A BRIEF ANALYSIS OF THE STATISTICS OF PUBLICATIONS ON NEMATODE CONTROL

C. E. Taylor

Scottish Horticultural Research Institute, Invergowrie, Dundee DD2 5DA

Summary The number of publications on plant nematology has increased in recent years from 560 in 1965 to 1299 in 1974, and the proportion on chemical control has remained almost the same (19-21%) throughout the period. Investigations on the mode of action of nematicides, affecting the dispersion and persistence of the chemical in the soil, methods of assaying the efficacy of nematicides, and not least on the biology of the nematode pathogen itself, are considered to be essential for any research and development programme aimed at improving the efficiency and reducing the cost of nematode control.

Resumé Le nombre de publications sur la phytonématologie a augmenté ces dernières années de 50 en 1965 à 1299 en 1974, et la proportion ayant trait au contrôle chimique est restée presque la même pendant cette periode. Les études sur le mode d'action des nématicides, les facteurs affectant la dispersion et la persistance du produit chimique dans le sol et particulièrement la biologie du nematode pathogène lui-même, sont considerées comme étant essentiel à tout programme de recherche et de developement ayant pour but l'amélioration et l'éfficacite et la réduction du cout du contrôle des nematodes.

The use of DD as a nematicide just over 30 years ago demonstrated the feasibility of obtaining effective control of pathogenic nematodes and introduced an era of research and development on chemical control in which there is no sign of abatement of interest by manufacturers, researchers or commercial users. A perusal of Helminthological Abstracts, which covers the world literature on plant nematology, reveals that in the 10 year period 1965-74 there were about 10,000 published papers or reports on plant nematology of which 1,987 dealt with chemical control of nematodes (Table 1). The number of different chemicals tested for nematicidal action and referred to in the publications was about 40, some of which were well known as insecticides or fungicides (e.g. parathion, systox, nabam). Of the 520 pesticide chemicals listed in the British Crop Protection Council's Pesticide Manual (4th edition; eds. H. Martin & C.R. Worthing) 20 are clearly identified as nematicides; in a recent issue of the American Phytopathology Society's "Fungicide and Nematicide Tests" 87 different products are listed but many of these are merely different formulations of the same chemical.

The publications on chemical control listed in Helminthological Abstracts for the period 1965-74 are mostly reports of experiments and DD featured in 320 of them and DBCP in 304. Even in the latter half of the period when there was considerable interest in organophosphates and oxime-carbamate nematicides, DD and DBCP were each referred to more frequently than any other nematicide. Allowing that these two nematicides are used as standards or controls in many experiments, and particularly when comparing the efficacy of a new chemical, it is evident that both are still widely used and are considered to be among the most effective nematicides available.

The number of publications on plant nematology has increased in recent years from 560 in 1965 to 1,299 in 1974, and the proportion on chemical control has remained almost the same throughout the period. In the first 5 years, 1965-69, just over 19% of the publications dealt with chemical control, and in the second period of 5 years, 1970-74, this had increased slightly to 21%. During the 10 year period membership of the European Society of Nematologists rose from 330 in 1965 to 498 in 1973/74. If it is assumed that two thirds of the world's plant nematologists are members of the Society, then the data indicate that there has been an increase in communication activity (which may or may not reflect work efficiency per se!) from approximately 1.3 publications per nematologist per year in 1965 to 2.0 in 1974.

Table 1

Frequency of publications on chemical control of nematodes noted in Helminthological Abstracts 1965-74

	Total titles[1]	No. of published papers on experimental use of some nematicides: DD	EDB	DBCP	Thionazin	Fensulfothion	Fenamiohos	Aldicarb	Oxamyl
Discovered/ first used :		1942	1946	1965	1958	1957	1969	1965	1969
1965	139	34	10	16	3	2	-	0	-
1966	119	22	9	25	9	2	-	0	-
1967	118	18	5	15	3	5	-	0	-
1968	138	13	1	12	9	4	-	3	-
1969	211	21	10	32	11	9	0	5	0
1970	278	42	13	37	14	6	3	15	2
1971	197	35	14	40	28	24	23	27	8
1972	265	56	25	48	14	18	24	38	16
1973	249	36	19	41	19	15	13	31	20
1974	273	40	14	38	14	7	17	29	23
Totals	1987	320	120	304	124	92	80	148	69

[1]Total titles listed on chemical control in Helminthological Abstracts for each year.

As indicated in Dr Hague's review paper "Nematicides, Past and Present" there is presently available an effective armoury of chemical nematicides which can be categorised as fumigant or non-fumigant. The latter group include the newly developed oxime-carbamates such as aldicarb and oxamyl which are of particular interest since they seem to satisfy the long-expressed want for a systemically translocated nematicide. This apparently overcomes the very real problem of distribution of the chemical within the soil and provides the plant with an overall system of protection; moreover, low dosage rates can be used which are less likely to introduce selection pressures for resistance to the chemical within the environment. However, whilst these systemically translocated nematicides may adequately protect the plant from nematode attack, and this is after all the basic requirement of control, their mode of action is to interfere with the host finding and feeding behaviour and also their persistence in soil is limited. Thus unless there is repeated application of the nematicide, which will eventually starve the nematodes to death, the population of nematodes which are being controlled remain as a future problem. On the other hand, the fumigant nematicides cannot economically be used at sufficiently high rates to completely eradicate a population of nematodes in the soil, and the trend is now to use sufficient to reduce the number of nematodes to be controlled below the economic threshold of damage for the particular crop.

Crop losses by nematodes can be sometimes avoided and often reduced by methods other than the use of nematicides. Crop rotations, the use of resistant varieties, cultivations such as ploughing or rotavating, manuring, and the encouragement of biological controlling agents, can all be used to alleviate nematode pathogen problems. In most instances, however, the use of nematicides remains as the most economically effective way of establishing control at the level required for modern-day crop production. There is still much to be discovered about the use of nematicides that will not only make them more effective and cheaper to use, and hence available for a greater range of crops, but also to make them biologically safer (e.g. low dosage rates to avoid build up of resistance, specificity of action against the nematode pathogen and thus preservation of other elements of the soil biota). Investigations on the mode of action of nematicides, factors in the soil environment affecting the dispersion and persistence of the chemical in the soil, methods of assaying the efficacy of nematicides, and not least on the biology of the nematode pathogen itself, are considered to be essential ingredients for any research and development programme aimed at improving the efficiency and reducing the cost of nematode control.

NOTES

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IMPROVEMENT OF BANANA YIELDS WITH NEMATICIDES

S. R. Gowen

Windward Island Banana Research Scheme, P.O.Box 115, Castries, St. Lucia

Summary Applications of ethoprop 5.0g, carbofuran 2.5g, phenamiphos 3.0g and oxamyl 6.0g a.i. at planting, 2 months and subsequently every 4 months and DBCP 75% EC at 2 months and subsequently every 6 months had a favourable effect on yields. Fewer bunches were lost in granular nematicide and DBCP treatments than in untreated. Better yields were obtained with 15.0ml DBCP/plant than lesser dosages. Dosages of oxamyl and ethoprop were decreased to 3.0g a.i./plant during the course of the experiments.

INTRODUCTION

The most important nematodes attacking bananas are *Radopholus similis* and *Helicotylenchus* spp. (Blake, 1969). These species are chiefly endoparasitic and cause extensive lesioning in root and corm tissue leading to the death of roots. Plants with severely infested roots are likely to fall over exposing the corm from which protrude the fractured remains of diseased primary roots. The disease was well described by Leach (1958) as 'blackhead toppling'.

The principal method of nematode control is by injection with DBCP (Edmunds, 1969, Minz et al, 1960, Vilardebo, 1973, Wehunt and Edwards, 1968), although this nematicide can also be applied in irrigation (Wehunt and Edwards, 1968, Minz et al, 1960).

The new granular nematicides have been tested in West Africa (Guérout, 1974) and the Windward Islands (Gowen, 1974) and the indications were that these new compounds were as effective or better than DBCP in improving banana yields.

This paper is a continuation of earlier work (Gowen, 1974) in which yield responses to four granular nematicides and DBCP were compared.

