbreak among cattle in the West Midlands.

Table 3.

Comparisons of mean root damage index from commercial applications of insecticides for cabbage root fly control on Brussels sprouts

Treatment	Root damage index Planted in 1966	Planted in 1968
Chlorfenvinphos granules	8	14
Diazinon granules	9	21
Dieldrin root dip	28	28
No treatment	21	30
Total number of fields examined	24	18

DISCUSSION

In the first year of the survey, granules gave a uniformly good control of larvae but results were not so satisfactory in subsequent years. Although this may be associated with the general increases in levels of larval attack, other factors are also involved. Accurate placement of the granules round the base of each plant is essential for good control. Good results were obtained by those growers who were known to be particularly careful with their applications, even to the extent of treating only one row at a time, not two, to avoid missing plants. It is easy to appreciate the difficulties of maintaining an accurate placement of insecticide for prolonged working periods when each acre carries between 5,000 and 14,000 individual plants! One possible solution is to apply granules by hand for only half of the day and do different work for the rest of the time.

It is also likely in some instances that treatment was delayed until the plants were too big for the granules to be correctly placed near the stem. Indeed, in 1968 and 1969 May and June were unusually wet and a number of growers stated that their summer cauliflowers rapidly grew so large that they could not be treated. Particularly in 1969, when egg-laying was later than usual, some growers had applied granules by early May but were forced to hand-hoe their crops in mid-May so removing the insecticide from around the stems before all the eggs had been laid. When possible, it is a reasonable precaution to avoid hoeing during May.

Between one-half and two-thirds of the fields of cauliflowers and sprouts examined in 1967-9 had been treated with organophosphorus materials, diazinon granules being the dominant insecticide applied to about one-third of the fields visited. During this period, the use of pre-planting organochlorine drenches on cauliflowers fell to a low level, unlike on Brussels sprouts where dieldrin root dips continued to be used on about one-quarter of the fields. One-quarter of the cauliflowers in 1968 and 1969, and one-fifth of the sprouts in 1966 and 1968 were not treated to control cabbage root fly.

It has been shown (Coaker, 1965; Winfield and Wardlow, 1966) that yields of summer cauliflower are improved by treatment against cabbage root fly and that a high level of available moisture in the soil is not in itself sufficient to overcome the yield losses due to this pest. Very few growers who had crops with a root damage index of less than 50 in 1968 and 1969 complained about poor yields, nearly all their crops being cut and marketed. Growers did not fully realise the importance of controlling cabbage root fly even when growing conditions were good.

It is concluded that while growers have been quick to change their methods of control of cabbage root fly to combat cyclodiene-resistant populations, they have not maintained the good control that they obtained initially, probably due to a variety of factors.

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CO-ORDINATED INSECTICIDE EVALUATION FOR CABBAGE ROOT FLY CONTROL

*S. W. H. Rolfe
National Agricultural Advisory Service, Westbury-on-Trym, Bristol

Summary An historical account is given of the development of a scheme co-ordinated by the N.A.A.S. Brassica Pests Working Party to rationalise the evaluation of insecticides for controlling cabbage root fly (*Erioischia brassicae*). Chemicals in an early stage of development can be evaluated very simply for activity against the pest in one year and compounds showing promise and having good market prospects can then be more critically tested at different sites in two subsequent years, to take into account their effects on crop yields. An outline of the methods used is given together with a summary of compounds tested to date.

INTRODUCTION

Many methods have been devised in the past to control cabbage root fly (*Erioischia brassicae*) ranging from the use of tarred-felt discs or repellent crops between rows of cabbages to the most up-to-date methods for applying chemical insecticides. Because of the varying means of control used in this country, the N.A.A.S. Entomologists' Conference set up a small group (the Cabbage Root Fly Working Party, now the Brassica Pests Working Party) in 1963 to assess the methods then in use and to give constructive advice. The first meeting was held in February 1963 and a questionnaire circulated to all N.A.A.S. Horticultural Advisers confirmed that brassica crops, particularly early cauliflowers and summer cabbages, suffered from cabbage root fly damage in all regions and that Brussels sprouts also suffered severely in many areas. 80% of growers were using insecticidal control measures and of these root dipping was generally the preferred method, although most growers recognised that this caused a check to plant growth. Drenching of individual plants was accepted as giving the most effective control but, in many places, this involved problems with water and labour supplies. It was agreed, therefore, to investigate a number of special means of control including dry-dust dipping and seed bed treatments. At the time of this first meeting early in 1963, organochlorine insecticides were in general use for the control of cabbage root fly and it was felt that a watch should be kept for the appearance of strains of the pest resistant to these materials.

The second meeting of this Working Party was held in October 1963 at the National Vegetable Research Station (N.V.R.S.), Wellesbourne, where all subsequent meetings have been held annually, thus enabling research workers and advisory entomologists concerned with cabbage root fly problems to attend and share experiences and views. Just prior to this meeting, resistance had occurred in an area of North Oxfordshire resulting in severe losses to the grower. It was anticipated that resistance to organochlorine insecticides would soon appear in other places also and, consequently, there was an urgent need for recommendations involving the use of chemicals with a different mode of action. The only one adequately evaluated at that time was the organophosphorus compound diazinon and a leaflet was prepared by the Working Party giving recommendations for its use in 1964.

Trials carried out on the control of cabbage root fly from 1962 to 1964 were summarised in the Supplement to Plant Pathology published in March 1965; this comprised ten papers giving the results of trials done by eleven entomologists.

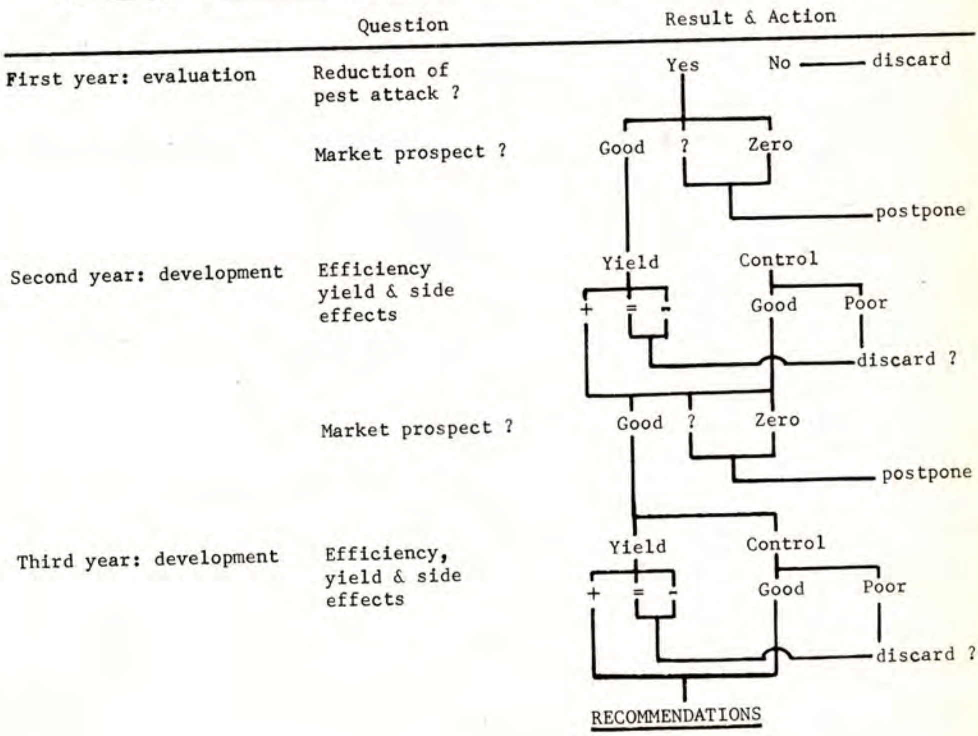
* Chairman : N.A.A.S. Brassica Pests Working Party

Twelve different organophosphorus insecticides had been compared against three organochlorine insecticides in these tests but the methods used differed so much that the results from the different trials could not be easily summarised into a single set of recommendations. In 1965 and 1966, a number of new chemicals and formulations were submitted for formal approval, often without the previous knowledge of the Advisory Entomologists thereby causing considerable confusion. More trials were carried out in various parts of the country and, again, the results were difficult to consolidate, and a comprehensive summary was impossible. In October 1966, the Working Party proposed uniform methods for use by the entomologists co-operating in the trials and, subsequently, this has proved to be of great value.

Assessments based on a root damage index (R.D.I.) (Wright, 1953) can necessarily be used only to determine the extent by which a control measure has reduced an attack by cabbage root fly. The visible effects relate only to damage done in the few weeks prior to lifting the plants and, consequently, unless the assessments are made just after the period when the crop is most susceptible to damage, there is unlikely to be a consistent relationship between R.D.I. and the final marketable yield. Furthermore, there are many factors other than pest control, including side-effects from the insecticide used, that can markedly affect yield in different sites in different seasons. Hence, elaborate trials for more than one season at more than one site are necessary to establish the effects of any proposed treatments on marketable yields (Coaker, 1968) and this involves a considerable amount of work. It would be very wasteful if detailed tests were made on all candidate insecticides without first deciding whether or not they controlled cabbage root fly successfully.

Table 1.

Scheme for the examination of new products for cabbage root fly control



In co-operation with the N.V.R.S., the Working Party arranged that there should be 2 types of trials (Table 1). Firstly, evaluation trials would be undertaken at the N.V.R.S. on a wide range of materials at an early stage in their development, using a minimum of effort to evaluate only the potential of each for controlling this pest. No attempt would be made at this stage to assess the effects of the candidate insecticides on final yields, although observations would be made on acute phytotoxicity. Secondly, compounds which had given promising results (R.D.I. <30) in the initial evaluation tests, and which had good market prospects, would be subjected to more detailed developmental tests by N.A.A.S. Entomologists at the Regional Centres to evaluate not only insecticidal activity but also other factors such as effects on plant growth and consistency of performance at different sites in different years.

METHODS

The precise details of the methods used for the initial evaluation and the second-stage developmental trials have been slightly modified from time to time in the light of experience but the principles in the designs of the tests have remained unaltered and these are as follows:-

Evaluation tests These are undertaken at the N.V.R.S. where high infestations of root fly occur annually. Manufacturers are encouraged to submit prospective chemicals for inclusion in these tests at an early stage in their development. Cauliflowers are used and small plots are adequate for this purpose. Each plot comprises 20 effective plants arranged in two rows at 2 ft x 2 ft spacing with guard plants at either end. Transplanting is done at the end of April to attract attack by flies from the overwintering generation and in mid-June for later attacks. For e.c. and w.p. formulations, drenches of 70 ml/plant are applied within a week of transplanting, using two concentrations 0.02 and 0.1% a.i. for each chemical and both are tested also as root-dip treatments at the same concentrations. Granular formulations are applied as spot applications to give 0.025 and 0.05 g a.i./plant. Comparable treatments with chlorfenvinphos act as standards for comparisons and untreated plots are also included. Observations of acute phytotoxicity are made and the R.D.I.'s are assessed 8 weeks after treatment. The mean R.D.I. values are calculated (Table 2) and treatments giving values <30 are considered for inclusion in the second-stage development trials.

Table 2.

Calculation of root damage index (R.D.I.) on brassicas (N.V.R.S. method)

Area of main root cortex damaged (%)	Mean	Number of plants
0	0	a
10 to 30	20	b
40 to 60	50	c
70 to 80	75	d
90 to 100	95	e

$$\text{Root damage index (R.D.I.)} = \frac{(20\,b + 50\,c + 75\,d + 95\,e)}{(a + b + c + d + e)}$$

Developmental trials Compounds selected from the initial evaluation tests are included in the subsequent developmental trials if reasonable assuranceshhave been given that they have sound market prospects. If such assurances are not forthcoming, further tests are postponed until the position regarding their future marketing has been resolved because these trials are less flexible and more time-consuming than the initial evaluation tests. The basic design allows for as many chemicals to be tested each year as there are sites available and each is tested at 2 sites for each of 2 seasons. Each trial usually includes 2 materials under test, one standard chemical (chlorfenvinphos) and untreated plots. Chemicals under test are applied at 2 doses, one being about that expected to be recommended and usually 16 oz a.i./ac, the other usually half this amount. Two methods of application most appropriate to the Region concerned are selected from:-

Liquid formulations	Granular formulations
Root dip	Spot application
Drench	Furrow placement; pre-planting
Band spray; post-emergence	Bow-wave; at sowing
Band spray; post-planting	Band; post-emergence
	Band; post-planting

Summer cauliflowers are used for the trials which usually each involve 12 treatments (2 candidate chemicals x 2 doses x 2 application methods + 1 dose of standard chemical by each method of application + 2 untreated plots) and 2 or 3 replicates of each, arranged in a randomised block design. Plots contain 7 x 17 = 119 plants, the outer rows being discarded leaving 5 x 15 = 75 effective plants/ plot. Of these, 15 are sacrificed for R.D.I. assessment 4 weeks after treatment leaving 5 x 12 = 60 plants per plot (120 or 180 plants per treatment) for yield determinations, sufficient to detect an effect on yield of about $\pm$ 10%. Transplanted crops are put out in late April or mid-June and treated within 1 week, and direct-drilled crops are sown and treated at the same time in early March or late May.

Phytotoxic effects are assessed usually within 2 weeks of treatment but observations are also made to detect any latent effects on the more mature crop. For plants, the effects are scored 0 = nil, 1 = light, 2 = medium and 3 = severe and any symptoms are described. On seedlings, a germination count is done at the second rough-leaf stage on 2 separate running yards of row and subsequent symptoms are noted as for transplants.

R.D.I. assessments (Table 2) are made after 4 weeks on transplanted crops to determine the level of pest control attained, and again at harvest so that an indication is obtained of the relative persistence of the active compounds. R.D.I. data is transformed to angles for statistical analysis.

Cauliflowers are cut 2 or 3 times weekly when the curds are mature. A recognisable criterion for maturity (e.g. "just beginning to 'crack' ") is carefully followed and, because this is subjective, it is best to have only one person cutting curds. Curds diameters are graded according to the standard sizes described by the marketing regulations, sizes are summed and the numbers of crates of marketable curds/ac are calculated to provide a measure of yield. Curds 2 inch diameter, or severely "bracted", "ricey" or blemished are recorded as unmarketable.

A computer program has been compiled at N.V.R.S. to facilitate the calculation and summarising of results from these, and similar, trials.

RESULTS AND DISCUSSION

Prior to this scheme starting in 1968, more than 28 compounds had been evaluated by workers at the N.V.R.S. and a further 15 have been evaluated in 1968 and 1969 (Table 3). It is interesting that all compounds found to give a R.D.I. 30 in the earlier evaluation tests subsequently received formal approval and are the basis for cabbage root fly control at the present time.

