Acknowledgements

We thank Eric Brodie, Liz Coates, Linda Dale, Frances FitzGibbon, Fran Rab and Don Logan for technical assistance. We are also grateful to those growers who participated in the study, gave us permission to use their orchards and took time to tell us about their pest management activities. We also thank Dr. E. Lindquist of the Biosystematics Research Institute, Agriculture Canada, and Ms. E. Shaul of the University of Toronto for identifying *Amblyseius* sp. near *herbarius* Wainstein.

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EFFICACY AND RESIDUES OF CHLORPYRIFOS APPLIED AGAINST ROOT MAGGOTS ATTACKING COLE CROPS IN BRITISH COLUMBIA

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Abstract

Chlorpyrifos proved to be as effective as chlorfenvinphos, and more effective than fensulfothion and diazinon for cabbage maggot control in root and stem crucifers. For short season crops such as cauliflower, broccoli and cabbage, the granular formulation applied at seeding, followed in 21 days with a single drench of the emulsifiable liquid formulation was adequate. In Brussels sprouts, the slowest of the stem crucifers to mature, a minimum of two drench applications were necessary for acceptable control. In rutabaga, another long season crop, chlorpyrifos 15G applied at seeding followed by 3 drench applications (i.e. at 21 day intervals) after seeding was necessary to produce rutabagas with acceptable damage levels at harvest. In the sandy-clay loam where these studies were undertaken, chlorpyrifos applied at the dosage rates and at the times prescribed for the stem and root crucifers studied did not give rise to appreciable residues at harvest. These studies show that a pre-harvest interval of 32 days would be appropriate for the 5 crops studied.

Introduction

The cabbage maggot, *Delia radicum* (L.), is a chronic and serious pest of cole crops grown in the Fraser Valley and Vancouver Island regions of B.C. If not adequately controlled, maggot feeding may kill, weaken or stunt developing plants and reduce yields considerably. In root crucifers such as rutabaga and turnip, maggots can render the crop unmarketable if more than slight damage caused by their feeding is evident on the roots at harvest. Research into the biology and control of this pest pertinent to this growing region has been reported by King and

Forbes (1954,1958); King *et al.* (1955); Forbes (1962); and Finlayson *et al.* (1967,1980). Since the 1950's, insecticides have been the mainstay of successful maggot control programs in commercial production in B. C. Initially, chlorinated hydrocarbon insecticides were used, until resistant strains of the maggot were identified in the Pacific Northwest in 1959 (Howitt and Cole 1962; Finlayson 1962). At present, control of root maggots attacking the stem crucifers, broccoli, Brussels sprouts, cabbage and cauliflower, relies exclusively on granular and/or drench applications of organophosphates such as chlorfenvinphos, fensulfothion, and diazinon. These chemicals, with the addition of phorate and carbofuran, a carbamate, are also registered for use on root crucifers such as rutabagas and turnips.

Although the arsenal of insecticides currently available against the cabbage maggot seems adequate, there are in fact problems associated with each registrant. Fensulfothion and diazinon, for example, have failed in recent years to provide commercially acceptable maggot control in both the field and seed bed (M. Sweeney, personal communication, Simonet 1981). Although not verified, an increasing tolerance of the pest to these insecticides is suspected. Chlorfenvinphos, although still effective, can, under certain environmental conditions, or if misapplied, reduce germination or stunt seedlings (Mackenzie and Vernon 1984). Phytotoxicity has also resulted from the improper use of fensulfothion. For the root crucifers, carbofuran still appears efficacious, however, chronic use of this material can result in the proliferation of soil bacteria antagonistic to the persistence of this pesticide (Felsot *et al.* 1981,1982). Where this has occurred, as in Illinois (Felsot 1982), the effective longevity of carbofuran has been markedly reduced. Locally, there is some evidence that such "antagonistic" soils are emerging in the muckland soil growing region of Cloverdale. Finally, phorate, available only in the granular formulation, is restricted to a single application at seeding and is prohibited from use in highly organic soils. These considerations cast doubt on the current and future usefulness of these insecticides for cabbage maggot control in B.C. For the B.C. cole crop industry to remain viable, it is essential to expand the chemical control options available to growers.

