Degradation of Terbufos in Soil and Its Translocation into Cole Crops

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When terbufos at 1.9 g of AI/10-m row was applied to a silt loam soil at seeding for cabbage maggot control, its effectiveness was comparable to or better than that of the registered chemicals fensulfothion, chlorfenvinphos and diazinon. Terbufos oxidized to its sulfoxide and sulfone in soil. The calculated half-lives of terbufos and total residues were 15 and 22 days, respectively. The total residues in soil were less than 1.0 ppm after 106 days. Terbufos translocated from soil into broccoli. The plant residues consisted mostly of terbufos sulfoxide, terbufos oxon sulfoxide, and terbufos sulfone, but the parent compound accounted for only 5% of the total. After 57 days there were 0.43 ppm total residues in the plant but only traces (<0.01 ppm, fresh weight) in the marketable heads of broccoli harvested 90 days after seeding. In marketable cabbage and cauliflower grown and treated and harvested in the same way, total residues ranged from nondetectable to trace.

INTRODUCTION

Granular formulations of Dasanit 15G (fensulfothion) at 1.9 g of AI/10-m row, Birlane 10G (chlorfenvinphos) at 1.4 g of AI/10-m row, and Diazinon 5G (diazinon) at 2.2 g of AI/10-m row are currently recommended in British Columbia, Canada, for control of cabbage maggot, *Delia radicum*, in cole crops. Terbufos, *S*-[(1,1-dimethylethyl)thio]methyl *O*,*O*-diethyl phosphorodithioate (Counter), is known to be effective against several soil insect pests (Eckenrode, 1972; Fagen, 1973; Lilly, 1973; Alvarez, 1975; Kinoshita et al., 1978; Straub and Davis, 1978). It has been widely used for control of soil insect pests that attack corn. In 1984 we evaluated terbufos against cabbage maggot in three cole crops and compared its efficacy with fensulfothion, chlorfenvinphos, and diazinon. Since terbufos is the *tert*-butyl homologue of phorate, which is known to be systemic, we also investigated the degradation of terbufos in soil and its possible translocation with its oxidative metabolites from soil into the cole crops.

EXPERIMENTAL SECTION

Apparatus. A wrist-action shaker (Burrell Corp., Pittsburgh, PA) and a Sorvall Omni-Mixer (DuPont Co., Newtown, CT) were used for the extraction of terbufos, including its oxidative metabolites, from soil and vegetables, respectively. Gas–liquid chromatographic (GLC) analyses were made with a Tracor MT 222 gas chromatograph equipped with an alkali flame ionization detector and an integrator.

Reagents. Activated charcoal (Nuchar C, Kodak Laboratory Chemicals) was acid washed prior to use (Brown, 1975), and a 2:5 (w/w) mixture of charcoal/Whatman CF-11 cellulose powder was prepared. All solvents were distilled in glass. Anhydrous Na_2SO_4 was heated at 260 °C overnight prior to use. GLC column packing was 3% OV-17 on 80–100-mesh Ultra-Bond 20 M (Ultra Scientific). Analytical standards of terbufos, terbufos oxon, and their corresponding sulfoxides and sulfones were obtained from American Cyanamid Co., Princeton, NJ.