From the evaluation tests in 1967, two materials (aldicarb and Bayer-77488)were selected for development trials in 1968 and, in addition, two chemicals already evaluated and approved for use (mecarbam and thionazin) were included. The 1968

Table 3.

Summary of compounds tested for cabbage root fly control

Test	R.D.I.	1964-6	1967	1968	1969
Evaluation (NVRS)	<30	[a] chlorfenvinphos [a] diazinon [a] thionazin [a] azinphos-methyl [a] mecarbam [a] phorate fonofos	Bayer-77488 aldicarb	"Dursban*" PP211	NC-6897 C-10015 GS-13006 M-2452 RD-22768
	>30	9 compounds	10 compounds	5 compounds	3 compounds
Development (NAAS, EHS, NVRS)		-	-	fonofos ‡ Bayer-77488 ‡ mecarbam ‡ thionazin ‡ aldicarb "Dursban*"	[a] fonofos dimethoate diazinon × trichlorphon PP211 "Dursban*"

[a] = Approved for use against cabbage root fly.

‡ = Withdrawn by manufacturers.

× = Experimental interest only.

* = Registered Trade Mark of the Dow Chemical Company.

Bayer-77488 = O,O-diethyl-thionophosphoryl-a-oximinophenyl-acetacid-nitrile.
PP211 = O,O-diethyl O-(2-diethylamino-6-methyl-pyrimidin-4-yl)-phosphorothioate.
C-10015 = 2-(4,5-dimethyl-1,3-dioxolane-2-yl)-phenyl-N-methyl-carbamate.
GS-13006= O,O-diethyl-S-(2-methoxy-1,3,4-thiadiazol-5(4H)-onyl-(4)-methyl)-dithiophosphate.
NC-6897 = 2,2-dimethyl-1,3-benzodioxol-4-yl N-methyl carbamate.
RD-22768= 4-dimethylamino-3,5-xylyl N-chloroacetyl-N-methyl carbamate.
M-2452 = O,O-diethyl phthalimidophosphonothioate.
"Dursban*" = O,O-diethyl O-(3,5,6-trichloro-2-pyridyl) phosphorothioate.

developmental trials were done at 5 Experimental Horticultural Stations, 2 regional centres and at the N.V.R.S. Table 3 indicates the progression of the compounds through the scheme. Unfortunately, four of the materials examined in the 1968 trials were subsequently withdrawn by the manufacturers and they were not therefore tested in 1969 as intended, to complete the three-year program. Sufficient time has not yet elapsed for the value of the second-stage development trials to have become fully apparent but it should be noted that fonofos had reached the first of its two seasons of development tests before it was formally approved for use, and the program with "Dursban*" was completed in 1969. Comparative information on the backlog of approved chemicals is also being accumulated and an opportunity was taken in 1969 to include other materials, not previously considered, which were particularly of interest to research.

In spite of the initial difficulties experienced, the Working Party believes that this scheme of tests will give more detailed and accurate comparative data about the chemicals which are used to control cabbage root fly. This will not only be of use to research workers and advisers but also to the manufacturers. The value of using basically standardised methods was noticeable at the annual meeting of the Working Party in October 1968 when, for the first time, it was possible to compare critically the results obtained in trials done at eight different centres.

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The following Regions, Stations and Entomologists co-operated in the 1968 development trials:-

East Midlands Region:	Shardlow R.O., Derby:	Miss A. M. Brock
South Eastern Region:	Efford E.H.S., Hants.:	Mr. C. W. Graham
South Western Region:	Bristol R.O.:	Miss S. Lewis
" " " :	Rosewarne E.H.S., Devon:	Mr. T. J. Legowski
Wales :	Cleppa Park E.H.S., Mon.:	Mr. D. P. Webley
West Midland Region :	Luddington E.H.S., Warwicks:	Mr. K. J. Coghill
Yorks. & Lancs. Region:	Stockbridge Ho., E.H.S., Yorks.:	Mr. J. R. Kelly
-	N.V.R.S., Warwicks.:	Mr. T. H. Coaker

The following also served as members of the Working Party and assisted in the development of the scheme: Mr. W. J. Bevan, Mr. P. W. Carden, Dr. W. H. Golightly, Mr. W. I. St. G. Light, Mr. G. Murdoch, Mr. J. M. Rayner, Mr. J. H. White (NAAS) and Mr. K. G. Gostick (Plant Pathology Laboratory).

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FORMULATIONS AND CONTROL OF CABBAGE ROOT FLY

Q. A. Geering and J. A. Bond
Chesterford Park Research Station, Nr. Saffron Walden, Essex

Summary Miscible oil, wettable powder, dust and granule formulations of dimethoate were applied as spot treatments to early cauliflowers and other brassica crops for control of cabbage root fly (*Erioischia brassicae*). The results confirmed the superiority of the dust formulation. The granules of dimethoate were also superior to the liquid drenches. Similar experiments including a range of formulations of diazinon have also demonstrated the superiority of a dust formulation for spot application. These differences are discussed.

INTRODUCTION

Dimethoate and diazinon have been used on brassica crops for a number of years in the United Kingdom. Dimethoate is used as a miscible oil (spray) for control of cabbage aphid (*Brevicoryne brassicae*) and diazinon is applied as a spot treatment of either the wettable powder (drench) or granules, for control of cabbage root fly (*Erioischia brassicae*).

Early in the development of dimethoate in the United Kingdom, drench applications were made to early cauliflowers, but they gave virtually no control of cabbage root fly. In 1967, however, Hertveldt, L. et al (1967) reported results of trials with a dust formulation of dimethoate on cauliflowers, and they found it "gave both a good control of *D. brassicae* and the highest yield of first grade cauliflowers". In contrast, the dimethoate emulsion drench had insufficient residual action to protect the cauliflowers from attack during one generation.

In view of the above results, a number of trials were undertaken during 1968 and 1969 to compare the performance of dimethoate formulated as miscible oil and wettable powder drenches and as granules and dusts, all applied as spot applications. In 1969 the same four types of formulation of diazinon were examined.

METHOD AND MATERIALS

Field Trials In small-plot field trials, transplanted brassica crops were given spot applications of insecticides to control either first or second generation cabbage root fly. Plots comprised twelve to twenty plants, the larger plots being taken to harvest.

The insecticides were formulated as 5% dusts, 5% granules, wettable powders and miscible oils or emulsifiable concentrates. Dusts were applied by hand with a graduated measure, granules by a hand spot applicator, and drenches by a ladle giving 75 ml/plant.

The granules of dimethoate were based on sand of particle size 0.23 to 0.85 mm diameter, and the granules of diazinon were based on limestone of particle size 0.40 to 0.85 mm diameter.

Assessment of root fly damage was made at 6-10 weeks after treatment, by the method used by Coaker, (1965).

Laboratory tests These were designed to assess the effects of soil-applied treatments, as used in the field, on adults of the cabbage root fly. Cages of 12 x 12 x 18 in contained radish seedlings growing in soil. Granule, dust and drench treatments were applied to the soil, adult cabbage root flies were introduced into the cages and their mortalities were recorded.

RESULTS

Trials in 1968 Two trials were done involving cauliflowers for first generation and late planted brussels sprouts for second generation root fly attack.

Cauliflowers were transplanted on 17 May, and spot treatments of dimethoate dust and diazinon granules were applied on 28 May. Each plot contained 20 plants and there were 4 replicates of each treatment. Plants were left until harvest, when yields (Table 1) showed the dimethoate dust to have given the highest total yield of curds.

Table 1.

Control of cabbage root fly on cauliflowers in 1968 by spot applications

Chemical	Formulation	Dose a.i./plant	No. of curds	Yield of curds/ plot (lb)
Dimethoate	5% dust	0.075 g (1.5 g dust)	14	26.6.
Diazinon	5% granules	0.06 g (1.2 g granules)	12	16.0
Untreated	-	Nil	7	3.5
S.E. ±			0.9	1.66
Degrees of Freedom			23	23

The Brussels sprouts were transplanted on 19 July and treated on 23 July. There were 15 plants per plot and 5 replicates of each treatment. Ten weeks later, on 27 September, the plants were all lifted and their roots examined and scored for cabbage root fly damage. The treatments of interest were dimethoate dust and granules applied at half the dose used for cauliflowers, compared with chlorfenvinphos granules. Root damage indices are given in Table 2.

Table 2.

Control of cabbage root fly on Brussels sprouts in 1968 by spot application

Chemical	Formulation	Dose a.i./plant	Root damage index (%)	Angles
Dimethoate	5% dust	0.0375 g	9.6	18.0
Dimethoate	5% granule	0.0375 g	5.5	22.9
Chlorfenvinphos	24% e.c. (drench)	0.0337 g	8.7	16.5
Untreated	-	Nil	83.8	66.6
S.E. ±			-	2.5
Degrees of Freedom			-	10

During the period of the trial, complete control of cabbage aphid was obtained on the plants treated with dimethoate dust.

Trial in 1969 On early cauliflowers, the control of first generation attack was assessed for the four formulations of each of dimethoate and diazinon.

Cauliflowers, variety "All the Year Round", were transplanted on 7 May, and spot treatments were applied on 13 May. Roots from half-plots were assessed for damage after 7 weeks, on 4 July. Unfortunately, yields were not obtained because more than 50% "blindness" occurred in all plots, due to seed bed conditions. Root damage scores are given in Table 3.

Table 3.

Control of cabbage root fly on cauliflowers in 1969 by spot applications of diazinon and dimethoate formulations applied to give 0.05 g a.i./plant

Chemical	Formulation	Root damage index Assessed %	Angles
Diazinon	40% wettable powder	16.5	23.8
Diazinon	40% emulsifiable concentrate	18.6	24.4
Diazinon	5% granule	16.8	24.0
Diazinon	5% dust	5.1	10.9
Dimethoate	20% wettable powder	36.2	37.0
Dimethoate	40% miscible oil	36.5	37.0
Dimethoate	5% granule	10.3	18.7
Dimethoate	5% dust	12.1	19.8
Untreated	Nil	59.6	50.6
S.E. $\pm$		-	3.2
Degrees of Freedom		-	8

The improved performance of dimethoate dust and granules was again evident in comparison with liquid drenches. There was also a notable improvement with diazinon dust. In trials where dimethoate dust or granules were applied some marginal leaf scorch occurred. This did not appear to affect the yield adversely.

Laboratory test, 1969 Adult flies were introduced into cages containing trays of radish seedlings treated with a range of dimethoate formulations at a dose equivalent to 32 oz a.i./ac, (equivalent to spot application of 0.09 g a.i./plant on cauliflowers). The mortalities of adults at 5 and 8 days is shown in Table 4.

Table 4.

% mortality of adult cabbage root flies in cages of treated radish seedlings

Dimethoate Formulations	Days after putting flies into cages on day of treatment 5 days	8 days
Wettable powder	19	63
Miscible oil	33	50
Dust	67	69
Granule	50	71
Untreated	0	10

For a short period after the introduction of the flies, the dust and granule formulations appeared to produce a higher, more rapid, mortality during the first 5 days of the exposure period.

DISCUSSION

The trials have confirmed that, with dimethoate, a highly significant improvement in control of cabbage root fly can be achieved by using a dust or a granule formulation to place the insecticide on the soil surface. In the case of diazinon, although the root drenches always performed as well as surface-applied granules, there appeared to be a significant improvement in control with the surface-applied dust.

The reasons for the observed differences have not been investigated for diazinon, and only partly examined for dimethoate. In the latter case, there is some preliminary evidence that kill of adults may be contributing to the improved performance of dust and granules. With dimethoate, the dust and granules may be acting simply as reservoirs of active ingredient, which is gradually released and becomes available for larval control over a longer period than occurs with the drench treatments.

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THE PROBLEM OF CARROT FLY CONTROL ON CARROTS

G. A. Wheatley
National Vegetable Research Station, Wellesbourne, Warwick

Summary Limitations in the performances of organophosphorus insecticides for carrot fly (Psila rosae) control on carrots are discussed and technical objectives are suggested. Control measures need to reduce carrot fly attack by at least 95% to ensure that fewer than 5% of the carrots are damaged when attacks are severe. A method is given for estimating relative efficiencies of control measures at different sites on different occasions.

Compared with a bow-wave application, the performance of chlorfenvinphos was improved 7-fold by placing it 4 inches deep 3 inches away from carrot rows 7 weeks after sowing.

When phorate, disulfoton, chlorfenvinphos and mecarbam were applied at sowing time by a bow-wave or by an experimental deep-placement method, their relative efficiencies changed during the autumn in both fen and sandy loam soil. For phorate and chlorfenvinphos, these changes could be attributed to behaviour of their residues. In fen soil, phorate was the most effective compound but the control given by chlorfenvinphos declined least during the season. Initially, in the sandy loam soil, disulfoton and chlorfenvinphos were the most effective compounds but, after 18 and 27 weeks respectively, they became less effective than phorate. Mecarbam was the least effective in both soil types. Bow-wave treatments declined in performance more quickly than deep-placement treatments applied at sowing-time, but the former tended to give better protection initially.

INTRODUCTION

The pre-sowing soil treatments with organochlorine insecticides, particularly aldrin and dieldrin, devised in the mid-1950's provided the first effective means for controlling high infestations of carrot fly (Psila rosae) on carrots. These treatments were gradually abandoned following the recommendations to restrict their use proposed in 1964 (Cook, 1964) but a more precipitous change to the alternative organophosphorus insecticides occurred in certain areas of East Anglia after 1967 when populations of the pest were found to have developed marked resistance to cyclodiene insecticides and cross-resistance to gamma-BHC (Wright and Coaker, 1968b; Gostick and Baker, 1968).

During the initial period of the changeover, the organophosphorus insecticides seemed to be controlling carrot fly satisfactorily. It was not until cyclodiene-resistant populations of the pest appeared and complete reliance had to be placed on the organophosphorus compounds that crops left in the ground after October were frequently found to be heavily attacked. It seems likely that dieldrin residues remaining in the soil supplemented the organophosphorus insecticides prior to resistance occurring (Wright and Coaker, 1968a). The situation has now been further aggravated, as predicted, by the re-occurrence of relatively high populations of carrot fly as a result of the lower levels of control that are being achieved.