METHOD AND MATERIALS

In November 1972 sword suckers (Simmonds, 1966) of banana (Musa AAA) 'Robusta' and 'Grande Naine' were planted in field experiments at Montreal, St. Vincent and Roseau, St. Lucia respectively. Treatments with granular nematicides were made at planting (in planting holes) at 2 months and subsequently every 4 months. After planting granules were applied by sprinkling measured quantities in a band up to 30cm from each plant. In the case of a plant which had produced or was still holding a bunch of fruit, granules were placed in half circles around the selected following sucker. DBCP (75% EC) diluted with water was applied with a hand injector at 8 weeks after planting and subsequently at 6 months intervals. In St. Vincent, soil injection was to a depth of 20cm with 6 injections around each plant. In the heavier soil at Roseau, St. Lucia, injection was at 15cm with 8 injections around each plant.

The planting densities were 1350 plants/ha in St. Vincent and 1700 plants/ha in St. Lucia with 18 and 24 plants per experimental plot respectively.

Treatments were replicated 5 times and were as follows:-

St. Vincent DBCP 3.3, 5.0, 6.6 and 15.0ml, carbofuran 2.5g a.i. (5% granules), phenamiphos 3.0g a.i. (5% granules) per plant

St. Lucia DBCP 5.7ml, carbofuran 2.5g a.i., phenamiphos 3.0g a.i. (5% granules), ethoprop 5.0g a.i. changed to 3.0g a.i. Oct.1974, oxamyl 6.0g a.i. changed to 3.0g a.i. Feb.1974 (10% granules) per plant

Regular assessments of nematode populations in roots and soil were made but are not presented in this paper.

Fruit was harvested at the usual export grade of maturity and entire bunch weights recorded. Bunches of fruit on plants which toppled were graded and if fit for harvest were weighed and recorded, immature bunches were discarded.

Banana plants vary considerably in the time taken to produce fruit. Because of this the separation of yields into different crop cycles becomes difficult after the first ratoon although this is often a more convenient method than recording yields on a monthly or annual basis.

RESULTS

Production from the nematicide treatments in St. Vincent was greater than that of the controls (Table 1) but no treatment differences were apparent in the plant crop of the St. Lucia experiment (Table 2).

There was a significant difference in speed of production in terms of days from planting to harvest between granular nematicide treatments and controls and DBCP in both experiments. These differences were between 25 and 48 days in St. Vincent (Table 1) and 22 and 30 days in St. Lucia (Table 2).

Greatest first ratoon yields in St. Vincent were obtained with the 15.0ml DBCP, carbofuran and phenamiphos treatments and all treatments were better than the untreated.

Table 1

Total yields and days from planting to harvest for 2 crop cycles in nematicide experiment - St. Vincent

	Phenamiphos	Carbofuran	DBCP ml/plant 3.3	5.0	6.6	15.0	Control
Plant crop							
Production(kg)	1917[a]	1863[a]	1895[a]	1767[ab]	1864[a]	1940[a]	1643[b]
t/ha	31.7	30.8	31.4	29.3	30.8	32.1	27.2
Days	370[ab]	363[a]	388[bc]	411[c]	395[c]	400[c]	403[c]
First Ratoon							
Production(kg)	2095[ab]	2033[ab]	1879[bc]	1727[c]	1933[bc]	2188[a]	1489[d]
t/ha	34.7	33.7	31.1	28.6	32.0	36.2	24.7
Days	642[a]	639[a]	672[b]	694[bc]	675[b]	682[b]	712[c]

abc Totals followed by same letter not different significantly (P=0.05) as shown by Duncan's Multiple Range Test.

There were no significent differences in first ratoon yields between the granular nematicide treatments in the St. Lucia trial. These treatments produced significantly greater yields than the untreated and ethoprop, carbofuran and phenamiphos treatments also yielded a significantly greater weight of fruit than did the DBCP.

Table 2

Total yields from three crops and days from planting to harvest for the first two crops in nematicide experiment, St. Lucia

	Control	DBCP	ethoprop	oxamyl	carbofuran	phenamiphos
Plant crop						
Production(kg)	1904[a]	2108[a]	2107[a]	1962[a]	1935[a]	2056[a]
t/ha	28.2	31.3	29.9	29.1	28.7	30.5
Days	378[a]	379[a]	349[b]	349[b]	356[b]	356[b]
First ratoon						
Production(kg)	2639[c]	2872[b]	3228[a]	3054[ab]	3173[a]	3199[a]
t/ha	39.1	42.5	47.7	45.2	46.9	47.3
Days	580[a]	583[a]	541[b]	535[b]	549[b]	542[b]
Second ratoon						
Production(kg)	2419[d]	2871[c]	3543[a]	3398[b]	3286[b]	3301[b]
t/ha	35.8	42.5	52.4	50.3	48.6	48.9

abc Totals followed by same letter not different significantly (P=0.05) as shown by Duncan's Multiple Range Test.

The second ratoon crop was complete 30 months after planting. The ethoprop treatment yielded significantly more fruit than all other treatments. All granular nematicide treatments produced between 13 and 16 t/ha more than the untreated. DBCP produced approximately 8 t/ha more than the untreated.

Bunch losses were greatest in untreated plots (Tables 3 and 4). In St. Vincent most were in the first ratoon and no bunches were lost from the highest DBCP treatments. In St. Lucia a total of 43 control bunches fell during the course of these crops. In contrast, 17, 3, 2, 1 and 0 bunches fell in DBCP, phenamiphos, carbofuran, oxamyl and ethoprop respectively.

Table 3

Numbers of bunches fallen either before or at harvest maturity
St. Vincent

	phena-miphos	carbo-furan	DBCP ml/plant 3.3	5.0	6.6	15.0	Control
Plant crop							
Mature	-	-	-	-	-	-	-
Immature	-	-	-	-	-	-	1
First ratoon							
Mature	-	-	-	-	-	-	1
Immature	2	2	3	2	-	-	12

Table 4

Numbers of bunches fallen either before or at harvest maturity
St. Lucia

	Control	DBCP	etho-prop	oxamyl	carbo-furan	phena-miphos
Plant crop						
Mature	4	2	-	-	1	1
Immature	9	-	-	1	-	1
First ratoon						
Mature	3	-	-	-	-	1
Immature	16	10	-	-	-	-
Second ratoon						
Mature	-	-	-	-	-	-
Immature	11	5	-	-	1	-

DISCUSSION

The value of DBCP in banana production has been well established but there are however considerable difficulties associated with its application; most of these difficulties can be overcome with the use of granular formulations of non-volatile nematicides.

All the granular nematicides tested appear to be useful for improving banana production. The treatment schedule of 3 applications per year is effective at least under St. Lucia conditions; future work may indicate where economies can be made by decreasing the dosages.

In areas heavily infested with nematodes , farmers often replant fields after 3-5 years. Good nematode control as reflected by a low incidence of toppling makes replanting unnecessary.

The effect of non-volatile nematicides speeding the production cycle has also been reported in the Ivory Coast (Guerout, 1970). This phenomenon is difficult to explain, particularly, as in other work (unpublished) it has not been so obvious.

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NOTES

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NEMATICIDE USAGE ON SUGAR BEET

D. A. Cooke

Broom's Barn Experimental Station, Higham, Bury St Edmunds, Suffolk IP28 6NP

Summary Soil fumigants and systemic nematicides control the ectoparasitic nematodes which cause Docking disorder of sugar beet grown on sandy soils. The commercial use of soil fumigants began in 1968, increased until 1973 (when 1,300 ha were treated) and has since declined. Systemic nematicides gained provisional clearance in 1974 when about 6,900 ha were treated; in 1975, 36,763 ha were reported to be treated, largely to control other soil pests and virus yellows. Yield increases given by aldicarb in experiments testing systemic nematicides on sites infested with *Heterodera schachtii* or *Ditylenchus dipsaci* were attributed more to the delay in the spread of virus yellows in treated plots than to control of nematodes.