Field Study. A field trial was conducted in a silt loam soil (Abbotsford soil series, classification Orthic Humo-Ferric Podzol, pH 5.76; organic matter content 5.1%, sand 39.6%, silt 54.1%, and clay 6.3%) at the Abbotsford substation, Agriculture Canada, Abbotsford, British Columbia, to determine the following: the efficacy of terbufos against cabbage maggot in comparison with fensulfothion, chlorfenvinphos, and diazinon; the degradation of terbufos in soil and its translocation into cole crops. The treatment plots were beds 7.5 m long and 1.8 m wide. Each individual plot consisted of a pair of rows that were 60 cm apart and located in the middle of the plot. The distance between rows in adjacent plots was 1.2 m. Each treatment was replicated four times in a randomized block design. Dasanit 15G at 1.9 g of AI/10-m row, Birlane 10G at 1.4 g of AI/10-m row, Diazinon 5G at 2.2 g of AI/10-m row, and Counter 15G at 1.9 g of AI/10-m row were applied at the time of seeding. Cabbage, cauliflower, and broccoli were seeded respectively on May 29, June 13, and June 14, 1984. The granular insecticides were applied in a band 15 cm wide with a geared applicator attached to a hand-propelled Stanhay precision seeder. The seeding action incorporated the granules into the soil to a depth of about 2.5 cm. Treatment efficacy was assessed by rating maggot damage to the roots of cabbage on July 27, broccoli on July 30, and cauliflower on August 3. Two plants from each replicate for a total of eight plants per treatment were uprooted and washed, and the damage was assessed visually as follows: none = 0, slight = 1, moderate = 2, severe = 4, very severe = 8. The numbers were averaged and expressed as the root maggot damage index. Concentrations of terbufos and its toxic oxidative metabolites in soil were determined at 6, 8, 11, 15, 43, 106, 114, 121, 129, and 149 days after application. To ensure that all soil samples were taken from a cross-section of each row perpendicular to the insecticide-treated band, a custom-made rectangular soil corer was used. The soil corer was 10 cm long, 4 cm wide, and 9 cm deep. For sampling, the corer was centered lengthwise across the 15-cm-wide treated band. Consequently, core samples were lifted entirely from within the treated area. A single core was taken from each replicate for a total of four cores per treatment. The cores were not pooled, but the terbufos residues were determined individually from each replicate.

Broccoli was chosen as an indicator to investigate the translocation of terbufos from soil. After seeding, three plants per replicate were collected at thinning for residue determinations on days 22, 29, 36, and 43. Subsequently, four leaves per plant and four plants per replicate were sampled 50, 57, and 64 days after seeding; and at harvest, i.e. 90 days after seeding, three marketable broccoli heads per replicate were collected for residue determination. All plant samples were pooled by replications and were homogenized with a Braun food processor to form four com-

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posite samples. Composite samples of cabbage and cauliflower were prepared in the same way at harvest to determine terbufos residues.

Residue Analysis. Since direct gas chromatographic analysis of the sulfoxides was known to be difficult (Wei and Felsot, 1982), terbufos and all its sulfoxides and sulfones were usually determined by gas chromatography with a nitrogen/phosphorus detector after all these compounds had been oxidized with perbenzoic acid to the oxon sulfone (Sellers et al., 1976). A gas chromatographic method for direct analysis of terbufos and its sulfoxide and sulfone has been described by Chapman et al. (1982), but this method is not applicable to the oxon sulfoxide and oxon sulfone. We therefore modified the method of Szeto and Brown (1982) originally described for disulfoton, and this modified method is capable of determining terbufos and its sulfoxides and sulfones.

Sample Extractions. After sieving and thorough mixing, aliquots of 50 g of moist soil as collected from the field were mixed with 50 g of anhydrous Na_2SO_4 and extracted with 100 mL of ethyl acetate by shaking for $^1/_2$ h on a wrist-action shaker. The extracts were filtered through Whatman No. 1 filter paper into 500-mL round-bottom flasks. The filter cakes were extracted twice more in the same manner. The combined extracts were concentrated in a flash evaporator at 35 °C under nitrogen, and the final volumes were adjusted to 10 mL for cleanup.

Similarly, aliquots of 10 g of plant tissues were mixed with 50 g of anhydrous Na_2SO_4, and the resultant mixtures were extracted three times with 100 mL of ethyl acetate by blending for 5 min in a Sorvall Omni-Mixer. The extracts were filtered through a Buchner funnel lined with a glass fiber filter paper. They were combined and concentrated under nitrogen in a flash evporator at 35 °C to 10 mL for cleanup.