From 1959 to 1968 very little work could be done to develop further control measures for this pest because the widespread use of organochlorine insecticides had reduced carrot fly populations to low levels. Makepeace and Smith (1965) encountered infestations affecting only up to 39% of the carrots in the untreated plots of trials done in 1964-5 and, even on experimental sites at Wellesbourne and Mepal, Cambs. where the soil was free from significant amounts of organochlorine insecticide residues, Wright (1961, 1962, 1965, 1966) experienced only 32-64% and 28-40% damaged carrots on the mineral and fen soil sites respectively. Under these conditions of attack, compounds with a modest performance can control carrot fly sufficiently to leave only a low incidence of attack on treated carrots. Misleading impressions can thereby be gained of the values of treatments to protect crops from more severe attacks, which may account for recent disappointments with the performances of the five insecticides at present approved for carrot fly control on carrots in the U.K., namely, diazinon, phorate, disulfoton, chlorfenvinphos and mecarbam. There is no doubt that all of these compounds are inherently toxic to carrot fly larvae. Their shortcomings are attributable mainly to their limited persistence in relation to the time over which protection is needed, particularly for maincrops sown in May and left in the ground after October. Furthermore, their biological activity and diffusive movement in the soil are probably more dependent on soil-type, soil-moisture status and rainfall than was the case with the organochlorine insecticides. The organophosphorus compounds therefore tend to be more variable in performance, and consequently less reliable, but there is also evidence that none of the present methods of application position them in the soil to best advantage (Wheatley and Hardman, 1968).

Objectives Technical objectives of pest control have been discussed by Wheatley and Coaker (1969) who stressed the importance of stipulating definite targets to be achieved by control measures. Carrot fly larvae cause direct damage to the edible part of a crop destined for human consumption and, ideally, the damage needs to be eliminated completely. A criterion of "zero damage" is, however, neither economically nor technically attainable and finite limits must be set depending on the particular pest/crop/market problem. For instance, some carrot fly damage can be tolerated on perhaps 10% of the carrots when they are destined for the fresh market because, at this level of attack, the amount of damaged tissue is usually so slight that most would be masked by soil adhering to the carrots. For this market outlet, a criterion of fewer than 10% damaged carrots is probably adequate. When crops are to be pre-packed or processed, more stringent criteria are necessary, stated either in terms of the % carrots damaged or the % carrots containing larvae. In either case, it is unlikely that more than 5% damaged carrots would be tolerable and for some purposes even 1-2% damaged carrots may pose grading and sorting difficulties. These limits are suggested as working criteria on the assumption that all damaged carrots are detected, by carefully examining individual washed roots. If less critical inspection systems are used, these criteria will need to be reduced accordingly.

Furthermore, when the incidence of damage is very low, large samples are needed in order that there may be a reasonable certainty that damage will be detected (Wheatley and Coaker, 1969). If a consignment contains 3% damaged carrots, and a sample size of 100 carrots is used, then 1 sample in 20 would, by chance, contain no damaged roots. This is a typical quality control problem which must be borne in mind when setting pest control objectives which, if over-critical, can neither be met by growers nor readily checked upon by an inspectorate.

Studies of carrot fly infestations have shown that for practical purposes the damage occurs approximately according to a Poisson distribution in samples of carrots (Wheatley, 1969) and this enables a relationship to be established between the efficiency of control measures, levels of attack and the residual levels of damage after treatment (Wheatley and Coaker, 1969). Infestation levels sufficient to damage in excess of 80% untreated maincrop carrots can once again be expected to occur in some areas and this relationship predicts that a control measure must reduce such a carrot fly population by more than 90% in order to ensure that fewer than 10% of the carrots would be attacked after treatment. If fewer than 5% attacked roots can be tolerated, the efficiency of control needed would be in excess of 95% reduction of carrot fly attack and for fewer than 1% attacked roots, the method must be more than 99% efficient. These levels of efficiency are the primary technical objectives and it is clear that for this pest only the highest standards of efficiency attainable in practice are likely to be adequate and therefore that only the very best methods of pest control will be acceptable. Second-rate methods are thus of little practical interest and this simplifies the selection of methods for carrot fly control.

METHODS

Assessment of efficiency The results of field experiments to assess the performances of insecticides against carrot fly are difficult to interpret when they are expressed only as "% attacked carrots" because the performances in different sites and on different occasions are confounded by the different levels of infestation encountered. The actual numbers of carrot fly larvae present in treated and untreated plots cannot be easily determined directly to assess the % reduction in carrot fly attack brought about by treatments, a measure which would be independent of infestation levels. A basic relationship (Wheatley, 1968) existing between % of undamaged carrots and the amount of damage, which is indicative of the numbers and stage of development of carrot fly larvae present, enables the % reduction in carrot fly attack (% efficiency) for treatments to be calculated as follows:

$$\% \text{ efficiency} = 100 \left[1 - \left(\frac{\ln p_t}{\ln p_c} \right) \right]$$

where $\ln p_t$ and $\ln p_c$ are the natural (Naperian) logarithms (negative values decreasing) of the proportions of undamaged roots from treated and untreated plots respectively. An example of results calculated in this way is shown in Table 1. The % efficiency thus expressed is equivalent to % mortality in laboratory toxicological experiments and hence an orthodox dose/response curve can be constructed by plotting probit-% efficiency against log-dose (Fig. 1). The dose needed to reduce the population by 95% (ED95) can be estimated graphically and this should be virtually independent of the level of infestation encountered on an experiment provided that root density is constant. The relative potency of treatments against the pest can be obtained by calculating the ratios of the ED95 values

Table 1.

Computation of % reduction in carrot fly population; 1967 experiment

Treatment	Dose (oz a.i./ac)	Unattacked carrots %	Unattacked carrots proportion $= \frac{\%}{100}$	*Natural log $\ln p_t$	*Natural log $\ln p_c$	% reduction $100\left[1 - \left(\frac{\ln p_t}{\ln p_c}\right)\right]$
Bow-wave, sowing-time, 7 June	8	65.3	0.653	-0.426	-	75.6
	16	71.2	0.712	-0.342	-	80.4
	32	85.3	0.853	-0.159	-	90.9
Late, deep-placement 21 July	8	87.5	0.875	-0.134	-	92.3
	16	94.9	0.949	-0.052	-	97.0
	32	96.0	0.960	-0.041	-	97.6
Untreated	0	17.5	0.175	-	-1.743	0

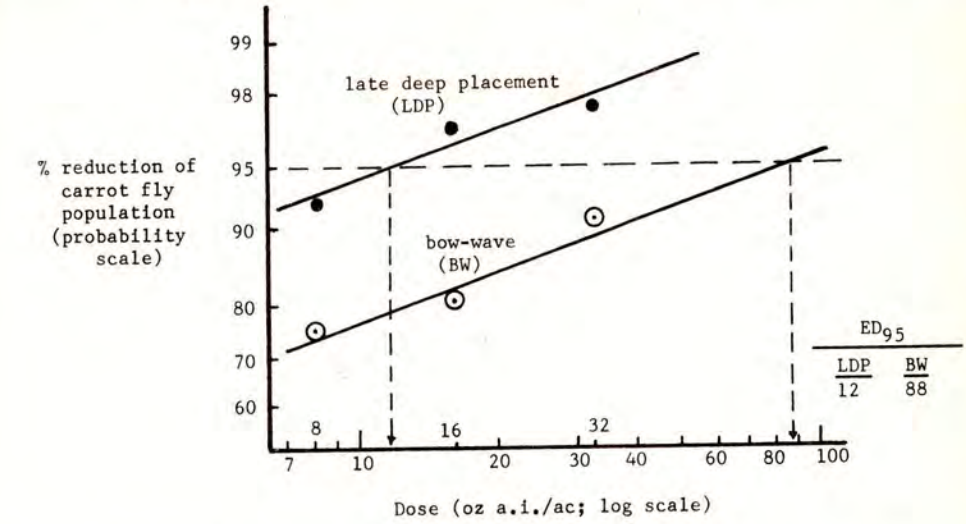
*negative values decreasing

using one of the treatments as a standard. In this way the results of a series of experiments can be assessed and the best treatments determined both in relation to efficiency and reliability. By examining samples at different times during one experiment, systematic increases in ED95 values will reveal the rate at which the efficiencies of the treatments are declining.

Experimental In 1967, a 3-replicate, randomised block experiment was undertaken at Wellesbourne to investigate the possibility that the performance of chlorfenvinphos

Fig. 1

Illustration of estimation of the ED95 doses for chlorfenvinphos granules (10% a.i.) applied by bow-wave and late deep-placement methods, 1967



could be improved by better placement and by delaying the application of the insecticide to minimise residue losses prior to the onset of second generation attack (Wheatley and Hardman, 1968). A 10% granular formulation of chlorfenvinphos was applied at doses of 8, 16 and 32 oz a.i./ac either by bow-wave technique at sowing time on 7 June or by placing it 4 inches deep at a distance of 3 inches from carrot rows (15-inch centres) late in July. Samples of carrots taken at the end of November were graded into "attacked" and "unattacked" roots and the % reduction in carrot fly was calculated for each treatment as described above.

In 1968, experiments were done (Wheatley and Niendorf, 1969) in which carrots (cultivar Amsterdam 5558) were sown in mid-April in 6-inch twin rows with a 22-inch interval between pairs of rows. Plots comprised 18 ft of twin-row and each treatment was replicated 3 times. Using specially devised tractor-mounted equipment for both bow-wave and deep-placement (3 inches from row centres, 4 inches deep) methods, the insecticides phorate, disulfoton, chlorfenvinphos and mecarbam were applied as 10, 7.5, 10 and 4% granular formulations respectively. Doses of 5.3 and 16 oz a.i./ac were used for an experiment on sandy loam soil at Wellesbourne and 8 and 24 oz a.i./ac for an experiment on black fen soil at Mepal, Cambs. At both sites, the carrots were sown and treated simultaneously in mid-April and carrot fly attack was assessed on the carrots from 4 ft of twin-row/plot sampled in late July or early August, early in October and in November (Table 2). The ED95 doses for each treatment were estimated and the relative efficiences were calculated, using the first assessment of the performance of phorate applied by bow-wave as the standard (relative efficiency = 1) for the comparisons in each experiment.

RESULTS

1967 experiment A summary of the assessments made on this experiment is given in the third column of Table 1 as "% unattacked carrots" but a better appreciation of the differences between the two types of application is revealed when the % efficiency is computed and presented graphically, as in Fig. 1. A comparison of the estimated ED95 doses indicates that the late deep-placement method was approximately

Fig. 2

Decline in effectiveness of insecticides applied by bow-wave and deep-placement methods at sowing time: sandy-loam, Wellesbourne 1968

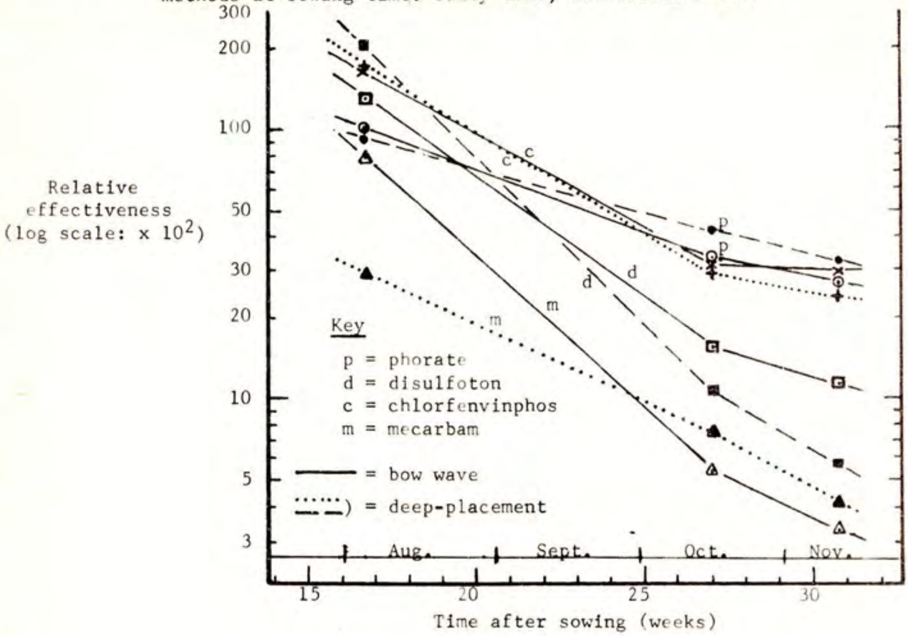
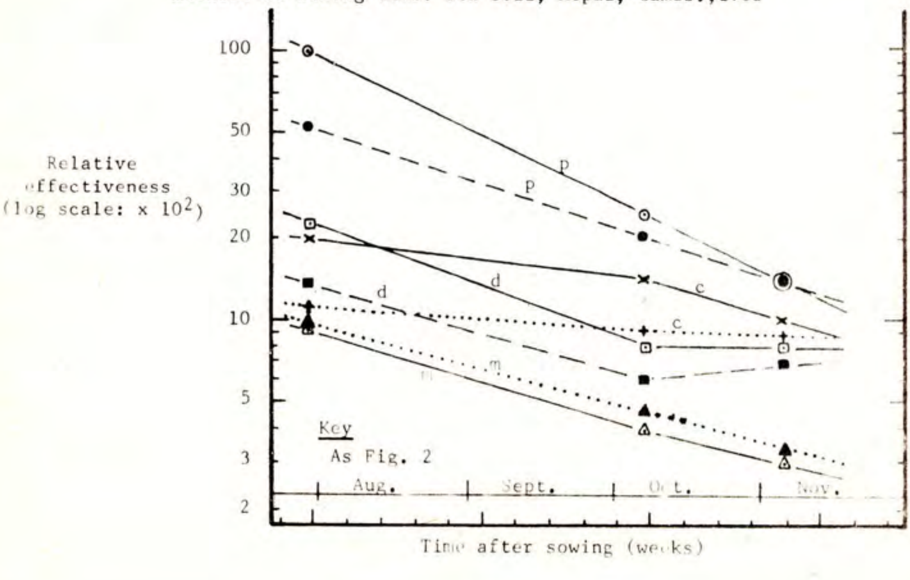


Fig. 3

Decline in effectiveness of insecticides applied by bow-wave and deep-placement methods at sowing time: fen soil, Mepal, Cambs.,1968



7 times more effective dose for dose than the bow-wave treatment. However, a substantial proportion of the carrots from the late-treated plots were fanged, almost certainly the result of the difficulty of steering the hand-drawn deep-placement coulter used for this experiment. The yields from these plots were 8% less (significant; P = 0.05) than for the carrots treated at sowing time by the bow-wave method.

1968 experiment The levels of attack on the untreated plots of these experiments are summarised in Table 2. By November, carrots treated at the higher doses by the bow-wave method had 10 and 24% attacked roots on the sandy-loam and fen-soil sites respectively. The relative efficiencies of the treatments, calculated as described above, are shown in Figures 2 and 3 which clearly display the differences in the rates of progressive decline in the effectiveness of the four insecticides.