INTRODUCTION

The only nematode-induced problem of sugar beet currently being treated by nematicides on a field scale is Docking disorder. Work during the 1960's confirmed that this condition resulted from injury to seedling root systems caused by the feeding of the ectoparasitic nematodes *Trichodorus*, *Paratrichodorus* or *Longidorus* (Whitehead and Hooper, 1970; Whitehead, Dunning and Cooke, 1971). These nematodes are widespread in England in sandy soils (i.e. those containing less than 15% silt + clay particles) and Docking disorder is virtually restricted to this soil type on which about 30,000 ha of sugar beet are grown annually. Several experiments have demonstrated that damage can be controlled by the use of soil fumigants applied overall (Cooke and Draycott, 1971; Whitehead, Fraser and Greet, 1970) or injected below the rows into which beet were to be sown (Whitehead, Tite and Fraser, 1970; Cooke, Dunning and Winder, 1974). Docking disorder is much more prevalent and severe following prolonged rainfall after seedling emergence and in seasons with a dry spring very little damage is apparent (Cooke, 1973; Jones, Larbey and Parrott, 1969). Since any effective control measures must be applied before or when the crop is sown, they must therefore either be cheap enough to act as an insurance against possible damage or must give some additional advantage to the crop.

Another economically important nematode parasite of sugar beet in England is *Heterodera schachtii*. At present, this species appears to be adequately controlled by crop rotation which is enforced in two ways, namely:

1. British Sugar Corporation contract with the grower. This permits sugar beet to be grown only after the land has been free of host crops for at least two years (except immediately after a ley of at least three years' duration when beet may be grown for two consecutive years or two years in three).

2. Beet Eelworm Orders. These restrict the growing of all host crops of H. schachtii on known infested fields and on all fields in certain scheduled areas (notably parts of the Fens). On uninfested fields within a scheduled area, a host crop may not be grown (without a licence) unless the land has been free of a host crop for two years. On infested fields, a host crop may be grown only with a licence and after the land has been free from host crops for three years. On heavily-infested (beet sick) fields, a host crop may be grown only with a licence and after the land has been free from host crops for five years and a soil sample shows that the nematode population has decreased sufficiently.

These measures are aimed at reducing the spread of the nematode and keeping yield losses to a minimum. However, they are time consuming and costly to administer and restrict the amount of beet grown at a time when an expansion in the industry is being sought. It seems likely that in some areas and on some soil types, sugar beet could safely be grown more frequently, especially if chemical control measures could prevent damage by moderate numbers of this nematode and inhibit the development of damaging populations. Consequently, experiments were started in 1974 to test aldicarb or oxamyl as broadcast applications in fields infested with H. schachtii.

Early invasion of sugar-beet seedlings by Ditylenchus dipsaci may cause malformation of cotyledons and kill the growing point leading to a multiple-crowned beet; the attack may develop into a crown canker in autumn which can cause yield losses exceeding 10 per cent (Dunning, 1957).

This paper outlines the changing pattern of nematicide usage on sugar beet, discusses the possibilities for widening their scope in the future and gives some results of the first year of experiments testing broadcast and row application of systemic nematicides on fields where damage by H. schachtii and D. dipsaci respectively were anticipated.

CURRENT USAGE

The commercial use of nematicides on sugar beet in England began in 1968 when a few fields near the village of Docking, Norfolk, were injected with dichloropropane-dichloropropene mixture (D-D) at 72 l/ha 15-20 cm below the rows 1-2 weeks before sowing the beet (Ripper, 1970). Following a year of widespread and severe Docking disorder in 1969, the use of fumigants increased and in 1970 D-D mixture or dichloropropene (Telone) were applied as row treatments to about 400 ha. The treated area increased steadily to about 1,300 ha in 1973 and would doubtless have been greater were it not for the inherent difficulties of this method of application. It is an additional operation requiring expensive chemicals and specialist machinery and usually necessitates a delay in sowing to minimize the risk of phytotoxicity. It also requires accurate matching of the sugar-beet rows with the fumigated bands of soil. The systemic nematicides aldicarb (Temik) and oxamyl (Vydate), which had limited clearance in 1973, were given provisional clearance in 1974; they were widely used during 1974, largely replacing the soil fumigants to which they were often preferred because of their ease of application and the fact that sowing need not be delayed to avoid the risk of phytotoxicity. Virus yellows occurred on an unprecedented scale in 1974 (Hull, 1974) and the effectiveness of the new systemic products (especially aldicarb) in delaying virus infection in treated crops was an important factor contributing towards their greatly increased use in 1975. Table 1 gives estimates of the area treated with nematicides since 1968.

The acreage of each factory area prone to Docking disorder differs greatly (Cooke, 1973) but the best estimate is probably given by the Broom's Barn pest and disease survey reports completed by fieldmen of the British Sugar Corporation in 1969 (the year of the most widespread and severe damage). Table 2 shows the total

Table 1

Area of sugar beet treated with nematicides 1968-75

Year	Area treated (ha) Soil fumigants (D-D mixture or dichloropropene	Systemic compounds (aldicarb or oxamyl)
1968	50	-
1969	50	-
1970	400	-
1971	800	-
1972	1,000	-
1973	1,300	300
1974	700	6,900
1975	132	36,763

area affected in 1969 in five groups of factory areas together with the 1975 nematicide usage in each. The factory areas comprising the groups are as follows:

Group	Factory areas
Northern	York, Selby
W. Midland	Allscott, Kidderminster
E. Midland	Bardney, Brigg, Newark, Nottingham
E. Anglia (E)	Bury St Edmunds, Cantley, Ipswich, King's Lynn, Wissington
E. Anglia (W)	Ely, Felsted, Peterborough, Spalding

Each factory area in the E. Anglia (E) group contains a significant amount of sandy soil susceptible to Docking disorder, whereas the disorder is only very rarely reported from any factory area in the E. Anglia (W) group.

The data on nematicide usage are from an annual British Sugar Corporation survey based on report forms completed by every grower immediately after sowing. This survey includes records of the amount of pesticides used and the purpose for which they were applied and is distinct from the 5% survey discussed by Dunning and Davis (1975).

Although the total area treated specifically to control Docking disorder was similar to the total area recorded affected in 1969, it appears that there is potential for a further increase especially in the Northern and E. Midland groups. In those groups, the number of hectares treated for protection from the disorder was considerably less than the number reported affected in 1969, although there is no evidence of any change in the proportion of beet grown on sandy soils. The survey reports for 1975 bear this out as 419 ha of Docking disorder were reported from the Northern group in June, almost entirely from untreated fields. Despite the fact that a large proportion of the E. Anglian (E) crop was treated in 1975, 381 ha of the disorder were reported, again mostly from untreated fields; smaller areas were reported from the W. Midlands (32 ha) and E. Midlands (40 ha) and none from E. Anglia (W).

Table 2

Docking disorder distribution (1969) and nematicide usage (1975)

Group	Docking disorder 1969 (ha) *	Area reported treated with nematicides, 1975 (that specifically for Docking disorder control in brackets)		
		Soil fumigants (ha)	Systemic compounds (ha)	Total usage (% of group area sown with beet)
Northern	2,093	43 (18)	3,145 (1,374)	19.8 (8.7)
W. Midland	380	0 (0)	199 (37)	1.3 (0.2)
E. Midland	2,018	26 (0)	5,687 (1,107)	16.1 (3.1)
E. Anglia (E)	3,763	31 (24)	19,807 (5,976)	26.7 (8.1)
E. Anglia (W)	17	32 (2)	7,925 (319)	19.9 (0.8)
Total	8,271	132 (44)	36,763 (8,813)	20.3 (4.9)

* These figures represent the total recorded area affected in July for the Northern group and in June for the other groups; these being the months with most recorded damage.

FIELD EXPERIMENTS

In 1974 three field experiments were made on fields in the scheduled area where sugar beet was grown commercially under licence, the previous beet crop having been infested with H. schachtii. Each experiment tested three rates of aldicarb or oxamyl (2.8, 5.6 and 11.2 kg a.i./ha) which were broadcast and rotavated into the soil to a depth of 15 cm shortly before the crop was sown. Plot size was 5 rows x 12.2 m and harvested area was 3 rows x 9.1 m.

Also in 1974 three experiments were made on fields where a previous onion crop had been attacked by D. dipsaci. Each experiment tested three rates of aldicarb or oxamyl (0.28, 0.56 and 1.12 kg a.i./ha) applied in the seed furrow. Plot size was 5 rows x 12.2 m and harvested area was 3 rows x 9.1 m.

The prolonged dry weather in spring was not conducive to nematode activity and nematode damage was not apparent in any of the six experiments. However, all experiments were severely infected with virus yellows. The spread of yellows was delayed in aldicarb-treated plots and sugar yield increases (Table 3) were probably largely due to this rather than to any nematode control that might have been achieved.