From 1980 to 1986, a number of insecticides were screened for cabbage maggot control on root and stem crucifers. Of those tested, chlorpyrifos, an organophosphate, appeared to be as efficacious as the insecticides currently registered, or more so and, because chlorpyrifos is registered for root maggot control in onions, it is well suited for expedient registration on cole crops. This paper reports: 1) the efficacy and phytotoxicity of the granular and liquid formulations of chlorpyrifos in comparison with other candidate insecticides for registration; 2) the optimum rates, number and timing of chlorpyrifos applications for effective use under B. C. growing conditions; and 3) residues of chlorpyrifos in marketable produce at harvest.

Methods and Materials

Efficacy and Phytotoxicity

Between 1981 and 1986, 20 field studies were carried out at the Abbotsford research substation of Agriculture Canada. With the exception of one cauliflower experiment, which was transplanted, all crops were direct-seeded in beds of 2 rows spaced 60 cm apart with 120 cm between rows in adjacent beds. The plants were thinned to 30 cm spacings within the row. Treatment plots were beds, i.e. row pairs, 7.5 m in length and replicated 4 times in a randomized block design.

Insecticides were applied to a sandy clay loam either as granules at the time of seeding or as drenches after seeding. The granular formulations were applied in a 15 cm wide band with a custom built geared applicator attached to and driven by a hand-pushed Stanhay precision seeder. Incorporation of the granules to a depth of about 2.0 cm was achieved by the bow-wave method, where the granule delivery tube is positioned directly in front of the seed coulter. During seeding the coulter ploughs the granules to either side of the furrow. The dragging-bar behind the coulter then fills in the furrow and spreads the granules in a band. The rear wheel of the seeder compacts the treated soil to complete the application. Drenches were applied to the soil at low pressure with a Solo back-pack sprayer to 10 cm on both sides of the plants in the row in a volume of 0.7-2 L water/10m row (1,100-3,300 L water/ha). Granular and liquid formulation rates are expressed as grams of active ingredient (a.i.) applied to 10 m of seeded row. Granular treatments included chlorfenvinphos 10G (10% a.i.); terbufos 15G (15% a.i.); fensulfothion 15G (15% a.i.); diazinon 5G (5% a.i); and chlorpyrifos 15G (15% a.i.). Rates of chlorpyrifos ranged from 0.9-2.2 g a.i./ 10 m of row in efficacy studies, and from 0.9-3.0 g a.i./10 m of row in phytotoxicity studies. Rates of the other insecticide granulars are shown in Table 1 or are mentioned in the Results. Drench treatments included chlorfenvinphos 40 E (40% a.i.), fensulfothion 6 E (60% a.i.) and diazinon 50 E (50% a.i.). Chlorpyrifos drenches were prepared from the 4EC and 4E-HF formulations, both containing 40.7% active ingredient. Rates and post-seeding dates of drench applications are shown in Tables 1 and 2, or are mentioned in the Results.

Treatment efficacy was assessed by rating maggot damage to roots. Plants from each treatment replicate were uprooted, washed free of soil, and the damage assessed visually using the method of King and Forbes (1954). Roots with no damage were assigned a value of 0 (=none); 1 (=slight); 2 (=moderate); 4 (=severe); and 8 (=very severe). The average value for each treatment was the maggot damage index (D.I.) of that treatment. Rutabagas graded with a D.I. higher than 1 were considered unmarketable.

Phytotoxicity was assessed by counting the number of emerged seedlings either along the entire length of seeded row or within a fixed length of row measured mid-way along the total plot length. Other symptoms of phytotoxicity, such as stunting, leaf cupping, discolouration, and burning were noted when apparent.

The data were transformed by the square root of x + .5 before analysis of variance.