Table 2.

Sampling dates and levels of infestation encountered in the 1968 experiments

Wellesbourne (sandy-loam)		Mepal (black fen)	
Date sampled	% attacked roots	Date sampled	% attacked roots
5 August	8.7	30 July	46.8
16 October	42.2	7 October	78.7
11 November	42.2	5 November	87.3

Phorate was the most effective insecticide on the black fen soil and it gave the best initial protection when it was applied by the bow-wave method at sowing time. The effectiveness of this method declined more rapidly than for the deep-placement method so that both methods were equally effective at the time of the last sampling in November and the trends indicated that the latter would have given better protection thereafter. The effectiveness of chlorfenvinphos declined relatively slowly particularly when it was placed 4 inches deep in the soil, and this caused a reversal in its order of effectiveness compared with disulfoton between the first and second sampling dates. By December, it would have been approximately equivalent in performance to phorate which, initially, had been so much superior.

On the sandy loam soil at Wellesbourne, when the first samples of carrots were lifted in August, the relative order of effectiveness was chlorfenvinphos $>$ disulfoton $>$ phorate $\gg$ mecarbam. Whereas chlorfenvinphos, disulfoton and mecarbam all declined in efficiency markedly between August and November, the efficiency of phorate changed less so that it was giving a better control than disulfoton after 18-19 weeks, and it became better than chlorfenvinphos after 26-27 weeks. On the fen soil, differences between the performances of the two methods of application were less obvious, the rates of decline in the effectiveness of the bow-wave treatments being greatest for phorate and mecarbam and least for chlorfenvinphos and disulfoton.

DISCUSSION

The experiments described above illustrate the advantages of using a method to evaluate insecticides that enables quantitative comparisons of performance to be derived and also minimises the confusing influence of variations in infestation levels.

The results of the 1967 experiment give a measure of the extent to which timing and placement of an insecticide could lead to improved levels of control within the limitations on dose imposed by residue and cost considerations. The late deep-placement method needs much more exploration to investigate the timing of the application and its effects not only on carrot fly control but also on the growth of the crop itself before practical recommendations can be made. It cannot be over-emphasised that this method requires specially designed equipment, operated with great care, to ensure minimum crop disturbance (Wheatley and Niendorf, 1969).

The changes in the relative efficiencies of the insecticides on the two soil types affords an explanation of how apparently conflicting results can be obtained, depending on the time elapsing between treatment and harvest. The differences in behaviour of phorate and chlorfenvinphos on the 2 soil-types is in accordance with known data on the persistence of their residues. In mineral soil, chlorfenvinphos residues decline to low levels, approximately exponentially, during the summer and early autumn (Beynon, K. I. et al, 1966; Wheatley and Hardman, 1967 but, after a rapid initial loss in fen soil, its residues decline only slowly during this period (Beynon, K. I. et al, 1966). In contrast, phorate seems to have a longer residual effect in mineral soil, presumably because of the slow decline of its biologically active sulphone breakdown product (Suett and Wheatley, 1969). The good agreement between the results of soil residue analyses and the biological effectiveness of these two compounds offers additional means for investigating and improving the performance of insecticides against carrot fly.

Acknowledgments

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EFFECTS OF TIMES AND METHODS OF APPLICATION ON THE PERFORMANCE OF INSECTICIDES AGAINST CARROT FLY AND CARROT WILLOW APHID

D. J. Mowat
Agricultural Entomology Division, Queen's University, Belfast

Summary A satisfactory control of carrot fly was obtained on late-harvested carrots when phorate was incorporated into the top soil, just before the onset of the second generation attack, to supplement either a presowing treatment or a gamma-BHC seed dressing. A similar late application of disulfoton was less effective and this insecticide failed to give satisfactory carrot fly control on late-harvested carrots, although it performed similarly to phorate when it was applied as a pre-sowing treatment and its effectiveness was less dependent on incorporation with the soil. The effects of disulfoton lasted longer than those of phorate when the insecticides were left on the soil surface, but phorate was the more persistent when they were incorporated into the soil. Disulfoton gave the better initial control of carrot-willow aphid, heavy infestations of which reduced yield by up to 50%.

INTRODUCTION

Although presowing applications of certain organophosphorus insecticides are satisfactory to control carrot fly (Psila rosae) on early carrots, they are of relatively short persistence, suggesting that a later application could be used with advantage on maincrop and late carrots. Carrots sown after mid-May are likely to escape much of the first generation attack but they require protection against the attacks that develop from late oviposition by the flies in mid-October. The purpose of the experiments described below was to determine the optimum time for insecticide applications, particularly for controlling the late attack. Observations were also made on the effects of some of the treatments on infestations of carrot-willow aphid (Cavariella aegopodii).

METHOD

Three experiments were undertaken on a medium loam soil, the first two on the same site in 1967 and in 1968. The granular formulations of phorate, disulfoton and chlorfenvinphos used in these experiments contained 10, 7.5 and 10% a.i. respectively.

Experiment 1 was sown on 14 April 1967 in beds with 6-inch inter-row spaces. Granules containing phorate, disulfoton and chlorfenvinphos were broadcast to give 48 oz a.i./ac either as presowing applications on 13 April which were raked into the top soil or as post-emergence applications on 4 May which were left on the soil surface. In addition, presowing applications at 24 oz a.i./ac were also made on 13 April and these were augmented on 17 July, shortly before the onset of second generation carrot fly attack, by further broadcast applications at 24 oz a.i./ac which were incorporated into the top soil between the rows.

In Experiment 2, the carrots were sown on 7 May 1968 at the same row-spacing as Experiment 1. Phorate and disulfoton granules were applied at 24 oz a.i./ac, post-emergence, on 29 May, 13 June or 11 July as 3-inch wide bands along the rows, where they remained on the soil surface.

For Experiment 3, a gamma-BHC seed dressing was used at 0.5 oz a.i./16 oz seed and the carrots were sown continuously in rows 12 in apart on 24 April 1968. Phorate and disulfoton were applied at 24 oz a.i./ac post-emergence on 14 June and

10 July as 3-inch wide bands along the rows. The granules were either lightly covered to simulate ridging or left on the soil surface.

First generation carrot fly damage and aphid infestations were assessed in early July and second generation carrot fly damage in October. Further examinations of samples from Experiments 1 and 3 were made in November to obtain additional information about the effectiveness of the treatments against the late attack. In the autumn assessments, the amounts of damage on the roots were scored 1 to 10 according to the number and the extent of the mines. The mean score per carrot was then calculated by dividing the summed score for each treatment by the total number of roots examined. This information was obtained in case the different insecticides gave differing degrees of protection depending on whether or not the larvae were killed by insecticide in the soil before they commenced feeding, a factor which could be of practical importance when only a slight attack is present.

RESULTS

The results of treatments applied in Experiment 1 are shown in Table 1. It was apparent that disulfoton was more effective than phorate as a post-emergence broadcast treatment left on the soil surface. However, the most effective control of carrot fly was given by the split application of phorate whereby half of the dose was applied presowing and half just before the beginning of the second generation attack, both applications being lightly incorporated into the soil.

Table 1.

Carrot fly control by insecticides broadcast at 48 oz a.i./ac

Application	Insecticide	Sampling dates			
		4 October		14 November	
		% damaged	Score	% damaged	Score
13 April presowing	phorate	23	0.64	32	0.95
	disulfoton	24	0.56	32	0.49
	chlorfenvinphos	32	0.78	56	1.53
4 May post-emergence‡	phorate	27	0.65	40	1.20
	disulfoton	16	0.37	23	0.65
	chlorfenvinphos	18	0.34	48	1.15
13 April and 17 July presowing & late*	phorate	6	0.11	10	0.17
	disulfoton	19	0.41	22	0.47
	chlorfenvinphos	19	0.37	32	0.72
Untreated	Nil	62	1.69	79	2.86
S.E. ±		5.9	0.20	5.7	0.27
d.f.		69	69	69	69

‡ left on soil surface; other applications incorporated into soil
* 24 oz a.i./ac on each occasion

The results for Experiment 2 are given in Table 2 and they again demonstrate the value of a late application of phorate on 11 July which gave better protection from carrot fly attack up to the time of sampling on 10 October than did either of the two earlier applications. Although an examination of the plants in early July showed that phorate and disulfoton were both giving a similar high level of control of carrot-willow aphid, the increased weights of the carrots from the disulfoton-treated plots indicated that, overall, it had probably given a better control of the aphids during the earlier stages of plant growth than had phorate.

Table 2.

Effects of post-emergence insecticide applications at 24 oz a.i./ac on carrot fly damage and carrot weight

Application	Insecticide	10 October				
		Carrot fly attack		Mean weight oz/carrot		
		% damaged	Score	All roots (a)	Undamaged roots (b)	Ratio a/b
29 May	phorate	15.7	0.29	2.16	2.00	1.08
	disulfoton	16.4	0.33	2.36	2.32	1.02
13 June	phorate	10.5	0.21	1.95	1.83	1.07
	disulfoton	7.3	0.12	2.44	2.43	1.00
11 July	phorate	4.2	0.05	2.14	2.09	1.03
	disulfoton	9.0	0.18	2.08	2.00	1.04
Untreated	Nil	38.4	1.04	2.00	1.62	1.24
S.E.			0.14			
d.f.			18			

Table 3.

Carrot fly control by seed dressing and late insecticide applications at 24 oz a.i./ac

Application	Insecticide	Cultivation after application	Date sampled			
			7 October		26 November	
			% damaged	Score	% damaged	Score
Seed dressing	gamma-BHC	-	46	1.32	54	2.30
		+	38	1.05	65	2.27
Seed dressing plus:-						
14 June	phorate	-	18	0.35	44	1.37
		+	19	0.35	17	0.28
	disulfoton	-	46	1.16	43	1.96
		+	27	0.88	43	1.73
10 July	phorate	-	12	0.17	22	0.44
		+	3	0.08	14	0.30
	disulfoton	-	33	0.70	50	1.65
		+	26	0.54	32	1.01
Untreated	Nil	-	84	2.74	90	3.75
		+	92	2.23	84	3.79
S.E. ±				0.18		0.24
d.f.				15		15

Experiment 3 was heavily infested by the carrot-willow aphid which, on 10 July, was found to have been better controlled by the disulfoton applied on 14 June than by the comparable application of phorate. A heavy carrot fly attack also developed on this experiment and when carrot samples were examined on 10 July, neither phorate nor disulfoton applied on 14 June were found to have increased carrot fly control beyond that achieved by the seed dressing alone which had reduced the percentage of damaged carrots from 65% on the untreated plots to 10%. At this stage, the plant stand in the untreated plots was unaffected but, soon after, considerable numbers of plants died from first generation carrot fly attack. The results for the samples examined on 7 October and 26 November are shown in Table 3. The best protection from second generation carrot fly attack was obtained when the seed dressing was supplemented by phorate applied on 10 July and lightly covered over with soil to simulate ridging. The earlier application of phorate on 14 June was less effective but the phorate granules, whether covered or uncovered, gave better carrot fly control than any of the disulfoton treatments in this experiment. The seed dressing was clearly contributing substantially to the level of control even at the time of the last sampling on 26 November. The very poor performance of disulfoton in this experiment contrasts with the appreciable, though inadequate, level of carrot fly control which it exerted in Experiments 1 and 2.

DISCUSSION

Wheatley and Hardman (1966) and Bevan (1967) have demonstrated that the performance of disulfoton against carrot fly is not much affected by placement whereas Wheatley and Hardman (1967) also found that the performance of phorate is more affected by depth of placement in the soil than is the case for disulfoton. In the present experiments, this was more noticeable in November than when carrots were examined six weeks earlier, suggesting that the main benefit of incorporating phorate into the soil may be increased persistence rather than an immediate enhancement of effect. Phorate is clearly less effective in giving long-term control when it is left uncovered on the soil surface than when it is mixed into the soil whereas the performance of disulfoton is less affected in this way. Disulfoton seems to be insufficiently effective to give adequate protection when very high infestations of carrot fly are encountered, as in Experiment 3, and this is supported by its failure to give a high level of control in either of the other experiments.

The differences between the carrot fly damage on treated and untreated plots, and also between the seed dressing and the other insecticide treatments, were more conspicuous when the damage was assessed by scoring than when only the percentage of damaged carrots was considered. However, there was no appreciable difference between the two methods when comparing chlorfenvinphos with phorate and disulfoton treatments supporting the conclusion of Wheatley and Hardman (1967) that carrot fly control is dependent on chemicals being taken up by the root tissues.

Yield reductions by aphid infestations occurring simultaneously with carrot fly attacks are difficult to estimate. It can be seen from Table 2 that the ratio of the mean weights of all carrots to those of undamaged carrots were always greater than unity implying, therefore, that larger carrots are more vulnerable to carrot fly attack. Similarly, it is not permissible to assess the effects of aphid infestations by comparing only the weights of undamaged carrots, except in samples having the same level of carrot fly attack. However, the data in Table 2 shows that, for each of the two earlier insecticide applications, the undamaged carrots from disulfoton-treated plots more closely approached the overall mean weights than did those from the phorate-treated plots. This must be attributed to better aphid control by disulfoton, although no differences were detected in the aphid populations on these plots 5 weeks after the first applications had been made and 3 weeks after the second applications. It also seemed likely that the surface applications of disulfoton had a more prolonged aphicidal effect than did those of phorate. The third applications of the insecticides were done after the peak aphid attack had occurred and the high level of carrot fly control given by phorate resulted in the ratio of carrot weights approaching unity for this treatment.

Table 3.

Treatments applied, seedling emergence, plant vigour, and yield at Thornton, 1967 (Trial XII)

Treatment	oz a.i./ acre	Seed-lings/ yard 30th May	Vigour score (0-5) 30th May	Vigour score (0-5) 5th July	Sugar %	Sugar yield* cwt/acre	No. of harvestable roots 1000/acre	Root fangi-ness (0-5)
Control	-	18.7	1.33	2.50	16.7	27.4	23.1	3.25
Menazon seed-dressing	3.6	18.4	1.21	2.50	16.4	29.8	22.3	3.32
Thionazin in seed pellet	0.5	17.1^{-}	1.38	3.00^{+}	16.8	32.4	24.7	2.96
Thionazin granules in furrow with seed	16.2	6.1^{---}	0.83^{---}	3.17^{++}	17.0^{+}	34.2	18.1^{--}	3.10
'D-D' 2 ml at 6 in depth and 12 in centres, 17th January (225 lb)	-	18.0	2.88^{+++}	4.83^{+++}	17.7^{+++}	52.5^{+++}	26.3^{+}	1.67^{+++}
S.E. ±		0.43	0.084	0.149	0.10	2.50	1.05	0.156

-, --, --- Significantly poorer than the control at the three levels of probability.
+, ++, +++ Significantly better than the control at the three levels of probability.