CONCLUSIONS

The use of systemic nematicide/insecticides on sugar beet has increased greatly in the last two years. The amount of land susceptible to Docking disorder that is treated with these materials will probably increase further following this year's practical experience, which confirmed experimental evidence, that they satisfactorily control nematode damage. Their effectiveness in controlling soil pests and the early season control of virus yellows given by aldicarb will ensure their use on an even wider scale.

Table 3

Effect of aldicarb and oxamyl on sugar yield

Nematicide	*D. dipsaci* sites		*H. schachtii* sites	
	Rate (kg a.i./ha)	Sugar yield (t/ha)	Rate (kg a.i./ha)	Sugar yield (t/ha)
None	0	6.20	0	5.05
Oxamyl	0.28	6.20	2.8	5.12
	0.56	6.56	5.6	4.98
	1.12	6.45	11.2	5.17
Aldicarb	0.28	6.82	2.8	5.21
	0.56	7.02	5.6	5.43
	1.12	7.05	11.2	5.59

The experiments on sites infested with *H. schachtii* and *D. dipsaci* gave little evidence on control of nematode damage or population increase given by systemic nematicides. Further work on *H. schachtii* is planned with the objective of providing an alternative to crop rotation as a method for controlling this pest. Damage by *D. dipsaci* is not usually severe or widespread and is unlikely to justify specific prophylactic treatment. Nevertheless, it would be valuable to know whether it is controlled by routine nematicide treatments so experiments testing row treatment will be continued.

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INCORPORATING GRANULAR NEMATICIDES IN SOIL

A.G. Whitehead, R.H. Bromilow, K.A. Lord, S.R. Moss*
Rothamsted Experimental Station, Harpenden, Herts.

&

J. Smith
Arthur Rickwood Experimental Husbandry Farm,
Mepal, Ely, Cambs.

Summary Potato cyst-nematodes (Heterodera rostochiensis Woll. & H. pallida Stone) were controlled better by mixing aldicarb or oxamyl in the top 15 than in the top 7.5 cm of the soil. This was best done by spreading the granules on the soil surface and incorporating them with an L-bladed or spiked rotavator working 15 cm deep or by applying the granules on the soil surface and at 5 and 10 cm deep and incorporating them by rotary harrow (Roterra) working 20 cm deep. The uniformity of incorporation of granules in the top 15 cm soil was affected by choice of cultivation machine and by soil type. Pea cyst-nematode (H. goettingiana Liebs.) was controlled in peas grown in closely spaced rows (12 cm apart) by incorporating aldicarb or oxamyl in the top 10 or 15 cm of soil or by applying oxamyl in the seed furrows or at sowing depth (5 cm) during sowing.

Résumé Pour lutter contre les nématodes kystiques de la pomme de terre (Heterodera rostochiensis Woll. et H. pallida Stone) il est plus efficace de mixionner l'aldicarb ou l'oxamyl avec le sol infesté jusqu'à une profondeur de 15 cm au lieu d'une profondeur de 7,5 cm. Pour réaliser cela les meilleures methodes sont a) de semer les granules sur la surface du sol et de les incorporer au sol avec un motoculteur rotatif barbelé ou avec un motoculteur rotatif aux pales en forme-L, ou, b) de semer les granules sur la surface du sol et aux profondeurs de 5 et 10 cm et de les incorporer avec une herse rotative (Roterra), travaillant jusqu'à une profondeur de 20 cm. La regularité de l'incorporation des granules dans le sol jusqu'à une profondeur de 15 cm est affectée par la choix du motoculteur et aussi par la nature du sol. Pour lutter contre le nématode kystique des pois (H. goettingiana Liebs.) dans les cultures des pois verts en rangs serrés (12 cm entre les rangs), on peut incorporer l'aldicarb ou l'oxamyl dans le sol jusqu'à une profondeur de 10 ou 15 cm, ou on peut incorporer l'oxamyl avec les graines ou à la profondeur de la semence (5 cm).

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* now at Weed Research Organization, Begbroke Hill, Yarnton, Oxford.

INTRODUCTION

A number of oximecarbamates and organophosphates control nematode diseases of annual field crops (e.g. Cooke, Dunning & Winder, 1973; Moss *et al*., 1975; Whitehead, 1973, 1975; Whitehead *et al*., 1974; Winfield, 1973). They are mostly very toxic to vertebrates as well as invertebrates, so for safe use are formulated as granules. The average weights of these granules differ considerably, as do the mobilities of the nematicides they release into the soil. As these nematicides are also costly, field experiments were made to find the best ways of applying 10% granules of aldicarb or oxamyl, two very effective nematicides, to soils infested with pea cyst-nematode (*Heterodera goettingiana* Liebs.) or potato cyst-nematodes (*H. rostochiensis* Woll., *H. pallida* Stone).

METHODS

Peas

Three field experiments, at Spalding, Lincolnshire, Bidford-on-Avon, Warwickshire and Evesham, Worcestershire, tested the effectiveness of aldicarb and oxamyl applied in different ways to the seedbed.

At Spalding, aldicarb or oxamyl at 2.8, 5.6 or 11.2 kg a.i./ha was applied to the soil surface by hand and incorporated in the topsoil by rotavation 7.5 or 15 cm deep. Aldicarb at 2, 4 or 8 kg a.i./ha was metered into pea seed furrows at sowing with a land-wheel driven ('Horstine Farmery') microband granule applicator. Plots were 3.05m x 1.52m wide (13 rows of peas). At Bidford and Evesham, aldicarb or oxamyl at 2.4, 4.9 or 9.8 kg a.i./ha were similarly applied and incorporated by rotavation 15 cm deep at Bidford or 10 cm deep at Evesham. Oxamyl at 2.4, 4.9 or 9.8 kg was metered into pea seed furrows during sowing 5 cm deep and at Bidford in a layer at seed depth (5 cm). Plots were 2.44m x 1.83m (13 rows of peas). All three experiments were enclosed in pigeon-proof netting.

Potatoes

Methods of incorporating aldicarb or oxamyl in peaty loam soils

Six experiments, on soils with more than 15% organic matter, tested the incorporation of 5.6 kg aldicarb or oxamyl a.i./ha by L-bladed rotavator, spiked rotavator, reciprocating harrow, rotary harrow or spring-tine harrow. All treatments were applied to the topsoil just before potatoes were planted in the spring. Plots were 9.14m x 4.58m (1973) or 3.05m (1974) (six or four rows of potatoes).

Depth of placement and incorporation of aldicarb or oxamyl in the soil

On peaty loam at the Arthur Rickwood Experimental Husbandry Farm, Mepal, Cambridgeshire, and on sandy loam at the Woburn Experimental Farm, Bedfordshire, aldicarb at 3, 6 or 12 kg a.i./ha was applied to the soil and incorporated in the soil in different ways, before potatoes were planted in the spring. The granules were applied (a) on the soil surface, or (b) half on the soil surface and half 5 cm deep, or (c) one third on the soil surface, one third 5 cm deep and one third 10 cm deep, and incorporated by rotary harrow (Roterra) working 20 cm deep, or they were applied on the soil surface only and incorporated by rotavation 10 or 20 cm deep. Plots at Woburn were 11.43m x 2.84m (four rows of potatoes) and at Mepal 7.62m x 3.05m (four rows of potatoes).

Eleven other experiments, at sites in eastern and central England, compared the effects of incorporating aldicarb or oxamyl at 5.6 or 3.4 kg a.i./ha by rotavating the soil 7.5 or 15 cm deep. Each experiment had two randomised blocks of treatments. Plots were 6.1m x 2.8 - 3.7m (four rows of potatoes). Potato cvs grown were King Edward (six experiments), Pentland Crown (three experiments), Record and Pentland Ivory (one experiment each), all of which are hosts of both species of potato cyst-nematode.

Assessments

A soil sample, comprising 12 cores (pea plots) or 20 cores (potato plots) 2.5 cm diam. and 20 cm deep, was collected from each plot before treatment and after the peas or potato tubers had been harvested. The numbers of cyst-nematode eggs in these samples were estimated by standard methods (Whitehead, Fraser and Storey, 1972). In some experiments, soil cores (6/plot) 4 cm diam. and 25 or 30 cm deep were taken immediately after the granules had been incorporated in the topsoil. Each core was cut into 5 cm lengths and the amount of nematicide in each of these lengths was assessed by solvent extraction and gas-liquid chromatography. Results were expressed in ppm chemical in soil oven dried to 110°C.