Residue Analyses

Preparation of Plant Tissue Samples. Plant tissue was analyzed for residues of chlorpyrifos and its degradative products using the following method. Samples of cabbage, cauliflower, broccoli, Brussels sprouts, and rutabagas were chopped and thoroughly mixed with a food processor according to crop, treatment and sampling date. Aliquots of 20 g of plant tissues were extracted twice with 100 ml of dichloromethane:acetone (3:2, V:V) mixture in a polytron homogenizer. The extracts were filtered through a Buchner funnel lined with a glass fibre filter paper. The combined extracts were transferred quantitatively to 500 ml separatory funnels to allow separation of the two phases. The aqueous phases were separated and re-extracted with dichloromethane after salting out with sodium chloride. The combined organic phases were dried on anhydrous sodium sulfate and then evaporated just to dryness in a flash evaporator at 38 C. The residues were dissolved in 10 ml of dichloromethane for chemical derivatization.

Chemical Derivatization of 3,5,6-trichloro-2-pyridinol. Crude extracts in dichloromethane equivalent to 2 g of tissue were transferred into 10 ml graduated glass stoppered reaction tubes, followed by the addition of 5 drops of etheral solution of diazoethane in a fume hood. They were thoroughly mixed and allowed to react at room temperature for 30 min. Upon completion of reaction, 10 drops of keeper (1% OV-1 methyl silicone in hexane) were added and the unreacted diazoethane was driven off with a stream of nitrogen. To the reaction products 4 ml of hexane was added, and mixed thoroughly for further clean-up on a Florisil column.

Clean-up of tissue extracts. Chromatographic columns (30 x 1.1 cm i.d.) with Teflon stopcocks were packed from bottom to top, with a glass wool plug, 1.5 cm of anhydrous Na_2SO_4, 6 cm of 2% water deactivated Florisil, 1.5 cm anhydrous Na_2SO_4, and another glass wool plug. The packed columns were prewashed with 10 ml of dichloromethane followed by 10 ml of hexane. The reaction products were then passed through the clean-up columns and the resulting eluates were collected. Chlorpyrifos, ethylated 3,5,6-trichloro-2-pyridinol (pyridinol) and 3,5,6-trichloro-2-methoxypyridine (methoxypyridine) were eluted with 25 ml of 25% dichloromethane in hexane. After the addition of 10 drops of keeper the eluates were concentrated to about 2 ml in a flash evaporator at 38 C. After the addition of 2 ml of isooctane the extracts were further concentrated to about 0.5 ml under a stream of nitrogen. The solvent exchange was repeated twice more and the final volumes were appropriately adjusted with isooctane before GLC analysis.

Gas Chromatography. GLC analyses were made with a Hewlett Packard Model 5890 gas chromatograph equipped with an electron capture detector for the ethylated 3,5,6-trichloro-2-pyridinol and 3,5,6-trichloro-2-methoxypyridine; for the chlorpyrifos a Hewlett Packard

Table 1. Efficacy in cauliflower (cv. Elgon) of chlorpyrifos and three insecticides registered for control of cabbage maggot on stem crucifers, as granules and drenches, Abbotsford, B.C., 1982.

	Dosage (g a.i./10 m)		Maggot damage index[3]		
Treatment	Granular	Drench	65 days[1]	85 days	93 days
Chlorpyrifos 15G + 4E (1 drench)	1.3	1.0	0.1a[2]	0.4a	0.6a
Chlorfenvinfos 10G + 40E (1 drench)	1.7	1.0	0.9ab	0.6a	0.3a
Fensulfothion 15G + 6E (1 drench)	1.3	1.3	2.8 cd	3.0b	4.4bc
Diazinon 5G + 50E (2 drenches)	1.9	1.5	1.7abc	4.1b	3.6b
Control	-	-	2.2bc	4.2b	3.7b

[1] Days after seeding.

[2] Values in each column followed by the same letter are not significantly different (Duncan's multiple range test, $P < 0.05$).

[3] Damage index: 0 = none; 1 = slight; 2 = moderate; 4 = severe; 8 = very severe.

Model 5880A gas chromatograph equipped with a flame photometric detector was used. The capillary columns were 10 m x 0.25 mm i.d. containing cross-linked methyl silicone. The operating parameters were: detector temperature 300 C for the electron capture detector and 200 C for the flame photometric detector; helium as carrier gas at 70 kPa; 5% methane in argon at 20 ml/min as makeup gas for the electron capture detector; hydrogen at 100 ml/min, air at 100 ml/min, and nitrogen at 30 ml/min for the flame photometric detector; column temperature program T_1 = 85 C, rate 1 = 30 C/min; T_2 = 165 C, rate 2 = 5 C/min; T_3 = 185 C, rate 3 = 20 C/min; T_4 = 225 C. Under the described chromatographic conditions the absolute retention times for 3,5,6-trichloro-2-methoxypyridine, ethylated 3,5,6-trichloro-2-pyridinol and chlorpyrifos were 3.89, 7.01 and 11.65 min respectively.