* With nitrogen top-dressing, yields were respectively - 33.8, 32.9, 42.6^{+}, 37.2, 57.3^{+++} cwt sugar/acre.

In 1967, Sharpe's Klein E and Triplex seed with and without menazon seed-dressing were tested at two drilling depths in single-row plots at twelve sites (Trials XI_1-XI_{12}). Triplex is a more vigorous growing variety than Sharpe's Klein E, and deep drilling ($1\frac{1}{2}$ in, compared with the usual $\frac{3}{4}$ in) was tested as an adverse factor on seedling vigour that might induce greater effect of nematode feeding on plant growth. Menazon had a consistent and slightly adverse effect on seedling population, plant population and root yield. Deep drilling had a similar adverse effect, except with root yield of Sharpe's Klein E, viz.

	Sharpe's Klein E				Triplex			
	Shallow		Deep		Shallow		Deep	
± menazon	–	+	–	+	–	+	–	+
Seedlings/yard	13.9	12.9	12.8	11.8	13.4	12.8	12.3	11.7
Plants/chain	74.3	70.4	74.0	70.1	74.7	73.3	76.7	73.1
Ton beet/acre	18.6	17.9	19.2	18.0	18.0	17.7	17.8	17.4

Mild Docking disorder was apparent only on parts of three of the twelve trials and the good root yield emphasised the lack of nematode damage.

Menazon seed-dressing, thionazin incorporated in the seed pellet and thionazin granules in the seed furrow were tested at two sites in 1967 (Trials XII and XIII). Overall soil fumigation with 'D-D' was also included in Trial XII. At both sites the plots were split for top-dressing with 'Nitro-Chalk'.

At Thornton, York, 4 cwt salt and 120:60:60 units N, P_2O_5, K_2O/acre were applied to the trial area in February, 1967. The plots were 1/63 acre arranged in a 6 x 6 Latin square layout, and there were 6,000 _T. anemones_/l of soil at sowing on 10th April. On 30th May seedlings showed pronounced symptoms of Docking disorder, many having dead tap roots with brown, stubby laterals, and leaves showing nitrogen and magnesium deficiency. The thionazin treatments and, especially, the 'D-D' soil fumigation improved root health, but menazon seed-dressing did not. Fewer seedlings emerged from the two thionazin treatments (Table 3). Plant vigour was improved throughout the season by 'D-D' and, after initial signs of toxicity to the beet had disappeared, by thionazin granules. At harvest, on 18th October, yield on the control plots (8.2 ton washed sugar beet, 27.4 cwt sugar/acre) was small and the roots were very fangy, indicating the severity of the Docking disorder. All treatments improved yield, 'D-D' fumigation almost doubling it. Nitrogen top-dressing (30 units N/acre on 31st May and again on 4th July) increased yield on the control, the thionazin seed treatment and 'D-D' treatment by 6.4, 10.2 and 4.8 cwt sugar/acre respectively. 'D-D' and both thionazin treatments decreased the amount of soil adhering after lifting ('dirt tare') but only 'D-D' decreased root fanginess.

At Hellesdon, Norfolk, 120:60:60 units N, P_2O_5, K_2O/acre were applied to the trial area in early March, 1967. The plots were 1/35 acre arranged in a 5 x 5 Latin square layout, and there were 2,000 _Trichodorus_/l of soil at sowing on 23rd March. Nematodes damaged the seedling roots only slightly and Docking disorder did not develop in the trial area. All treatments depressed seedling numbers, and thionazin granules at 17.4 oz a.i./acre in the furrow with the seed depressed seedling vigour (Table 4). At harvest, on 26th October, yield on the control plots (15.8 ton of washed sugar beet, 54.1 cwt sugar/acre) was satisfactory, as was root shape, and emphasises the mildness of Docking disorder. Thionazin granules at 17.4 oz a.i./acre in the furrow with the seed decreased the number of roots harvested; no other treatment did so, and none of the treatments influenced any of the other factors measured at harvest. Top-dressing with nitrogen at 50 units/acre on 14th June slightly increased the yield of tops (not shown in Table 4), but did not affect sugar yield.

Table 4.

Treatments applied, seedling emergence, plant vigour, and yield at Hellesdon, 1967 (Trial XIII)

Treatment	oz a.i./ acre	Seed-lings/ yard 3 May	Vigour Score (0.5) 16th May	Sugar yield cwt/ acre	No. of harvest-able roots 1000/acre	Root fangi-ness (0-5)
Control	-	20.7	3.30	54.1	36.9	1.23
Menazon seed-dressing	2.8	18.9^{-}	3.33	58.0	36.5	1.51
Thionazin in seed pellet	0.5	19.1^{-}	3.37	58.9	36.7	1.39
Thionazin granules in furrow with seed	4.8	19.0^{-}	3.23	55.6	37.1	1.16
Thionazin granules in furrow with seed	17.4	12.5^{---}	2.43^{---}	56.7	32.8^{--}	1.65
S.E. ±		0.46	0.089	3.85	0.78	0.195

-, --, --- Significantly poorer than the control at the three levels of probability.

At both Thornton and Hellesdon in 1967 some newly-available nematicides were compared with thionazin in single-row plots. Docking disorder was more severe at Thornton than at Hellesdon and thionazin granules increased yield only at Thornton. In contrast, methomyl solution, and aldecarb granules still more, decreased fanginess and increased yield at both sites (Table 5).

Table 5.

Treatments applied, root fanginess and sugar yield, Thornton and Hellesdon, 1967 (Trials XIV and XV)

Pesticide	oz a.i./ acre	Thornton, York		Hellesdon, Norwich	
		Root fanginess (0-5)	Sugar yield* (cwt/acre)	Root fanginess (0-5)	Sugar yield* (cwt/acre)
Control	-	3.1	29.2	1.8	48.5
Thionazin seed-dressing	0.1	3.2	35.8	2.1	54.0
Thionazin granules	9.0	2.0	45.8^{+++}	1.4	51.9
Aldecarb granules	4.8	1.0^{+++}	55.9^{+++}	0.5^{+++}	77.4^{+++}
Methomyl solution	5.3	2.6^{+}	40.4^{+}	0.4^{+++}	70.4^{++}

+, ++, +++ Significantly better than the control at the three levels of probability.
* Yield increases probably exaggerated because of single-row plots.

DISCUSSION

The above-ground symptoms of Docking disorder of sugar beet are irregularly stunted growth, with leaf symptoms of nitrogen and magnesium deficiency. Root growth is so curtailed that the plants' requirements of nitrogen and magnesium cannot be taken up. Some granular nematicides placed in the root zone of stunted plants in Trial III killed or inactivated some L. attenuatus, and phorate increased yield. Injection into the root zone by knife-coulter probably damaged roots, and distribution of the active material was probably inadequate in Trials I-III. Point-injection of solution into the root zone in Trials IV-VII increased plant vigour and yield more. The water soluble systemics - aldecarb, methomyl, phorate and thionazin - were more beneficial than dibromochloropropane. In some of the trials nitrogen placed into the root zone improved growth and yield; nitrogen topdressing was helpful in later trials (X and XI) and is simpler than injection.

Cooke, et al. (1969) showed that nitrogen readily leaches down in the sandy soils where Docking disorder occurs. Extra nitrogen alleviates the nematode damage, probably because it makes good a deficit from leaching, but perhaps also because it is better absorbed by a damaged root system. The 1966 Thornton trial (X) showed the benefit of 100 extra units N/acre in the seedbed at sowing, although 120 units/acre were applied only two weeks earlier (Table 2). Root fanginess is decreased by nematicides, but also by extra nitrogen in the seedbed, as shown in this trial and in those of Draycott and Cooke (1969). Root fanginess arises from loss of the tap root tip; one or more laterals then take over the function of the tap root (Daniels, 1965). With adequate or excess nitrogen in the seedbed, the roots presumably grow quickly through the critical stage when nematode feeding can kill the root tip and cause fanginess. Soil fumigation in Trial XII increased sugar yield more than did any other treatment in any of the trials discussed. Nematode control probably contributed more to this yield increase than did the extra nitrogen available after fumigation (Draycott and Cooke, 1969).

The preliminary row-treatment trials in 1964 showed that benefit could be obtained from small amounts of nematicide placed with the seed; menazon, dibromochloropropane, phorate and thionazin increased crop vigour or sugar yield, or both. However, the yield increases at these two sites (Trials VIII and IX) were less than the soil sterilisation effects in adjoining trials, where both 'D-D' and chloropicrin doubled yield (Heathcote, et al., 1966). The 1966 trial at Thornton (Trial X) again showed that menazon seed-dressing decreased fanginess and improved yield, but extensive trials in 1967 (Trials XI_1-XI_{12}, XII and XIII) failed to confirm this. Menazon is not nematicidal (Peacock, Pers comm.) and its mode of action in the 1964 and 1966 trials is not known. Thionazin was more effective than phorate in the 1966 trial, increasing the seedling population and final sugar yield, and decreasing root fanginess; thionazin must have protected the seedling tap root from severe nematode damage but killed few or no nematodes. The thionazin-treated sugar beet plants grew vigorously early in the season, but less vigorously later because deficient in nitrogen.

In 1967 (Trials XII and XIII) thionazin application severely damaged plant growth early in the season at both sites when used at 16-17 oz a.i./acre. However, it improved vigour greatly at Thornton from July onwards, and tended to increase yield at both sites. Less thionazin damaged growth less but did not increase yield. Thionazin incorporated in the seed pellet (0.5 oz a.i./acre) increased sugar yield in both trials, especially with nitrogen top-dressing at Thornton (viz. 33.8 $\rightarrow$42.6 cwt sugar/acre). In further trials with thionazin in 1967 it again increased sugar yield, whether as a seed dressing or as granules with the seed, but aldecarb and methomyl decreased fanginess and increased sugar yield considerably more (Table 5) (Dunning and Winder, 1968).

Concurrently with these trials testing menazon, thionazin and, more recently aldecarb and methomyl, Whitehead and Greet (1967) and Whitehead and Tite (1968, 1969) have been developing row treatment with soil fumigants. 'D-D' or 'Telone' applied by knife-coulter at 6-8 in depth in the seed row two weeks before sowing now seems likely to become a common commercial practice, especially as about 20,000 acres suffered from Docking disorder in 1969. Row fumigation increases sugar yield considerably because it kills nematodes, and possibly some other pathogens, in the seedling root zone and also makes extra nitrogen available. Applying a systemic nematicide in the seed furrow during sowing is much easier than fumigating the rows two weeks earlier, but it may be less reliable and does not obviate the need for adequate nitrogen. Phorate and thionazin are too liable to damage beet to be used safely, but our current trials with methomyl and, especially, aldecarb show promise.

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CONTROL OF STEM NEMATODE (DITYLENCHUS DIPSACI) IN FLOWER BULBS WITH HOT WATER OR THIONAZIN

A. L. Winfield
National Agricultural Advisory Service, Cambridge

Summary Treatment of narcissus bulbs heavily infested with stem nematode (Ditylenchus dipsaci) using hot water or the systemic nematicide thionazin did not control it for two years. Nematode control was improved by raising the temperature of the water, but higher temperatures damaged the bulbs. Drenching or spraying heavily infested narcissus with thionazin in the field was unsatisfactory. For tulips, hot water treatment at 115°F (46°C) or dipping in thionazin (2,300 ppm) soon after the bulbs were lifted in July, controlled the stem nematode well, but hot water treatment impaired vigour and flowering the following season. Thionazin was not phytotoxic to tulips or narcissi, although with twice the recommended strength, early treatment (July) gave better results than late treatment (September). Infested narcissus bulbs were successfully forced when stored for six weeks at 48°F (9°C), then treated for two hours with either 2,300 ppm. of thionazin or hot water at 112°F (44°C).

INTRODUCTION

Stem nematode (Ditylenchus dipsaci) is a major limiting factor in narcissus production, and a very serious threat to the tulip crop. There are about 12,000 acres of tulips and narcissi in the British Isles, and in the small area of silt land near the Wash, mainly in the Holland division of Lincolnshire, there are about 6,250 acres of bulbs with an annual value (including forced flowers) estimated to be more than £12 million. Each year growers spend much time and effort, sometimes unsuccessfully, on control measures against stem eelworm. Until Ramsbottom (1919) showed that hot water treatment (HWT) could give a satisfactory control, there was no other method except digging out obviously infested plants from the growing crop and sorting out soft bulbs at lifting time. Such expensive procedures are still used as well as HWT and the most successful growers find that careful field inspection, roguing and sorting can considerably reduce the proportion of infested bulbs for HWT thereby improving the general level of control.

In the 1950's there was mounting concern among growers and advisers that the recommended HWT of 110°F (43°C) for three hours was not controlling the nematode sufficiently. Narcissus bulbs are perennial storage organs, and are usually planted out in the field for two years. Control must therefore be very good if stem nematode is not to cause severe damage in the second year after treatment. The temperature of treatment is near the limit that the bulbs can tolerate without damage (Rees and Turquand 1967) and Slootweg (1962) has shown that long periods (up to five hours) may be needed to give a good control at temperatures of 110-113°F (43-45°C). This increases the risk of bulb damage, and the throughput of bulbs in the HWT tanks is very slow.

Systemic nematicides were first used in 1964 by a small number of growers in Lincs. (Holland), Cornwall and the Channel Islands, following successful experiments with thionazin by Purnell and Hague (1965). As with hot water treatment a number of difficulties arose as experience was gained, and some of the experiments described here were carried out because of these problems. In normal commercial stocks a high proportion of bulbs are free from eelworm, so it is important that any routine treatment should not cause injury to healthy bulbs. Generally there should be less risk of damage to bulbs with a cold nematicide dip than with HWT, and when thionazin was introduced this was the chief attraction for growers. The balance between the degree of nematode control and the extent of damage to the bulbs may be affected by variety, growing conditions during the spring, duration of treatment and time of year at which it is done, temperature of HWT or concentration of nematicide, and the storage conditions of the bulbs before treatment (Wood, 1944; Horton, 1957; Hesling, 1965; Anon.; 1967; Rees and Turquand, 1967; Turquand and Rees, 1968).

Tulips are seldom given HWT as they are easily damaged, and apart from roguing out obviously infested plants during the growing season, dipping the bulbs in thionazin is at present the only effective means of controlling stem eelworm.