Yields of potato tubers were measured from the middle two rows in each plot. All pea pods produced in each plot were harvested and yields of fresh peas were calculated from the weights of fresh peas contained in subsamples of the pods.

RESULTS

Peas

At Spalding, in clay loam infested with pea cyst-nematode (on average 54 eggs/g soil), aldicarb or oxamyl, applied to the soil surface at 2.8, 5.6 or 11.2 kg a.i./ha, greatly increased yields of fresh peas, whether incorporated in soil to 15 or 7.5 cm deep. Aldicarb applied in the seed furrows at 2, 4 or 8 kg a.i./ha did not increase yields. The best treatments increased yields threefold and did not allow pea cyst-nematode numbers to increase.

At Bidford-on-Avon in sandy loam (on average 55 eggs/g of soil) and at Evesham in clay loam (on average 14 eggs/g soil), aldicarb or oxamyl very greatly increased yields of fresh peas. The largest yield increases were obtained with the largest doses applied and 9.8 kg aldicarb a.i./ha, incorporated in the top 15 cm soil increased yields most. At Bidford, oxamyl applied in the seed furrows, or in a layer at sowing depth (5 cm), increased yields as much and controlled pea cyst-nematode as well as when incorporated in the top 15 cm of the soil. At Evesham, oxamyl in the seed furrows controlled pea cyst-nematode as well and increased yields more than did oxamyl incorporated in the top 10 cm of the soil.

Table 1

Yield of fresh peas and nematode increase
(eggs/g soil before peas sown: eggs/g soil after peas harvested)

Treatment	Incorporation depth (cm)	Peas (t/ha)	Nematode increase
	Spalding		
Untreated	-	1.6	x1.1
Aldicarb	7.5	3.3	x0.8
	15	3.6	x0.7
Oxamyl	7.5	2.8	x0.7
	15	3.0	x0.7
S.E. of difference (±)			
untreated v. any of remainder		0.32	0.09
between any of remainder		0.37	0.10
	Bidford		
Untreated	-	0.1	x1.4
Aldicarb	15	3.7	x1.6
Oxamyl	15	2.6	x1.3
in seed furrow	5	2.7	x2.0
at seed depth	5	3.0	x1.2
S.E. of difference (±)			
untreated v. any of remainder		0.38	0.48
between any of remainder		0.34	0.43
	Evesham		
Untreated	-	0.8	x2.4
Aldicarb	10	3.8	x1.7
Oxamyl	10	2.2	x2.1
in seed furrow	5	4.3	x1.8
S.E. of difference (±)			
untreated v. any of remainder		0.42	1.03
between any of remainder		0.38	0.92

Potatoes

Methods of incorporating granular nematicides in peaty loam soils

Incorporation method had little effect on yield response to nematicide treatment, but in 1974 the rotavators increased yields more consistently than the harrows. In 1973, and especially in 1974, aldicarb or oxamyl controlled potato cyst-nematodes better when incorporated by rotavation than when incorporated by harrowing. The spiked rotavator was as effective as the L-bladed rotavator.

Table 2

Effect of incorporating 5.6 kg aldicarb or oxamyl a.i./ha in the soil with different implements on total yield and on nematode increase (means of treatments)

Experiment	1973 Mepal	1973 Yaxley	1973 Chatteris	1974 Mepal	1974 Welches Dam	1974 West Row
Eggs/g soil before treatment	40-140	60-300	130-300	60-150	40-80	20-150
		tuber yields (t/ha)				
Untreated	35.1	27.4	29.9	45.9	39.2	41.4
L-bladed rotavator	43.9	32.1	39.2	58.0	54.5	54.0
Spiked rotavator	46.7	32.9	39.2	58.2	55.2	50.0
Reciprocating harrow	46.4	31.4	40.2	54.7	49.5	48.2
Rotary harrow (Roterra)	47.0	32.4	35.1	54.2	50.2	51.0
Spring-tine harrow	-	-	-	55.2	45.4	49.2
S.E.(±)	1.78	1.86	1.61	3.84	2.31	3.06
		nematode increase				
Untreated	x22.6	x6.0	x7.9	x6.2	x6.6	x32.0
L-bladed rotavator	x 7.4	x6.3	x1.4	x2.6	x4.3	x 8.7
Spiked rotavator	x 6.3	x4.4	x1.4	x2.5	x3.6	x 7.9
Reciprocating harrow	x12.5	x6.7	x2.9	x7.0	x4.4	x11.2
Rotary harrow (Roterra)	x14.3	x12.3	x4.0	x6.5	x5.8	x11.0
Spring-tine harrow	-	-	-	x4.3	x4.7	x11.8

At the Arthur Rickwood E.H.F., Mepal, in 1973, the L-bladed rotavator incorporated 10% granules of Dowco 275 uniformly to the depth of cultivation (10 cm or 20-25 cm). Further tests at Mepal in 1974, using Temik 10G-BC granules showed that cultivation with the reciprocating harrow or Roterra left three-quarters of the granules in the top 5 cm of soil, whereas the spiked rotavator incorporated the granules fairly uniformly to the working depth of 15-20 cm (Fig. 1). The spring-tine harrow incorporated the granules to between 5 and 10 cm deep but there was considerable variation between cores.

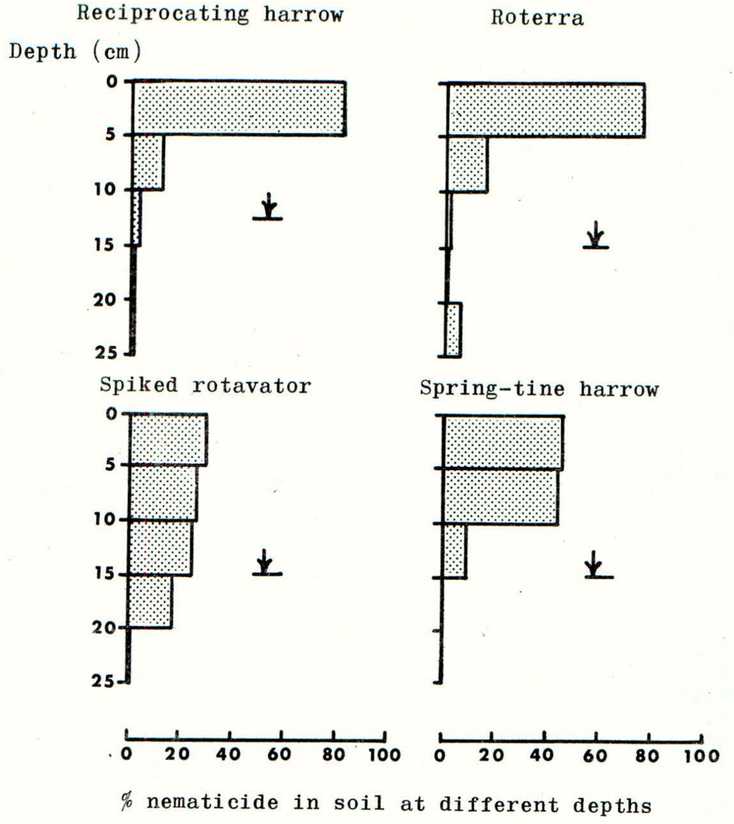

Fig. 1 Comparison of granule incorporation in peaty loam by different implements. ↓ nominal working depth.

Depth of placement and incorporation of aldicarb or oxamyl in soil

Results obtained in 1974 suggest that the incorporation of aldicarb is more critical in a peaty loam than in a sandy loam. For in sandy loam at Woburn aldicarb controlled potato cyst-nematodes equally well, whichever dosage was applied and however it was incorporated in the soil, whereas in peaty loam at Mepal 6 or 12 kg aldicarb a.i./ha controlled potato cyst-nematodes better than 3 kg/ha. Control was also better when aldicarb was incorporated by rotavation than when it was incorporated by Roterra. Similarly tuber yields were influenced more by incorporation technique and by dosage of aldicarb in the peaty loam than in the sandy loam.