Cleanup. Glass columns (30 × 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, 4 cm of a 2:5 (w/w) mixture of Nuchar-activated charcoal/Whatman CF-11 cellulose, 1.5 cm of anhydrous Na_2SO_4, and another glass wool plug. The packed columns were prewashed with 10 mL of ethyl acetate followed by 10 mL of hexane. Aliquots of 1 mL of crude extracts equivalent to 5 g of soil or 1 g of tissue were mixed thoroughly with 4 mL of hexane and passed through the cleanup columns. The resulting eluates were collected and numbered. The fractionation of the constituents present in the crude extracts was accomplished by eluting terbufos and terbufos oxon in fraction I with 25 mL of 20% (v/v) ethyl acetate in hexane and the terbufos sulfoxides and sulfones in fraction II with 20 mL of 20% (v/v) methanol in ethyl acetate. Both fractions I and II were concentrated under nitrogen to appropriate volumes in a flash evaporator at 35 °C for GLC analysis.

Since terbufos sulfoxide and terbufos oxon sulfoxide cannot be chromatographed directly, they were determined as their corresponding sulfones after oxidation with $KMnO_4$ following the procedures of Szeto and Brown (1982). After determination of the concentrations of terbufos sulfone and terbufos oxon sulfone by GLC analysis, fraction II was oxidized and the concentrations of the two sulfones were again determined. The concentrations of the two sulfoxides were the difference of the two determinations with adjustment for the difference in molecular weights between the two sulfoxides and the two sulfones.

Gas Chromatographic Analysis. The gas chromatographic column (120 cm × 2 mm i.d.) was made of Pyrex glass. Helium was the carrier gas at 60 mL/min. The operating parameters were as follows: detector temperature 240 °C; inlet and outlet temperature 210 °C; column temperature 200 °C; plasma gas flow rate 3.5 mL/min for hydrogen and 120 mL/min for air.

Detector response was calibrated daily with analytical standards. Quantification was based on average peak heights of these external standards, which were injected before and after the sample.

Table I. Effectiveness of Insecticide Band Treatment in Soil against the Cabbage Maggot, *D. Radicum*

insecticide	rate, g AI/10-m row	maggot damage index[a] cabbage	broccoli	cauliflower
Counter 15G (15% terbufos)	1.9	0.1 a	0.7 a	0.2 a
Birland 10G (10% chlorfenvinphos)	1.4	0.6 a	nt[b]	nt
Dasanit 15G (15% fensulfothion)	1.9	4.6 b	2.4 b	2.3 c
diazinon 5G (5% diazinon)	2.2	6.2 b	4.0 c	1.2 b
control		6.0 b	3.8 c	3.0 c

[a] Numbers followed by the same letter are not significantly different at the 5% level (Duncan's multiple-range test); values were transformed $[(x + 0.5)^{1/2}]$ for analysis. [b] nt = not tested.

Sample Fortification for Method Evaluation. Stock solutions (100 μg/mL) for sample fortification were prepared in acetone. They were diluted with ethyl acetate to 0.04 μg/mL for the parent compound and the oxon and 0.2 μg/mL for the sulfone and the oxon sulfone as reference standards for GLC analysis. Untreated silt loam from the Abbotsford substation was sieved to pass a 10-mesh screen. Aliquots of 50 g of air-dried soil with 9.8% residual moisture were weighed into 250-mL beakers and fortified separately with appropriate volumes of the stock solutions of terbufos, terbufos oxon, and their sulfoxides and sulfones at 0.1, 1.0, and 10.0 ppm. The solvent was evaporated at room temperature in a fume hood for about 2 h; the soil samples were mixed thoroughly during drying. When no trace of the solvent remained, they were stored at 4 °C for 24 h prior to extraction. Tissue samples of broccoli, cabbage, and cauliflower, collected from untreated plots, were cut up with a Braun vegetable shredder and mixed thoroughly in a plastic bag. Similarly, aliquots of 50 g of untreated tissue were fortified at 0.1 and 1.0 ppm to determine recovery. They were equilibrated in a fume hood for 2 h at room temperature prior to extraction. Four replicates of soil and tissue samples were fortified at each level, and they were analyzed separately to determine the percentage recoveries of each compound.