METHODS

In this paper seven experiments and observation studies have been selected from a series carried out at Kirton between 1960 and 1967. Bulbs were lifted in July, stored at about 65°F and treated during the period July to September. Experimental layouts varied, but usually were randomised blocks or factorial designs. Bulbs were planted in autumn, usually during October, and the results given here for six of the experiments are restricted to the observations made in the spring and summer following treatment. The narcissus experiments were all carried on for a second season, and from some of the tulip experiments the larger size bulbs were forced during the second winter after treatment or were replanted without further treatment for a second year. Because size of bulb can influence the results, each plot was planted with equal numbers and weights of similarly sized bulbs.

RESULTS

Hot Water Treatment of Narcissus Bulbs

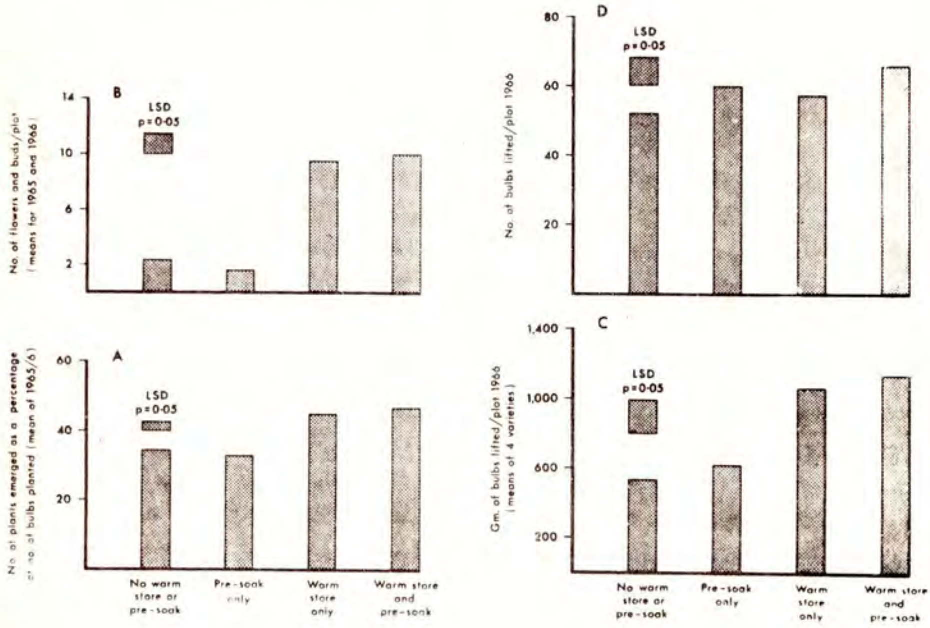
Wood (1944) suggested that warm-storing before HWT reduced the risk of damage to the bulbs, and under some circumstances it may give improved control of stem nematode (Slootweg 1962). Pre-soaking the bulbs was also said to give improved nematode control, without the necessity of raising the temperature or increasing the duration of treatment (Wallis 1965). Figures 1 and 2 show the results of an experiment on warm-storage and pre-soaking using four cultivars of narcissus bulbs, heavily infested with stem eelworm before treatment. A range of HWT temperatures was chosen with the lowest (112°F) that would be likely to give a control of eelworm, and the highest (118°F) that the plants would tolerate without being killed. Warm storage before treatment was 93°F (34°C) for four days, and presoaking was for three hours at 65°F (18°C).

(a) The effect of warm storage and presoaking

Warm storage improved plant emergence, yield of flowers, and the weight and number of bulbs lifted; presoaking had little effect. The emergence and flowering of bulbs that were neither warm-stored nor presoaked was very poor, mostly due to stem nematode, but at the higher temperatures due to HWT damage. A normal uninfested crop, without HWT, should have given 100% emergence, and an average of about 50 flowers/plot. Leaf spickels (Dutch "spikkels") containing live nematodes were found during the first season after treatment in most plots of warm-stored bulbs, up to and including 114°F (45°C) HWT. Slootweg (1962) found that HWT of 113°F for five hours gave poor nematode control if bulbs were first warm-stored, and the present experiment confirms this. In another study at Kirton it seemed that warm storage conditioned the nematode to withstand HWT and this was confirmed by Green (1964) and Woodville (1965).

Figure 1

The effect of warm storing and presoaking narcissus bulbs on (A) plant emergence; (B) flowering; (C) yield of bulbs, and (D) number of bulbs



(b) The effect of hot water treatment

Untreated bulbs died, most after only one season. Emergence, flowering and yield were greatly improved by HWT at 112°F, better still at 114°F, and were progressively poorer with increasing temperature. Nematode control was good at temperatures of 116°, 117° and 118°F, but moderate at 112° and 114°F.

Comparison of thionazin and hot water treatment of narcissus

(a) On bulbs grown outdoors

Table 1 shows the results of observations (1964-5) in which all the bulbs were very heavily infested with stem nematode before treatment. The chief object was to test thionazin against heavily infested bulbs, as Purnell and Hague (1965) used uniformly, but lightly, infested bulbs in their experiments.

Thionazin at all three concentrations, and HWT improved plant emergence and flowering, and reduced leaf spickelling. A year after treatment untreated bulbs contained most nematodes and those treated with the highest concentration of thionazin at least; the standard HWT, and what subsequently became the recommended thionazin treatment (2,300 ppm.), were comparable throughout, except that thionazin consistently gave a better result with warm stored bulbs. It has been suggested that warm-storage dried the bulbs and so allowed a greater uptake of water and nematicide during dipping (N.G.M. Hague - personal communication). None of the treated bulbs in this experiment would have survived a second season without lifting and re-treatment.

Figure 2

The effect of HWT temperature on (A) plant emergence; (B) flowering; (C) yield of bulbs, and (D) number of bulbs

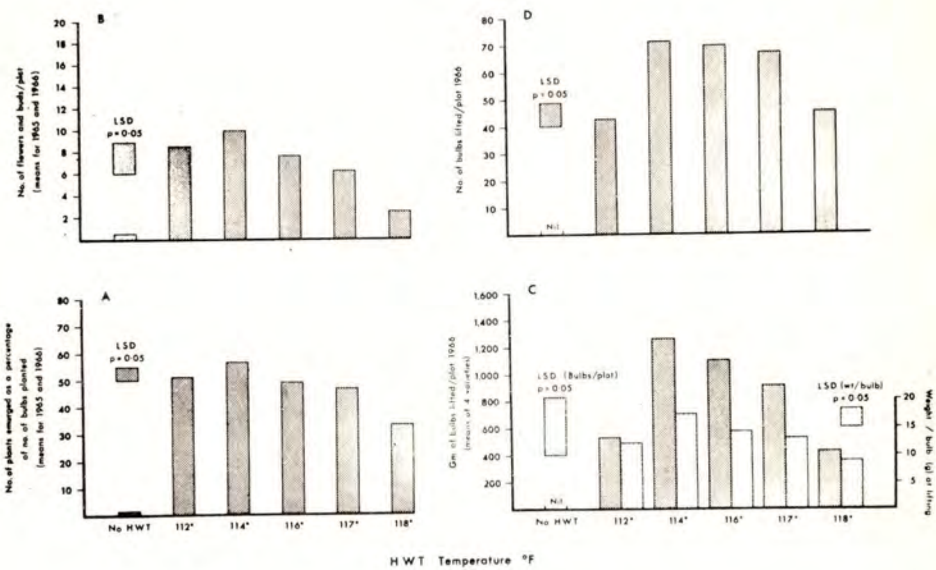


Table 1

Comparison of thionazin and hot water treatment of narcissus bulbs (cv's Carlton and King Alfred) heavily infested with *Ditylenchus dipsaci*

(Means of two plots; W.S. = 4 days storage at 93°F before treatment)

	Plants emerged(max.= 75)March 1965		% plants spickelled March 1965		Flowers/ plot March, April 1965		Stem nematodes/ 1 ml bulb tissue, Aug 1965	
	W.S.	No W.S.	W.S.	No W.S.	W.S.	No W.S.	W.S.	No W.S.
Control, no treatment	27	24	96	98	22	21	90.5	97.1
Thionazin, 1,150 ppm. /2 hr	33	23	69	75	26	26	22.5	60.0
Thionazin, 2,300 ppm. /2 hr	40	32	39	50	43	26	10.0	27.7
Thionazin, 4,600 ppm. /2 hr	35	33	35	28	35	28	4.2	14.0
HWT, 112°F/ 3 hr	47	38	48	34	42	37	21.3	30.5

(b) On forced bulbs

In a previous experiment (Winfield, 1967) thionazin dipping and HWT for short periods of time controlled stem nematode satisfactorily in forced narcissus. It is most important not to damage bulbs intended for forcing, and partial nematode control is usually sufficient. The bulbs in this experiment (Table 2) were uniformly, but lightly infested, and were stored for six weeks at 48°F (9°C) from late July until early September 1966, to advance the flowering date. Treatments were done on 9-12 September, deliberately late in the season in order to accentuate any phytotoxic effects.

Table 2

Growth and forcing performance of cv. Quirinus following thionazin and hot water

	Plants emerged Feb. 1967 (max.=50)	Lengths of longest leaves (cm) Early Feb., 1967 (Means of 10 plants)	Lengths of longest leaves(cm) late Feb., 1967 (Means of 10 plants)	No. of marketable flowers/box 13-28 Feb., 1967	Total flowers and buds/box
HWT 112°F/2 hr	46.0	10.2	51.8	23.5	39.8
HWT 112°F/1 hr	42.5	8.2	54.1	28.3	46.3
Thionazin, 2300 ppm. /2 hr	48.3	8.2	52.5	31.8	45.8
Thionazin, 2300 ppm. /1 hr	44.0	6.7	53.3	25.3	41.8
Control, no treatment	34.3	4.3	42.2	9.5	23.3
Standard Error	± 0.99	± 0.54	± 1.34	± 3.98	± 2.67

All treatments improved plant emergence and vigour, and gave more flowers than the controls, which showed severe nematode injury. Many live nematodes were extracted from untreated leaves, but only small numbers in some of the treated plants, so there was no consistent trend to indicate survival of nematodes after treatment. The appearance of the leaves varied with treatment; thionazin consistently gave green healthy-looking leaves, whereas HWT particularly for two hours, showed leaf-tip mottling and lamina roughening, normally associated with treatment too-late in the season (Anon; 1958).

Thionazin drenches on narcissus growing in the field

Oliff (1969a) obtained excellent control of stem nematode, lasting three years, without damaging the bulbs, by a single foliar drench of thionazin applied in spring. The bulbs used in his experiments were lightly infested and the present experiment was carried out on heavily infested bulbs to see if this technique could be used by growers. When narcissus plants show leaf spickels the stock is heavily infested (Hesling, 1965), but growers would have to use this criterion to decide whether or not to use a thionazin drench. The experiment was laid down in a commercial crop of King Alfred near Spalding, Lincs. Drenches were 475 gallons of water, and sprays 75 gallons of water, per acre. In summer the bulbs were lifted, and 100 were taken at random from each plot and planted at Kirton in uninfested soil.

There was much variation between plots and between blocks but none of the

Table 3

Thionazin drenches and foliar sprays against *Ditylenchus dipsaci* in narcissus

(1 lb = 453.6 g)

	Date of Treatment	% Plants emerged	Percent Plants Spickled %	Percent Plants Spickled Angular Transformation	Flowers + buds/ 100 bulbs planted
		Observations in March 1965 on bulbs re-planted in clean soil in October 1964			
Thionazin drench, 25 lb a.i./ac.	25.4.64	75	100	84	50
Thionazin drench, 25 lb a.i./ac.	9.5.64	86	81	65	55
Thionazin drench, 10 lb a.i./ac.	25.4.64	79	85	67	45
Thionazin drench, 10 lb a.i./ac.	9.5.64	87	70	58	64
Thionazin spray, 39 lb a.i./ac.	25.4.64	67	85	67	29
Thionazin spray, 39 lb a.i./ac.	9.5.64	81	48	44	50
Control, no treatment	-	59	95	77	32
Standard Error	-	± 9.3	-	± 12.5	± 7.3

treatments controlled the nematode satisfactorily. Foliar sprays caused premature leaf senescence, and the earlier spray reduced flowering the year following treatment, presumably because flower-bud initiation had been arrested.

Effect of thionazin on uninfested narcissus

To test for thionazin phytotoxicity there were two experiments with healthy bulbs in 1965 and 1966. It was not possible to carry out replicated experiments with more than a few cultivars, and the three representatives chosen were known to be sensitive or tolerant to a variety of factors, including HWT, storage conditions, pests and diseases. In both experiments the hot water treated bulbs grew most vigorously, and flowered earliest, but the flowers themselves were severely distorted and notched. All the other treatments flowered normally. The yields of bulbs after one year's growth are shown in Table 4.

Late treatment with either thionazin or cold water reduced yield of Carlton but not Golden Harvest or Actaea. Thionazin could be used therefore at any time from July to September with little risk of phytotoxicity. Twice the recommended rate did not seem to be harmful, but cultivars other than the three tested may react very differently.

Table 4

Effect of thionazin on yields of narcissus bulbs (lb/plot), in the year following treatment

	1965 cv. Carlton	1966 cv. Golden Harvest	1966 cv. Actaea
Thionazin, 2,300 ppm./2½ hr July	34.3	38.6	24.2
Thionazin, 4,600 ppm./2½ hr July	33.6	37.1	26.1
Cold water dip/2½ hr July	34.7	36.2	20.8
Thionazin, 2,300 ppm./2½ hr Sept.	29.6	34.8	20.4
Thionazin, 4,600 ppm./2½ hr Sept.	30.0	34.7	22.1
Cold water dip/2½ hr Sept.	32.3	35.4	20.4
HWT, 112°F/3 hr July	35.6	38.2	20.7
Control, no treatment	35.3	34.6	22.3
Standard error	± 0.67	± 0.94	

Comparison of hot water and thionazin on tulips

A factorial experiment using infested bulbs was laid down at Kirton in 1966 to compare the effects of a high temperature of HWT for a short duration with standard HWT which was known to cause severe damage to most tulip cultivars; thionazin dipping was for one and two hours duration at 2,300 ppm. Treatments were done as soon as possible after the bulbs were lifted in July, and a short time before planting in September. The results are shown in Tables 5 and 6.