Table 3

Effect of different methods of incorporating aldicarb granules (mean of 3, 6, 12 kg a.i./ha) on yield of Pentland Crown or King Edward tubers and on nematode increase

Treatment	Mepal (peaty loam)		Woburn (sandy loam)	
	Total K. Edward tubers (t/ha)	Nematode increase	Total P. Crown tubers (t/ha)	Nematode increase
Untreated RT	37.2	x6.1	30.3	x4.2
S. RT	61.8	x2.5	58.1	x0.7
SM. RT	60.9	x2.2	58.3	x0.8
SMD. RT	57.5	x2.6	59.4	x0.8
RT.S. RV1	67.1	x1.4	60.9	x0.6
RT.S. RV2	63.6	x1.6	62.9	x0.7
S.E. of difference (±)				
untreated v. any of remainder	2.63	0.65	2.30	0.30
between any of remainder	1.86	0.46	1.62	0.21

RT. Roterra working 20 cm deep.
S. All applied to soil surface.
SM. Half on soil surface, half 5 cm deep.
SMD. One third on soil surface, one third 5 cm and one third 10 cm deep
RV1 Rotavated 10 cm deep.
RV2. Rotavated 20 cm deep.

At Woburn and Mepal the L-bladed rotavator incorporated aldicarb granules fairly uniformly to the working depth in the soil, whereas the Roterra left 70-80% of the granules in the top 5 cm of the soil. In a silt soil at Terrington, however, both machines distributed the granules fairly uniformly to the working depth (Fig. 2). The Roterra was operated similarly in all three experiments, so the differences in incorporation achieved by it must be attributed to the effects of soil type.

Split application of granules i.e. on the soil surface and at 5 or 5 and 10 cm deep, followed by incorporation with the Roterra, distributed the granules fairly uniformly to 10 cm deep, as would be expected, but few were incorporated deeper than this at Mepal or Woburn. Again, most granules applied to the soil surface only and incorporated by Roterra were recovered from the top 5 cm of the soil.

In eleven other experiments aldicarb or oxamyl applied to the soil surface at 5.6 kg a.i./ha usually controlled potato cyst-nematodes better when rotavated into the top 15 cm than when rotavated into the top 7.5 cm of the soil. At 3.4 kg a.i. the nematodes were usually less well controlled and there was little to choose between the two depths of incorporation.

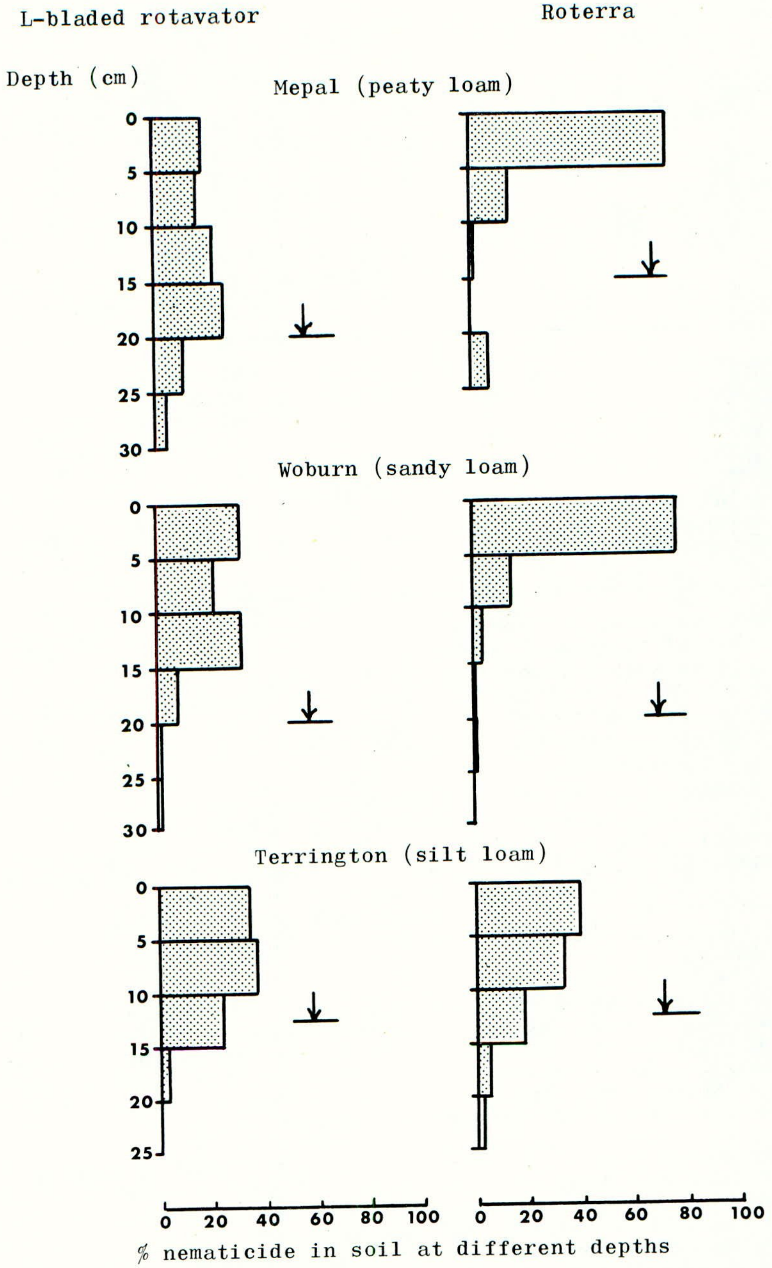

Fig. 2 Comparison of granule incorporation by L-bladed rotavator and Roterra in three soils. ↓ nominal working depth.

Table 4

Effect of two dosages and two depths of incorporating aldicarb or oxamyl in the soil on the control of potato cyst-nematodes on susceptible potato cvs in eleven experiments

Treatment		Nematode increase	
Untreated		x19.2	
Dosage (kg a.i./ha)	Depth incorporated (cm)	Aldicarb	Oxamyl
5.6	15	x2.9	x3.9
5.6	7.5	x7.3	x6.5
3.4	15	x6.5	x8.0
3.4	7.5	x6.8	x8.8

DISCUSSION

Most oximecarbamate and organophosphate nematicides appear to act on nematodes in the soil water, rather than in plants following systemic uptake of the chemical (Hague & Pain, 1970, 1973; Boparai & Hague, 1974). To control cyst-nematodes, which move only small distances in soil, effective nematicides must therefore be mixed well with infested soil. This means that the soil must be treated before sowing. Granular nematicides applied to the soil after sowing are less effective a) because they cannot be mixed adequately with the soil and b) because the seedlings are much damaged by nematodes soon after sprouting or germination. Even when thorough mixing is achieved, a formidable task, the effectiveness of the nematicide is influenced by the number of granules applied to the soil, for this determines the average soil volume in which nematicide from a single granule must operate (Table 5).

Movement of non-volatile chemicals away from granules in soil occurs by leaching and diffusion through the soil water. For a given water flux the rate of these processes is determined by the extent to which the chemicals are adsorbed onto soil, especially soil organic matter, and the five nematicides listed (Table 5) are put in mobility classes based on soil adsorption data (Briggs, 1973; Bromilow, 1973). So, to achieve maximum effect, granules containing strongly sorbed and hence less mobile nematicides, such as carbofuran and the organophosphates, may need to be spaced more closely and more uniformly in the soil than is necessary for the more mobile oximecarbamates, such as aldicarb or oxamyl (Bromilow & Tucker, 1973). This may be particularly important in soils containing much organic matter, where, because these nematicides are not ionised at normal soil pH levels and so are adsorbed mainly onto the soil organic matter, they therefore move less than in less organic soils.

Table 5

Granule sizes and mobilities of five nematicides in soil

Chemical	Granule formulation* name	year	Av. granule wt (mg)	Av.vol. of soil per granule+ (ml)	Mobility of chemical in soil
0,0-diethyl 0-(6-fluoro-2 pyridyl) phosphorothioate	Dowco 275	1973	0.082	2.5	low
fenamiphos	Nemacur	1972	0.32	9.6	low
carbofuran	Furadan	1974	0.37	11	low
aldicarb	Temik 10G-BC	1974	1.1	33	high
oxamyl	Vydate	1974	0.083	2.5	very high

* All 10% a.i. + Calculated for 50 kg granules/ha, incorporated uniformly in soil to 15 cm deep.