Method Evaluation. Plant tissue from the untreated control was fortified with 3,5,6-trichloro-2-methoxypyridine, 3,5,6-trichloro-2-pyridinol and chlorpyrifos at 1.0, 0.1, and 0.01 ppm (fresh wt.). Quadruplicates of the fortified samples at each level were processed and analyzed as described. The percentage recovery ranged from 81.1% to 96.2%.

Results

Preliminary Studies. In eight experiments from 1981 to 1984, the efficacy of chlorpyrifos was compared to the efficacy of one or more of the insecticides chlorfenvinphos, fensulfothion and diazinon, which were registered for stem crucifers. Trends in efficacy observed in these studies (typified by the study in Table 1) were comparable, regardless of the crop (*ie.* cabbage, broccoli or cauliflower).

In the study shown in Table 1, granular formulations of each insecticide were applied at seeding of cauliflower (cv Elgon), followed by a single drench 16 days later. Diazinon plots received a second drench 34 days after seeding. Treatments of chlorpyrifos gave control equivalent to that of chlorfenvinphos, and significantly ($P < 0.05$) better control than either fensulfothion or diazinon (Table 1). In this trial, the two drenches of diazinon plus the granular formulation at seeding did not even reduce the damage below that of untreated plots. Moderate damage was observed when roots were examined only 31 days after the second diazinon drench. Root damage observed in plots treated with chlorpyrifos and chlorfenvinphos was from none to slight, 77 days after the single drench. Similar long-term efficacy was observed in four studies comparing granular or drench applications of chlorpyrifos and chlorfenvinphos on direct-seeded broccoli, cauliflower and cabbage.

In 1982, a study was undertaken to further investigate the observed lack of efficacy with diazinon. Diazinon granules were applied at seeding, to broccoli (cv. Premium Crop), followed by drenches 17 and 31 days after seeding, using up to twice the registered rates, *i.e.* 3.4 and 2.67 g a.i./10 m of row for the 5G and 50E formulations, respectively. Roots examined for maggot damage in diazinon-treated plots 29 days and at harvest 42 days after the last drenches, were not significantly different from those in the untreated plots. Moderate to severe damage was observed in all plots at harvest.

Chlorpyrifos Efficacy. A series of studies aimed at identifying the most effective formulations, dosage, and timing of chlorpyrifos applications were conducted from 1984 to1985. With respect to dosage, chlorpyrifos 15G was tested alone at 0.9, 1.6, and 2.2 g a.i./10 m row, and the 4E formulation was tested alone in a drench at 1.0 and 2.0 g a.i./10 m. Drenches were applied 3 days after seeding broccoli, (cv. Premium Crop). Fifty-four days after seeding, root maggot damage was significantly lower in all plots treated with chlorpyrifos granular or drench as compared to the untreated plots. Root damage indices were 0.6, 0.4, and 0.1 in plots treated with the lowest to highest rates of granular chlorpyrifos, respectively, while indices of 1.2 and 0.1 were assessed in plots receiving the lower and higher drench rates, respectively. A damage index (D.I.) of 3.9 (= severe damage) was recorded in the untreated plots. The importance of chlorpyrifos 15G dosage on root maggot efficacy is also shown in Table 2 for three stem crucifers. Applied at 0.9 or 2.2 g a.i./10 m of row, chlorpyrifos-treated plots had significantly less damage than untreated plots 72, 82 and 88 days after seeding cabbage, broccoli and Brussels sprouts, respectively. Chlorpyrifos 15G, even at the low rate tested, resulted in only slight damage (D.I. = 1.7) as compared to severe damage (D.I. = 6.7) in the untreated plots. In a study conducted in 1981, under an above normal population of cabbage flies, chlorpyrifos 15G applied at 1.3 g a.i./10 m of row did not provide significantly better control compared to untreated plots after 65 days.