Table 5

Control of *Ditylenchus dipsaci* in tulip (cv's Clara Butt and Orange Favourite) by hot water treatment or thionazin

(Means of six replicates)

	Plants with symptoms 5th May 1965 (max = 50)		*Ditylenchus dipsaci*/50 g bulb tissue, Aug., 1967	
	Treated July 1966	Treated Sept. 1966	Treated July 1966	Treated Sept. 1966
HWT 112°F/2 hr	0	0	30	0.3
HWT 115°F/1 hr	0	0	0.9	20
Thionazin, 2300 ppm./2 hr	0	0	0.5	5
Thionazin, 2300 ppm./1 hr	0	0	0.7	14
Water only dip/2 hr	5	20	961	5000
Control, no treatment	5	3	280	1566

HWT and thionazin controlled the nematode well, but HWT especially in September, severely damaged the bulbs and reduced emergence, vigour and flowering the following year. The nematode infestation was not great enough to prevent the untreated controls from growing and flowering normally. The early thionazin was slightly better than the late treatment both for the degree of nematode control obtained and for crop vigour and flowering. Late HWT was unsatisfactory for both cultivars used in the experiment, but early HWT with 115°F for one hour seemed satisfactory.

Table 6

Effect of hot water and thionazin treatments on growth and flowering (cv's Clara Butt and Orange Favourite) of tulips

(Means of six replicates)

	% Plant emergence March 1967		Lengths of longest leaves (cm) April 1967 Means of 10 plants		No. flowers and buds/plot May 1967	
	Treated July 1966	Treated Sept.1966	Treated July 1966	Treated Sept.1966	Treated July 1966	Treated Sept.1966
HWT 112°F/2 hr	64	10	22	10	12	0
HWT 115°F/hr	84	14	25	12	34	0
Thionazin, 2,300 ppm. /2 hr	89	90	27	27	46	40
Thionazin, 2,300 ppm. /1 hr	91	90	27	27	43	42
Water only dip/2 hr	93	91	30	28	44	42
Control, no treatment	93	93	30	29	45	45
Standard error	± 6.4		± 1.5		± 4.0	

Effect of thionazin on uninfested tulips

There were two experiments in 1965 and 1966, similar to those with healthy narcissus but excluding HWT. The yields of bulbs are given in Table 7.

Table 7

Effect of thionazin on yields of tulip bulbs (lb/plot) in the year following treatment

	1965		1966	
	cv. Rose Copland	cv. Elmus	cv. Apeldoorn	cv. Paul Richter
Thionazin, 2,300 ppm./2 hr July	17.8	17.3	21.7	21.1
Thionazin, 4,600 ppm./2 hr July	18.6	16.9	21.3	20.2
Water only/2 hr July	20.1	17.5	23.7	21.7
Thionazin, 2,300 ppm./2 hr Sept.	18.5	16.3	22.3	20.6
Thionazin, 4,600 ppm./2 hr Sept.	17.0	17.2	21.5	19.7
Water only/2 hr Sept.	17.7	16.7	22.3	20.9
Control, no treatment	19.1	16.9	22.6	22.1
Standard error	± 0.69		± 0.80	

None of the treatments significantly reduced yield although Rose Copland, regarded as a cultivar sensitive to adverse conditions, showed slight (but non-significant) reductions in yield with double strength thionazin, and with late treatment. No differences in growth, vigour or flowering were noted in either experiment.

DISCUSSION

The experiments show that results obtained with bulbs lightly infested with stem nematode may not apply to more heavily infested bulbs. In commerce one of the advantages of HWT is that infested bulbs become soft after treatment, especially at the neck, and the degree of softness is a good guide to the degree of infestation in individual bulbs. Thionazin dipping seems to have the reverse effect, and tissue damaged by eelworm tends to become dry and hard. Many narcissus growers have attempted to substitute the thionazin dip for their previous unsuccessful attempts at HWT, without improving either their field inspections in spring or their grading and sorting of the bulbs before and after treatment. As a result, thionazin has sometimes failed to give adequate control of stem nematode. The experiments have also shown that treating heavily infested narcissus bulbs with either hot water or thionazin is of little value, because even a comparatively small number of survivors can set up a severe nematode infestation in the rest of the bulbs during the second year after treatment. Thionazin tends to leave small infestations in all affected bulbs (Purnell and Hague, 1965; Oliff 1966b) whereas HWT gives complete control in most bulbs, survivors occurring only where "eelworm wool" (fourth stage nematode larvae) had been formed before treatment (Hastings and Newton, 1934; Woodville and Morgan, 1961). When planted in the field thionazin treated bulbs are therefore seldom far from a focus of infestation, whereas with HWT the foci are usually some distance apart. This gives rise in the second year to a relatively even infestation of stem nematode after thionazin, and a patchy distribution after HWT. The severity of the attack will vary with the degree of initial infestation, the survival rate after treatment, and whether or not conditions in the field are favourable for spread. However, "failure" of thionazin treatment is likely to be much more dramatic than "failure" of HWT, and for this reason the latter treatment is recommended for infested narcissus.

Stem nematode in tulips is usually much easier to control, chiefly because a new bulb is produced each year, and must therefore be infested during the limited period of its formation in spring and early summer. Spread between bulbs after lifting is usually slight unless they are left for any length of time in a wet condition. Early lifting ensures that there are smaller numbers of eelworms to kill, and that most of them are concentrated in the outer fleshy scale which is easily penetrated either by heat or by a systemic nematicide. The experiments with tulips show that thionazin gives a high degree of control, with little or no harmful effects on the bulbs, and this is now the standard recommendation in Britain.

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THE EFFECT OF THIONAZIN ON DITYLENCHUS DIPSACI

N.G.M. Hague & M. Kondrollochis.
Zoology Department, Imperial College, London.

Summary   Thionazin is shown to have no contact action on *Ditylenchus dipsaci* (stem nematode) but acts indirectly by absorption into bulb tissues. There is evidence that the nematodes are controlled by prevention of feeding.

Stem nematodes migrate from treated as readily as from untreated bulbs, so two-year down narcissus may be re-invaded as soon as thionazin has been metabolised in the bulbs.

For thionazin to be used successfully for control of stem nematode in narcissus the crop would have to be grown, as tulips, on a one year cycle.

INTRODUCTION

Thionazin (O, O-diethyl O-2-pyrazinyl phosphorothioate) has been commercially effective as a dip for the control of the stem and bulb nematode (*D. dipsaci*) in tulips at a concentration of 2500 ppm for 2 hours. It has also been used as an alternative to Hot Water Treatment (HWT) for the control of *D. dipsaci* in narcissus but commercially has not been very satisfactory for reasons outlined by Hague & Kondrollochis (1969). The present paper attempts to elucidate how thionazin controls *D. dipsaci*. The studies on uptake were done on narcissus because it is difficult to estimate the chemical in tulips.

EXPERIMENTAL

Contact action

Fourth stage larvae ('eelworm wool') of *D. dipsaci*, collected from heavily infested narcissus bulbs, were revived in water and aliquots of about 1500 nematodes were pipetted into beakers containing a range of concentrations (0, 1000, 2500 & 5000 ppm) of thionazin. After exposure for 3 hours (the normal time for a narcissus bulb dip) the nematodes were washed thoroughly and the number of survivors estimated, using the cotton wool filter technique (Purnell, 1964). Similarly treated and washed larvae were exposed to onion seedlings, which they invaded readily. In both experiments therefore, no toxic effect could be detected. Thus thionazin has no effect as a contact poison even at a concentration twice that in the commercial treatment.

Systemic activity

In earlier experiments reported by Purnell & Hague (1965) and Oliff (1966), some evidence of indirect action was demonstrated. Duplicate batches of 25 infested bulbs (var. Carlton) dipped for ½, 2 or 8 hr in thionazin concentrations of 1000,3000, and 9000 ppm made up from the commercial 46% e.c., were planted in October and the number of nematodes assessed the following June (Table 1) by extraction on a modified Seinhorst mistifier.

TABLE 1.

Number of nematodes extracted from 130 ml of chopped up bulb.

Dipping time	Concentration of thionazin (ppm).			
	0	1000	3000	9000
½ hr.	18860	20290	450	240
2 hr.	14250	1386	105	160
8 hr.	25100	920	85	95

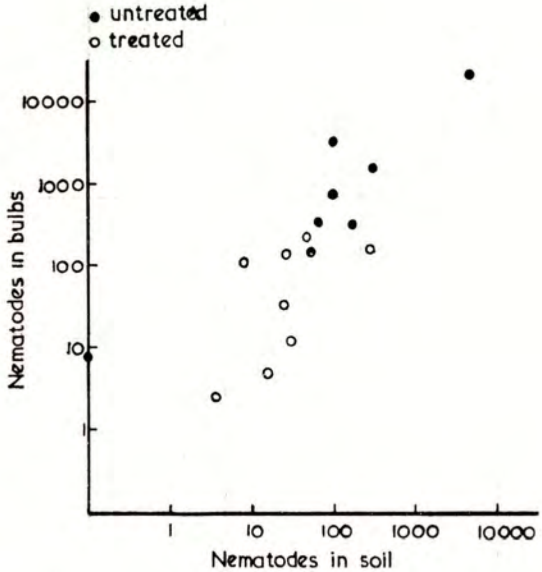
The results at 3000 ppm (just above the commercial rate) after 2 hours exposure gave good control but the recovery of even a few hundred nematodes represents a potential hazard. Oliff (1965) reported that thionazin, incorporated in agar on which mushroom mycelium was growing, was very effective in controlling D. myceliophagus. Oliff's criterium of mortality was based on the non-multiplication of the nematode and therefore it is difficult to be certain that the nematodes were killed by feeding, they may have been unable to feed. Recent work by Nelmes (private communication) with aldicarb, and one of us working with thionazin showed that Aphelenchus avenae, feeding on Fusarium sp. in agar containing these chemicals, stopped feeding and became inactive; no eggs were laid.

Migration of nematodes from treated bulbs.

Hague and Kondrollochis (1969) showed that D. dipsaci migrate from narcissus bulbs dipped in thionazin. In a similar experiment the number of nematodes extracted from both treated and untreated tulips was plotted against the number in soil (Fig. 1), and shown to be positively correlated, migration occurring from both treated and untreated bulbs.

The migration of nematodes into soil may lead to re-invasion of tulips planted back into the same soil: for narcissus, which are usually down for two years, re-invasion could occur when the thionazin in bulbs has been metabolised.

Fig. 1. Relationship between stem nematodes extracted from tulip bulbs and soil.



Uptake and retention of thionazin in narcissus bulbs

To estimate the uptake of thionazin by narcissus bulbs, batches of 12 bulbs from an infested stock were dipped at 2500 ppm for 2½ hours in August 1968: half the bulbs were stored dry, and the other half planted. Samples were taken monthly for 5 months. Bulbs were chopped up and the nematodes from a 300 ml sample extracted by the mistifier. Another sample of 50 g of bulb material was placed in 200 ml of a benzine/hexane/acetone mixture (8:1:1) with 50 g of anhydrous sodium sulphate to absorb water: the mixture was homogenised for 15 min and left to stand for 24 hr. The supernatant was decanted and the thionazin concentration determined by standard gas liquid chromotography techniques. The nematode counts and concentrations of thionazin are shown in Table 2. The concentration of thionazin in the unplanted bulbs was 8 - 10 times as great as that in the planted bulbs, indicating that metabolism of the chemical was, as expected, greater in growing bulbs. There were, however, far fewer nematodes in the planted bulbs.

The nematode counts confirm the work of Winfield and Hesling (1966) which showed that prolonged storage of untreated bulbs was undesirable. The recovery of large numbers of nematodes from treated bulbs stored dry is again indicative of non-feeding by the nematodes: under these conditions the population remains static for a few months until the bulbs start some form of growth even though they are out of the soil.

TABLE 2.

Concentration of thionazin (ppm) and number of nematodes in planted and stored narcissus bulbs dipped for 2½ hr in 2500 ppm thionazin.

Time of examination	Unplanted			Planted		
	Conc$^{n.}$ (ppm)	Treated	Untreated	Conc$^{n.}$ (ppm)	Treated	Untreated
Aug.	368	16082	8310			
Sept.	150	11725	34812	25.2	75	9561
Oct.	176	16690	42375	7.3	61	1304
Nov.	45	1071	78812	2.4	665	5450
Dec.			38500	16.2	51	8925

Behaviour of nematodes in treated bulbs

Infested narcissus and tulips were dipped in thionazin. After 29 and 64 days respectively the bulbs were chopped up and nematodes extracted on the mistifier. 2000 nematodes from each of the treated and untreated samples were added to five 6-days onion seedlings grown on filter pads in petri dishes and after one week the seedlings were examined. All seedlings contained nematodes and eggs again indicating that nematodes in treated bulbs are not feeding and remain viable.

In a similar experiment the activity of treated nematodes in planted and unplanted bulbs was examined at 1, 2, 5, 8, 15, 29, 62 and 124 days after treatment. Immediately after treatment nematodes were inactive at first but regained activity after about one hour. Up to 62 days nematodes were mostly inactive, usually straightened out or kinked and a few were twitching slightly. On day 124 nematodes from treated bulbs were as active as nematodes from untreated bulbs, indicating that thionazin was no longer having an effect.

Fate of nematodes in bulbs stored dry after treatment

Batches of 20 infested narcissus bulbs were dipped in a thionazin concentration of 2500 ppm for 2½ hr and planted in sterile soil at weekly intervals up to 10 weeks. Bulbs were grown on in a glasshouse and nematodes extracted the following June. There was no significant difference between the counts from bulbs planted at different times after treatment. The mean count for treatments was 17 nematodes, while that for untreated was 17,000 from 300 ml of chopped bulb material.

Although nematodes may remain alive in treated bulbs which are stored (Table 2) they are clearly eliminated as soon as bulbs are planted. It is possible that the amount of thionazin left in the stored bulbs (Table 2) is sufficient when metabolised in a planted bulb to give an effective control.

DISCUSSION

Evidence has been presented in this paper which confirms that the main effect of thionazin is to prevent the multiplication of *D. dipsaci* in bulbs containing the chemical. There seems no doubt that thionazin interferes with the activity of the nematode but treated *D. dipsaci* recover and will invade onion seedlings and reproduce therein. *D. dipsaci* tolerates immersion in concentrations of up to 5000 ppm of thionazin and thus there is no contact action.

These results are extremely important when considering the practical control of *D. dipsaci* in the field. The degree of control seems dependent on the retention of the chemical in the bulb and it may be significant that control has been good in tulips, a one year down crop in the U.K., and poor in narcissus which is normally down for two years. Hesling (1967) has shown that clean dipped narcissus bulbs only remain clean for about 6 months when planted into infested soil, biological evidence confirming the chemical retention reported by Hague & Kondrollochis (1969). These authors also reported that the LD 50 for thionazin against *D. dipsaci* in onion seedlings grown in solutions of the chemical was of the order of 0.15 ppm, a figure similar to that reported by Oliff (1965) for *D. myceliophagus* on mushroom.

D. dipsaci which emigrate from treated bulbs are clearly a menace to the crop. What evidence we have to date seems to suggest that thionazin is retained in bulbs long enough to prevent multiplication and re-invasion during the first year. For satisfactory control to be achieved it seems narcissus bulbs must be lifted yearly if a chemical dip is used as an alternative to Hot Water Treatment.