Our potato experiments showed that even with highly mobile nematicides, like aldicarb or oxamyl, soil type and incorporation technique, because they can influence the distribution of the granules in the soil, may still affect nematode control. Potato cyst-nematodes were best controlled in soil to 20 cm deep when 10% aldicarb or oxamyl granules were thoroughly mixed in the top 10-15 cm of soil, i.e. in the soil which later formed the potato ridges. When the granules were mixed in the top 7.5 cm of the soil, the roots of the planted tubers had less treated soil in which to grow, so nematode control was often reduced. In contrast, incorporating granules in the top 20 cm of the soil reduces the concentration of nematicide in the ridges, where most nematode multiplication occurs and nematode control is, again, reduced (Whitehead et al., 1975). Fenamiphos or aldicarb controlled potato cyst-nematode better in a peaty loam soil when incorporated by a rotavator with L-shaped tines than when incorporated by a rotary harrow (Roterra) (Whitehead et al., 1973). Experiments in 1973 and 1974 on peaty loam soils further showed that the spiked rotavator was as effective as the L-bladed rotavator and that rotavators were more effective than reciprocating, spring-tine or rotary harrows (Roterra), the granules being mixed well in soil to the working depth by the rotavators but not by the harrows. The poor results at Yaxley in 1973 may have resulted from inadequate mixing of the nematicides with the soil. Similarly, results at Welches Dam in 1974 may have been affected by lime spread on the soil at the same time as the aldicarb or oxamyl granules. The L-bladed rotavator is apt to 'glaze' moist soils with appreciable clay contents. The spiked rotavator is less likely to do this and requires less power to operate. An alternative solution is to place the granules at different depths in the soil (0, 5 and 10 cm) and incorporate them with a rotary harrow (Roterra).

In Australia, Brown (1973) found that 2.2 kg aldicarb/ha applied in the seed furrows during sowing controlled cereal cyst-nematode (*H. avenae*) on wheat as well as 9 kg/ha incorporated in the top 10 cm of the soil. At Spalding in 1974, aldicarb at 2, 4 or 8 kg/ha in the pea seed furrows had little effect on pea cyst-nematode but at Bidford and Evesham in 1975 oxamyl controlled pea cyst-nematode as well when applied to the pea seed furrows during sowing as when incorporated in the top 10 or 15 cm of the soil. These results were probably due to the lack of rain after sowing in 1974, so aldicarb was not leached through the soil, whereas in 1975, heavy rain after sowing leached oxamyl from the seed furrows, so the extending root system was protected from invasion by nematode larvae. This is supported by the fact that at Evesham and Bidford in 1975 pea yields were largest following the largest doses of aldicarb or oxamyl applied to the seedbed, whereas at Spalding in 1974 pea yields were influenced much less by dosage. Row applications of oximecarbamate nematicides are ineffective in controlling cyst-nematodes in potatoes or sugar beet grown in widely spaced rows (Whitehead *et al*., 1975; Dunning & Winder, 1974) but may be useful for the control of nematodes attacking the roots of peas, cereals and other annual field crops grown in closely spaced rows, providing the nematicide is leached rapidly enough to protect the extending roots from nematode invasion.

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THE EFFECTS OF FIVE NEMATICIDES AND TWO FUNGICIDES ON SIX SPECIES OF LONGIDORIDAE

D. L. Trudgill

Scottish Horticultural Research Institute, Invergowrie, Dundee

Summary Two fungicides benomyl and quintozene gave good control of *Longidorus elongatus* and prevented transmission of RRV or TBRV. The carbamate nematicides oxamyl, aldicarb and carbofuran delayed increase in numbers of *L. elongatus* only briefly and gave poor protection against virus transmission. Thionazin and fenamiphos had little effect on nematode numbers or on virus transmission. In 25 ppm solutions of oxamyl *L. caespiticola* and *Xiphinema diversicaudatum* rapidly protracted their stylets. Carbofuran and aldicarb also caused stylet protraction in these two species but benomyl, quintozene, thionazin and fenamiphos were ineffective. *Longidorus attenuatus* did not protract its stylet in solutions of oxamyl and the response of *Paralongidorus maximus*, *L. macrosoma* and *L. elongatus* was variable.

INTRODUCTION

The oximecarbamate nematicides oxamyl and aldicarb appear to act on nematodes by disorganising feeding behaviour or host finding (Nelmes, Trudgill & Corbett, 1973). In solutions of oxamyl, nematodes respond with stylet protraction and with oesophageal bulb pulsations (Forer, Trudgill & Alphey, 1975). This mode of action and short persistence in soil results in many ecto-parasitic nematodes surviving treatment with oximecarbamate nematicides, and suggests that they are likely to be unsuitable for use in perennial crops where nematode-transmitted virus diseases are the main problem.

In Scotland the fungicide quintozene has been found to give long-term control of virus transmission by *L. elongatus* whilst decreasing nematode numbers only slowly (Taylor & Murant, 1968). Its mode of action is unknown. A second fungicide, benomyl, has also been found to give long term control of plant parasitic nematodes (Hide & Corbett, 1973) and to prevent the reproduction of *L. elongatus* in strawberries for at least 48 weeks, as reported in this paper.

The slow decrease in numbers of *L. elongatus* following incorporation of quintozene or benomyl into the soil suggested that these chemicals might affect nematodes in a manner similar to oxamyl, but are more effective because of their greater persistence. This hypothesis was examined in field trials and in *in vitro* tests reported here.

METHOD AND MATERIALS

Field trials. In the first of two field trials, dazomet, D-D and quintozene were applied in November to soil infested with L. elongatus carrying raspberry ringspot virus (RRV). In the following March, immediately prior to planting raspberries, aldicarb and oxamyl were applied as granules and incorporated by rotary cultivation. There were four replicates of each treatment and the plots were sampled immediately prior to treatment and at intervals after planting the raspberries. The virus infectivity of the nematodes was tested in the glasshouse by planting Chenopodium quinoa bait plants in 10 cm pots containing soil from the experimental plots.

In the second field trial the test chemicals were applied and incorporated prior to planting strawberries in April. The chemicals and the rates of active ingredient applied are shown in Table 2. As the population of L. elongatus was largely virus-free its ability to acquire and transmit tomato black ring virus (TBRV) was tested by first planting virus-infected Petunia hybrida in 10 cm pots filled with soil from the plots. After 1 month the infector plants were removed and replaced by virus-free Petunia hybrida bait plants. After a further month the roots of the bait plants were washed free of soil and nematodes and incoulated to the leaves of C. quinoa indicator plants.

In vitro treatments. Groups of ten freshly extracted nematodes were tested in solutions of the non-fumigant chemicals used in the field trials. In the first test the effect of different concentrations of oxamyl on stylet protraction by L. elongatus and X. diversicaudatum was observed. In the second test six nematode species were tested and the two most responsive species, L. caespiticola and X. diversicaudatum, together with L. elongatus, were then used to test the chemicals under trial. Each test was repeated once. Except for oxamyl and carbofuran, the solutions used in the in vitro tests were prepared from the same chemicals used in the field trials. As some of the chemicals had low solubility in water the solutions were shaken for 24 h before use.

RESULTS

Field trials. In the first field trial all the test chemicals had significantly decreased numbers of L. elongatus 14 weeks after planting compared with the untreated control (Table 1). Thirty-four weeks after planting, numbers of L. elongatus had increased in the oxamyl and aldicarb treated plots; L. elongatus does not multiply on raspberry (Taylor, 1967) and weeds present in the plots were the hosts. Dazomet, D-D and quintozene prevented transmission of RRV but aldicarb and oxamyl were less effective and some transmission of virus occurred especially in bait tests 34 weeks after planting.

In the second field trial (Table 2) only benomyl prevented any increase in numbers of L. elongatus. Carbofuran and oxamyl slowed the rate of increase in numbers of L. elongatus but thionazin and fenamiphos had little or no effect.

Benomyl completely inhibited acquisition and transmission of TBRV 3 and 6 weeks after planting. Carbofuran and oxamyl were only partially effective, decreasing the rates of virus transmission, with one bait test per plot, from four out of four in the untreated control to two plots out of four, 3 weeks after planting.