The effects of timing and number of chlorpyrifos applications on root maggot efficacy are also shown in Table 2. In these studies, chlorpyrifos 15G and chlorpyrifos 4E-HF (applied in 1-4 drenches) were tested alone or in combination on the stem crucifers cabbage, broccoli and Brussels sprouts, and on the root crucifer, rutabaga. In all crops, maggot damage indices were significantly lower in plots treated with chlorpyrifos than in untreated plots. Damage was from none to slight in cabbage, broccoli and Brussels sprouts plots receiving a granular plus single drench application, or two drench applications alone, as compared to severe damage in the untreated plots. To maintain rutabagas during the 113-day growing period, in the slight damage category required for marketing, a granular application plus three drench applications was needed. Four drench applications alone gave between slight and moderate damage. In another rutabaga study, a slight D.I. of 0.4 was found in plots treated with as few as three drenches compared to a D.I. of 6.2 in the control. Damage in plots receiving fewer applications, however, was moderate.

Chlorpyrifos Phytotoxicity. In phytotoxicity studies completed in 1985 and 1986, chlorpyrifos 15G did not significantly reduce seedling emergence or reduce vigour when applied at 2.2 g a.i./10 m row to direct-seeded cauliflower, Brussels sprouts, broccoli and rutabaga. In one 1985 study, however, a 30% reduction in cabbage seedling emergence was observed in chlorpyrifos plots treated with 0.9 and 2.2 g a.i./10 m row. When this study was repeated in 1986, no reduction in emergence occurred even at a rate of 3.0 g a.i. Chlorpyrifos 4E, applied to moist soil at 1.0 g a.i./10 m of row in a drench 7 days after seeding did not reduce seedling emergence of the five crops. Three days after drenching, however, the primary leaves of cabbage seedlings showed a moderate cupping and bluish discoloration. Broccoli and rutabaga seedlings suffered milder symptoms, but after 2 weeks no symptoms were noticeable on any of the crops. In another study, chlorpyrifos 4E applied at 1.0 or 2.0 g a.i./10 m row in a drench 3 days after seeding significantly reduced the emergence of broccoli.

Residues. In the study shown in Table 2, rutabaga samples were taken from the experimental plots and analyzed for residues of chlorpyrifos and its degradative products. Total residues in rutabaga tissue sampled from plots treated with four drenches of chlorpyrifos 4E were only 0.06 ppm 17 days after the last application, and 0.05 ppm after 15 days in tissue from plots treated with granular at seeding and three drenches. Samples of broccoli, Brussels sprouts, cabbage and cauliflower tissue were analyzed by the same procedure. No residues of chlorpyrifos or its degradative products were detected in any of the samples of stem crucifers at harvest.

Discussion. The results from these studies clearly indicate that, in B.C., chlorpyrifos and chlorfenvinphos provided better protection against cabbage maggot damage than diazinon and fensulfothion. The possibility that resistance or tolerance to diazinon and fensulfothion is developing in *Delia radicum* locally is a subject that warrants further investigation. Chlorpyrifos proved to be as efficacious as chlorfenvinphos for cabbage maggot control in all the major stem crucifers, and showed excellent promise for use in root crucifers. Phytotoxicity does not appear to be a serious problem with the granular formulation of chlorpyrifos. Applied as a drench, however, chlorpyrifos did cause some seedling mortality when applied 3 days after seeding. At that time, seeds were just germinating and would have been in a very susceptible stage of growth. Drenching with chlorpyrifos 7 days after seeding or thereafter resulted in only mild symptoms of phytotoxicity which were rapidly outgrown. Usually no symptoms were observed. When drench-related symptoms of phytotoxicity did occur, they were associated with conditions of high temperature or drought. In an Ontario study, chlorpyrifos caused no phytotoxic effects when applied after emergence to cabbage, chinese cabbage, broccoli, rutabaga, Brussels sprouts or cauliflower at 1.12 and 2.24 Kg a.i./ha (Harris *et al.* 1975).