Hague and Kondrollochis (1969) reported improved control using combined treatments of HWT at 110oF for 3 hrs in August, followed by thionazin (September) and vice versa, although the later HWT caused some flower damage. Any alterations to traditional growing practice are difficult to achieve and it is probable that growers will not change to one year cropping of narcissus with its attendant increased lifting and labour charges. The main advantage of thionazin over HWT is its lack of flower damage in the first year and thus until flowers become as important as bulbs it is unlikely that growers will change their practices.

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SOIL FUMIGATION WITH SMALL DOSES OF DAZOMET IN FIELD VEGETABLE CROPS

J. Kradel and H. Will

BASF, Agricultural Research Station, Limburgerhof

Summary 20 g Dazomet/m^2 (180 lb/ac) mixed in the topsoil to 10 cm or 15 to 20 cm depth controlled free-living nematodes (Pratylenchus, Tylenchorhynchus, Paratylenchus, Rotylenchus and Helicotylenchus), weeds and some fungi and increased the yields, quality and profitability of vegetable crops grown intensively in fields in the Upper Rhine Valley.

INTRODUCTION

In greenhouse soils all plant pathogens must be well controlled. This can be done by steaming the soil or by using large doses of Dazomet (3,5-dimethyl-tetrahydro-2-thio-1, 3, 5-thiadiazine). Dazomet has been used for 15 years for fumigating potting soil and soil in greenhouses. 'Basamid-Granulat', an easily spread, granular form (prill) with a low dust content, is suitable for treating fields. It is easily spread by conventional fertiliser distributors (but not those of the 'spinner' type) and when incorporated in the topsoil by rotary cultivation will control nematodes and other pathogens to a depth of about 20 cm.

In Jersey, Lush et al. (1967) found that 15 to 20 g Dazomet/m^2 (135 to 180 lb/ac) controlled potato cyst nematode (Heterodera rostochiensis) on tomatoes. Dern (1969) found that 10 g Dazomet/m^2 (90 lb/ac) killed 70% of free-living nematodes (Pratylenchus sp. and Tylenchorhynchus sp.). 30 g/m^2 (270 lb/ac) only killed 89%. 40 g/m^2 (360 lb/ac) killed no more. Köhler (personal communication) had better results, 20 g/m^2 (180 lb/ac) killing nearly all Pratylenchus, Paratylenchus and Rotylenchus in the soil.

Many trials have shown that 15 to 20 g Dazomet/m^2 controls grasses and broad leaved weeds. Dern (1969) found that, mixed with soil to only 10 cm depth, 10 g Dazomet/m^2 also controlled weeds (Stellaria media and Galinsoga parviflora).

Other trials (Domsch, 1958, 1962; Ebbels, 1967; Lush et al., 1967) showed that Dazomet controlled soil fungi.

METHODS

In spring, 1968 trials with Dazomet were made in the vegetable growing region of the Upper Rhine Valley (Around Ludwigshafen, Speyer, Neustadt). In this region for many years 4 or 5 crops have been produced every 2 years. 20 g 'Basamid-Granulat'/m^2 was applied to fields in which damage by pathogenic fungi or nematodes had not been noticed. The plots varied from 50 to 250 m^2 and there were 2 to 4 replicates of each treatment. 'Basamid-Granulat' was incorporated with a rotavator to depths of 10 or 15 to 20 cm. Crops were planted or sown on these fields 18 to 25 days after treatment, when a cress test showed there was no risk of phytotoxicity.

RESULTS

4 to 5 weeks after treatment, soil samples were taken and estimates of the number of nematodes in them were made. In 13 of the 17 trials, the untreated plots were well infested with Pratylenchus, Tylenchorhynchus, Paratylenchus, Rotylenchus and Helicoty-

lenchus. The nematode counts were repeated at 15 to 21 weeks. The results are in Table 1.

Table 1

Effect of Dazomet on free-living nematodes

	% killed weeks after treatment 4 to 5	15 to 21	50 to 60
Basamid-Granulat 20 g/m^2 (180 lb/ac) incorporated to a depth of			
10 cm	79	79	38
15 to 20 cm	86	71	44
nematodes/250 ml soil, untreated plots	560	705	906
no. of trials	16	15	11

These trials showed that 20 g Dazomet/m2 (180 lb/ac) controlled free-living nematodes well whether it was incorporated to 10 cm or 15 to 20 cm depth.

Dazomet increased the yields of the first crops after treatment by 20-23% and of the second crops by 10-13% (table 2).

Table 2

Increased yields of vegetable crops after applying 20 g Dazomet/m^2

No. of trials	% increase depth of incorporation 10 cm	15 to 20 cm
1st crop (12) (cabbage 6; lettuce 3; celery 1; tomato 2)	20	23
2nd crop (4) (cabbage 1; lettuce 2; tomato 1)	10	13

A large percentage of marketable products, particularly at the first date of harvest, increases the profitability of the crop. In 4 trials (3 cauliflower, 1 cabbage), Dazomet-treated plots yielded more first quality vegetables at the first harvest than untreated plots (table 3).

Table 3

Effect of Dazomet (20 g/m^2) on quality

	% 1st quality	
	only 1st date of harvest	total harvest
Dazomet incorporated to		
10 cm	62	75
15-20 cm	59	79
untreated	50	65

DISCUSSION

Frequent applications of small doses of Dazomet to the soil may allow intensive and profitable cultivation of vegetable crops to continue where damage caused by nematodes might otherwise prevent it.

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INVESTIGATIONS INTO THE ACTIVITY OF ALDICARB FOR THE CONTROL OF SOME NEMATODE PESTS OF SUGAR BEET, POTATOES AND ROSES

C.R. Dash, R.C. Vallance and R.A. Broadley,
The Murphy Chemical Co. Ltd.,

D.H. Spencer-Jones and C. Sinclair,
Mi-Dox Ltd.

Summary Field trials in 1968 with aldicarb, 2-methyl-2-(methylthio) propionaldehyde O-(methylcarbamoyl) oxime, assessed the control of (i) Docking disorder in sugar beet caused by *Longidorus* spp. and *Trichodorus* spp. (ii) potato cyst nematode (*Heterodera rostochiensis*), and (iii) *Pratylenchus vulnus* and *Paratylenchus* spp. on roses under glass. 2 to 16 oz a.i. aldicarb/ac increased sugar yields by up to 9%. 1.5 to 4.5 lb a.i. aldicarb/ac broadcast in the topsoil prior to ridging, or applied in the seed furrow as a four inch band, greatly increased yield of ware potatoes. These results were not achieved when aldicarb was applied as a 2 in band in the furrow. On glasshouse roses 10 lb a.i. aldicarb/ac controlled *Pratylenchus vulnus* and 15 lb controlled *Paratylenchus* spp. Other trials confirmed that aldicarb also controlled aphids on potatoes and sugar beet.

INTRODUCTION

Aldicarb is the common name for 2-methyl-2-(methylthio) propionaldehyde O-(methylcarbamoyl)oxime, and is formulated as a 10% granule under the trade name of 'Temik'.

Aldicarb is a systemic pesticide translocated from roots to shoots with little or no translocation from shoots to roots. Aldicarb controls a wide range of insect, mite and nematode pests by cholinesterase inhibition.

Dunning and Winder (1968) found that as little as 2 oz aldicarb/ac in single row plots of sugar beet controlled Docking disorder and increased sugar yields from 48.5 to 76.9 cwt/ac (58% increase). Whitehead and Tite (1968) using 13 oz a.i. aldicarb/ac increased the yield of sugar beet affected by Docking disorder from 22.1 to 37.2 cwt/ac (68% increase).

Following these encouraging results further field trials with aldicarb began in 1968 on sugar beet, potatoes and glasshouse roses.

METHODS AND MATERIALS

Sites were selected for the control of potato cyst nematode (*Heterodera rostochiensis*) and Docking disorder, based on a history of poor crops and high nematode counts. Aldicarb was applied to roses to control red spider mite (*Tetranychus urticae*). No pre-treatment nematode counts were made.

All trials were laid out in a randomised block design with at least four replicates.

Applications were made in four ways:- (i) broadcast on the flat prior to ridging (two potato cyst nematode trials); (ii) using a Horstine Farmery 'Microband' granule applicator to give a 4 to 5 in band in the furrow at planting (two potato cyst nematode trials); (iii) as in (ii) above to give a 2 in band (two potato cyst nematode trials and all Docking disorder trials); (iv) distributed over the soil surface and worked into the topsoil (rose trials).

Docking disorder experiments Aldicarb was applied at 2,4,8, and 16 oz a.i./ac in the rows. Germination was assessed in mid-May, crop vigour in June and July and yields and root quality in November. Nematode populations were estimated in June.

Potato cyst nematode experiments Aldicarb was applied at 1.5, 3.0 and 4.5 lb a.i/ac in the row or broadcast. Crop vigour was assessed in June and July and yields were taken in September. The number of cysts in each plot was estimated before aldicarb treatment and after harvest. For experiments where aldicarb was applied in a 2 in band the number of cysts/6 in root was determined. Larval invasion counts were made in all other trials.

Nematodes on roses Aldicarb was applied at 5, 7.5, 10, and 15 lb a.i./ac broadcast. The numbers of *Pratylenchus* and *Paratylenchus* were estimated from soil samples taken four months after application. (D.E. Green - personal communication).

Aldicarb residues in potatoes and sugar beet were small and clearance of these crops for normal disposal was obtained from the Ministry of Agriculture Fisheries and Food under the Pesticides Safety Precautions Scheme.

RESULTS

Table 1

Effect of aldicarb on *Trichodorus* and sugar beet crops. (means of three trials).

Aldicarb oz a.i./ac	Germination (%)	Plant vigour June	Plant vigour July	Root quality Fangy	Root quality Non-Fangy	Root Yield ton/ac	*Trichodorus*/ 1 soil
2	97	135*	107	61	39	15.22	413
4	85	113	104	66	34	15.86	396
8	92	122*	107	59	41	15.50	353
16	107	128*	110	58	42	15.63	390
Control	100	100	100	67	33	14.45	420

* = significant at 5% level

Table 1 shows that significant differences were found only in crop vigour in June.

Table 2

Effect of aldicarb on potato cyst nematode and potato crops.

Trial	Method of application	Aldicarb lb a.i./ac	Full-cysts/100 g soil. before treatment	after harvest	Cysts/ 6 in root	Vigour after 7 weeks	Yield (ware ton/ac)
A	2 in band in furrow	0	39	87	160	10	3.4
		1.5	44	66	76***	10.3	4.0
		3.0	37	72	96***	10.5	4.4
		4.5	51	80	70***	10.5	3.9
B	2 in band in furrow	0	84	140	71	10	9.6
		1.5	64	143	63	11	9.8
		3.0	100	237*	62	12	9.3
		4.5	67	260*	94	12.3	9.5
					larvae/ 0.5 g root		
C	4 in band in furrow	0	13.3	39.5	-	12	3.56
		1.5	12.1	31.1*	-	21.7	5.78***
		3.0	11.0	30.3*	-	21.2	6.66***
		4.5	10.8	21.7*	-	26.5	8.14***
D	4 in band in furrow	0	11.83	18.7	-	4.00	1.51
		1.5	16.00*	15.8	-	8.39	4.20***
		3.0	16.00*	22.0	-	7.50	3.63***
		4.5	11.75	23.9	-	9.22	5.40***
			Cysts/100 g soil before treatment	after harvest			
E	Broadcast	0	47	57	625	10	9.8
		1.5	60	42	300	20	15.8***
		3.0	69	57	50*	22	17.5***
		4.5	61	38	50*	24	16.6***
F	Broadcast	0	40	66	344	10	- +
		1.5	50	51	219	10	-
		3.0	45	57	100	10	-
		4.5	40	39	163	10	-

* = significant at 5% level

*** = significant at 0.1% level

\+ = harvested before yields obtained

The results in table 2 show that aldicarb treatment increased the number of cysts in the soil in trial B but reduced the number of cysts in trial C. No significant differences were observed in the remaining trials.

The number of cysts on the roots was significantly reduced by all doses in trial A but not in trial B. Larval invasion was reduced by the two largest doses in trial E but not in trials C, D, and F.

Crop vigour was increased by aldicarb on five of the six trials. Trial F was not harvested. In trials C to E aldicarb significantly increased yields of ware potatoes.

Table 3

Control of *Pratylenchus* and *Paratylenchus* with aldicarb.

Nematodes	Aldicarb lb a.i./ac					
	0	2.5	5.0	7.5	10.0	15.0
Pratylenchus/l soil	220	15	0	60	0	0
Paratylenchus/l soil	80	20	860	120	140	0

DISCUSSION

Docking disorder trials Due to the dry spring there was much less Docking disorder in 1968 than in 1967, although aldicarb increased root quality, yield and vigour of sugar beet crops (Table 1). These increases were small and were much less than those obtained in 1967, by Dunning and Winder (1968) and Whitehead and Tite (1968).

Dunning and Winder (1969) also obtained small but significant increases in sugar yield and root quality with 2, 4, 9 and 18 oz a.i. aldicarb/ac in 1968.

Potato cyst nematode trials Post harvest cysts were best controlled by broadcast applications of aldicarb. Conversely, 2 in band applications did not control post-harvest cysts, and in Trial B, aldicarb increased them.

From the yield figures given it would appear that narrow band applications in the furrow were not as effective as the other methods tested. However the yield increases on trial A approached 5% significance and there was a significant reduction in numbers of cysts on the roots.

Whitehead and Tite (1969) found that potato cyst nematode was controlled by aldicarb incorporated into the topsoil immediately before planting, and obtained yield increases of 6.6 tons ware/ac.

In two out of three trials in 1969 yields have been increased by 56 to 100%.

Pratylenchus and Paratylenchus on Roses under glass
Pratylenchus vulnus was controlled by 10 and 15 lb a.i. aldicarb/ac, *Paratylenchus* spp. were controlled by 15 lb a.i. aldicarb/ac (Table 3). In the same trial, aldicarb controlled red spider mite for at least three months, and significantly increased the number of buds and blooms.

Aphids on Potatoes and Sugar Beet The control of aphids on sugar beet and potatoes by aldicarb was excellent, and persisted for at least 17 weeks. This resulted on sugar beet in a significant reduction of virus yellows transmitted by *Myzus persicae*.

Acknowledgements

We thank all farmers and nurserymen who co-operated in these trials and Mr. W.D. Fraser, Huntingdon Research Centre, and Mr. D.A. Cooke, Brooms Barn Experimental Station, for helping us with nematode counts.

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