In vitro tests. In a preliminary test the effect of different concentrations of oxamyl on the numbers of L. elongatus or X. diversicaudatum protracting their odontostyles beyond the external opening of the stoma was assessed (Table 3). Both species responded only slightly in 0.25 ppm, the maximum response being produced in 25 and 100 ppm solutions.

Table 1

Effect of four nematicides and one fungicide on numbers of L. elongatus and transmission of RRV

Treatment	Time after planting	Nematodes per 200 g soil 14 wks	34 wks	Virus infectivity 14 wks	34 wks
Control		58	68	3/4	4/4
Dazomet	336 kg/ha	1**	7**	0/4	0/4
DD	336 kg/ha	3**	9**	0/4	0/4
Quintozene	89 kg/ha	14*	16**	0/4	0/4
Aldicarb	3.36 kg/ha	15*	59	0/4	2/4
Oxamyl	7.84 kg/ha	15*	26**	1/4	2/4

* Significantly different from the control p = 0.05
** " " " " " p = 0.01

Table 2

Effect of four pesticides and one fungicide on numbers of L. elongatus and transmission of TBRV

Treatment	Time after planting	Nematodes per 200 g soil 14 wks	48 wks	Virus infectivity 3 wks	6 wks
Control		140	115	4/4	4/4
Thionazin	111 kg/ha	87	132	4/4	4/4
Fenamiphos	111 kg/ha	93	165	4/4	4/4
Benomyl	221 kg/ha	19**	8**	0/4	0/4
Carbofuran	111 kg/ha	57*	88	2/4	4/4
Oxamyl	5.6 kg/ha	45*	125	2/4	1/4

* Significantly different from the control p = 0.05
** " " " " " p = 0.01

Table 3

Effect of rates of oxamyl on numbers of L. elongatus and X. diversicaudatum protracting their stylets. Results from twelve nematodes

	L. elongatus				X. diversicaudatum			
	oxamyl (ppm)							
Time (min)	0.25	2.5	25	100	0.25	2.5	25	100
0	0	0	0	0	0	0	0	0
5	0	1	7	7	0	1	9	12
15	0	4	5	6	0	3	12	12
35	0	3	4	4	2	6	12	12
55	1	3	1	2	2	6	12	12

Table 4

Effect of 25 ppm oxamyl on stylet protraction
Results are from two groups of ten nematodes

Time (min)	*L. caespiticola*		*L. macrosoma*		*L. elongatus*		*L. attenuatus*		*P. maximus*		*X. diversicaudatum*	
0	0	0	0	0	0	0	0	0	0	0	0	0
10	10	7	1	3	5	2	0	0	4	1	7	9
20	10	9	4	8	5	1	0	0	7	3	8	10
40	10	10	3	9	4	0	0	0	7	1	10	10
60	10	10	3	9	1	0	0	0	7	1	10	10

Table 5

Effect of six chemicals on stylet protraction by three nematodes
Results from ten nematodes

Time (min)	Aldicarb 25 ppm	Carbofuran 25 ppm	Oxamyl 25 ppm	Fenamiphos 25 ppm	Thionazin 25 ppm	Benomyl Saturated sol.	Quintozene Saturated sol.
L. caespiticola							
0	0	0	0	0	0	0	0
15	0	9	9	0	0	0	0
30	0	10	10	0	0	0	0
45	1	10	10	0	0	0	0
60	3	10	10	0	0	0	0
90	10	10	10	0	0	0	0
L. elongatus							
0	0	0	0	0	0	0	0
15	0	2	2	0	0	0	0
30	0	0	0	0	0	0	0
45	0	0	0	1	0	0	0
90	0	0	0	0	0	0	0
X. diversicaudatum							
0	0	0	0	0	0	0	0
15	0	7	8	0	0	0	0
30	1	8	8	0	0	0	0
60	8	8	8	0	0	0	0

The responses of six species to a 25 ppm oxamyl solution varied (Table 4). Longidorus caespiticola and X. diversicaudatum rapidly protracted their stylets which remained almost fully protracted for the duration of the tests (1 h). Longidorus attenuatus showed no apparent response. The response of P. maximus, L. macrosoma and L. elongatus varied between tests and some nematodes retracted their stylets during the test.

In the final tests the most responsive species, L. caespiticola and X. diversicaudatum, together with L. elongatus were tested in solutions of the non-fumigant chemicals used in the field trials. Only carbofuran, oxamyl and aldicarb induced stylet protraction. Longidorus caespiticola and X. diversicaudatum responded rapidly to oxamyl and carbofuran, but more slowly to aldicarb. Only two of ten L. elongatus responded to carbofuran and oxamyl and none responded with stylet protraction when placed in 25 ppm aldicarb solution (Table 5). The test was repeated with L. caespiticola only this time with sufficient chemical to produce 100 ppm solutions (Table 6). After 18 h those in water and quintozene were still active at the end of the test but those in oxamyl, benomyl (with or without 2% acetone), thionazin, fenamiphos and carbofuran were paralysed or dead and did not move even when their bodies were compressed with a needle. Those in oxamyl and carbofuran had retracted their stylets fully by the end of the test, but six of ten in aldicarb still had their stylet protracted and two were still active.

Table 6

Effect of six chemicals on stylet protraction by L. caespiticola
Results from ten nematodes

Time (h)	Water Control	Aldicarb 100 ppm	Carbofuran 100 ppm	Oxamyl 100 ppm	Fenamiphos 100 ppm	Thionazin 100 ppm	Benomyl Saturated sol.	Quintozene Saturated sol.
0	0	0	0	0	0	0	0	0
1	0	0	8	10	0	0	0	0
2	0	8	10	10	0	0	0	0
3	0	8	10	10	0	0	0	0
4	0	9	10	10	0	0	0	0
18†	0	6	0	0	0	0	0	0

† After 18 h nematodes were inactive in all solutions except quintozene aldicarb and the water control.

DISCUSSION

Quintozene and benomyl gave effective, long-term control of L. elongatus and transmission of RRV or TBRV. Aldicarb, oxamyl and carbofuran were effective for only a few weeks. Thionazin and fenamiphos appeared to have little or no effect on L. elongatus when applied to the soil.

Only the carbamate pesticides induced stylet protration and species of Longidoridae varied in their response. Nelmes (1970) reported abnormal stylet protrusion of Heterodera rostochiensis larvae in solutions of aldicarb and Kondrollochis (1971) observed similar behaviour by Aphelenchus avenae in solutions of thionazin. However in Longidorid spp. both stylet protractor and retractor muscles appear to be stimulated and stylet protraction occurred only when the protractor muscles were stronger, or more strongly stimulated, than the retractor muscles.

The two fungicides, quintozene and benomyl, did not induce stylet protraction but as both these chemicals have low solubility in water the result may not be meaningful. However, quintozene still did not induce stylet protraction when its solubility was enhanced by dissolving in 2% ethanol. The action of quintozene and benomyl is still therefore a matter for speculation.

More surprisingly thionazin and fenamiphos failed to induce stylet protraction and it appears that only some chemicals with acetylcholine esterase-inhibiting properties provoke this behaviour in Longidorid species. Stylet protraction by Longidorid spp. does not therefore provide a method of screening candidate chemicals for nematicidal activity.

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Les éffets de 5 nematicides et de deux fongicides sur 6 espèces de Longidoridae

Resume Deux fongicides, le benomyl et le quintozene ont controlé, de manière satisfaisante le *Longidorus elongatus* et ont empeché la transmission des virus RRV ou TBRV. Le nématicide du type carbamate telque l'oxamyl, l'aldicarbe et le carbofuran n'ont retardé la multiplication du *Longidorus elongatus* que brievement et n'out pu donner une protection éfficace contre les transmissions de virus. La thionazine ainsi que le fenamiphos n'ont en pratiquement aucun effet sur le nombre des nématodes ou la transmission virale. Dans des solutions de 25 ppm d'oxamyl le *L. caespiticola* et le *Xiphinema diversicaudatum* ont rapidement étiré leurs stylets. Le carbofuran et l'aldicarbe ont aussi cause l'allongement du stylet pour deux espèces, mais le benomyl, le quintozene, la thionazine et le fenamiphos n'ont eu aucun effet. Le *Longidorus attenuatus* n'a pas étiré son stylet dans des solutions d'oxamyl, et la reaction du *Paralongidorus maximus*, du *L. macrosoma* et du *L. elongatus* a été variable.

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