Our studies indicate that for direct-seeded crucifers, combined treatments of chlorpyrifos granular and emulsifiable liquid formulations consistently provided excellent maggot control. For short season crops such as cauliflower, broccoli and cabbage, the granular formulation applied at seeding, followed in 21 days with a single drench of the emulsifiable liquid formulation would be adequate. In a heavy cabbage maggot infestation, a granular or single drench application alone would not be sufficient to prevent damage, as was observed in one of the studies. In Brussels sprouts, the slowest of the stem crucifers to mature, a minimum of two applications were necessary for acceptable control. Considering the long growing season requirements of Brussels sprouts, and the potential for late season invasion by cabbage maggots into developing sprouts (Finlayson and Mackenzie 1979), we think that three applications would give adequate protection, even in years when high numbers of flies are

Table 2. Comparison of chlorpyrifos granular and emulsifiable formulations applied at different rates, schedules and numbers of applications on four major crucifers, Abbotsford, B.C., 1982.

	Mean Root Damage Indices							
Chlorpyrifos treatment	Cabbage		Broccoli		Brussels sprouts		Rutabagas	
15G (0.9 g a.i.)	1.0a[1]	75[2]	0.5a	82	1.7a	88	NT[3]	
15G (2.2 g a.i.)	0.2a	75	1.1a	82	1.5a	88	4.6c	113
15G + 4E[4] (1 drench)	0.2a	53	0.0a	60	0.1a	67	3.0b	93
15G + 4E (2 drenches)	NA[5]		NA		NT		2.1ab	69
15G + 4E (3 drenches)	NA		NA		NA		1.0a	44
4E (1 drench)	0.8a	68	0.8a	75	1.6a	80	4.5c	98
4E (2 drenches)	0.1a	45	0.1a	52	0.9a	60	3.0b	82
4E (3 drenches)	NA		NA		0.2a	39	2.3ab	61
4E (4 drenches)	NA		NA		NA		1.6ab	40
Control	6.7b	-	4.6b	-	6.7b	-	6.6d	-

[1] Values followed by the same letter are not significantly different (Duncan's multiple range test, $P < 0.05$).

[2] Days to root examination from last chlorpyrifos application.

[3] NT: Not tested.

[4] Except where noted, granular treatments were applied at a rate of 2.2 g a.i./10 m seeded row, drenches at 1.0 g a.i.

[5] NA: Not applicable since small number of days from seeding to harvest do not permit this many drench applications.

laying eggs. In rutabaga, another long season crop often requiring 110 days to mature, the roots must be virtually free of maggot damage at harvest. Due to the long growing period involved, and the strict damage limits, chlorpyrifos 15G applied at seeding followed by three drenches at 21 day intervals after seeding, would be necessary to produce rutabagas with no more than slight damage.

With respect to dosage, chlorpyrifos 15G provided acceptable control, *i.e.* slight damage, when applied at 0.9-2.2 g a.i./10 m of row. In the U.S., chlorpyrifos 15G is currently recommended for use on stem crucifers at rates of 0.6-1.4 g a.i./10 m of row, which compares favourably with our results. Chlorpyrifos 4E at 1.0 g a.i./10 m of row in a drench was efficacious and economical for post-planting maggot control. In the sandy-clay loam where these studies were undertaken, chlorpyrifos applied at the dosage rates and at the times prescribed for the stem and root crucifers studied, would not result in appreciable residues at harvest. Our studies suggest that pre-harvest intervals of 32 and 28 days would be appropriate for the 4 stem crucifers tested and for rutabagas, respectively. A 32-day pre-harvest interval is currently recommended for use of chlorpyrifos on stem crucifers in the U.S.

Recently, chlorpyrifos 4E was granted registration for use as a drench on the stem crucifers cauliflower, broccoli and cabbage in Canada, and this insecticide is now being used almost exclusively for maggot control in these crops in B.C. Complete registration of chlorpyrifos 4E and 15G formulations, to be applied according to the optimal findings reported herein on stem and root crucifers, is also being sought.

Acknowledgements

The authors thank M. J. Brown for assistance in residue determinations, H. Troelsen and D.L. Bartel for field assistance, Dr. H. R. MacCarthy for his critical review of the manuscript. We also thank the Lower Mainland Horticultural Improvement Association and the pesticide manufacturers for their cooperation and support.

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