RESULTS AND DISCUSSION

Two of the three insecticides currently registered for maggot control in cole crops, namely fensulfothion and diazinon, did not significantly reduce root damage when compared with the control (Table I). Some protection was indicated with fensulfothion in broccoli and diazinon in cauliflower. Terbufos effectively reduced maggot damage in all three crops, and only slight damage was observed in the roots. Our results indicate that terbufos is very promising for cabbage maggot control in cole crops.

Samples of soil, broccoli, cabbage, and cauliflower from the control were processed and analyzed according to the procedures described. There was no GLC response that interfered with terbufos, terbufos oxon, or their sulfones. Analytical standards used in all analyses were 0.04 μg/mL for terbufos and terbufos oxon and 0.2 μg/mL for the two sulfones. Standards of the two sulfoxides at 20 μg/mL gave no measurable response under the described chromatographic conditions. This indicated that the proce-

Table II. Percent Recovery of Terbufos and Its Metabolites from Soil and Tissues of Broccoli, Cabbage, and Cauliflower

	% recovery ± SD (n = 4)								
	soil			broccoli		cabbage		cauliflower	
compd[a]	10.0 ppm	1.0 ppm	0.1 ppm	1.0 ppm	0.1 ppm	1.0 ppm	0.1 ppm	1.0 ppm	0.1 ppm
terbufos	94.8 ± 1.7	93.4 ± 5.6	96.0 ± 2.4	87.0 ± 6.2	84.1 ± 3.5	82.9 ± 3.9	82.6 ± 3.0	85.6 ± 4.1	87.4 ± 3.9
TOA	96.3 ± 2.0	92.8 ± 2.0	97.6 ± 2.5	87.9 ± 5.1	84.1 ± 1.7	90.2 ± 4.9	83.7 ± 2.0	91.2 ± 4.6	85.1 ± 2.4
TSO	103 ± 1.4	88.5 ± 8.7	89.5 ± 4.6	86.5 ± 5.0	92.8 ± 4.1	84.0 ± 4.2	93.9 ± 6.3	88.6 ± 5.1	95.4 ± 6.1
TOASO	102 ± 5.9	91.1 ± 3.9	93.8 ± 5.6	91.1 ± 6.1	96.5 ± 7.2	95.0 ± 4.1	92.9 ± 6.9	94.3 ± 5.6	91.4 ± 5.1
TSO_2	96.5 ± 0.8	91.0 ± 2.9	95.3 ± 3.9	89.7 ± 3.2	91.9 ± 1.7	87.0 ± 5.5	90.7 ± 3.8	90.1 ± 3.6	92.5 ± 4.1
$TOASO_2$	91.1 ± 2.7	94.8 ± 5.3	99.9 ± 5.5	93.7 ± 5.5	111 ± 1.7	99.1 ± 3.1	107 ± 1.5	92.4 ± 5.4	106 ± 2.7

[a] Key: TOA = terbufos oxon; TSO = terbufos sulfoxide; TOASO = terbufos oxon sulfoxide; TSO_2 = terbufos sulfone; $TOASO_2$ = terbufos oxon sulfone.

Table III. Terbufos Residues in Soil from Abbotsford Substation

posttreat interval, days	residues, ppm (dry wt, $\bar{X}$ ± SD, n = 4)[a] (total residue,[b] %)					
	TS	TSO	TSO_2	TOASO	$TOASO_2$	total
6	25.5 ± 13.7 (88.5)	2.86 ± 0.65 (9.9)	0.18 ± 0.21 (0.6)	0.23 ± 0.04 (0.8)	ND[c]	28.8 ± 14.2
8	20.1 ± 8.93 (84.5)	3.28 ± 0.90 (13.8)	0.22 ± 0.15 (0.9)	0.12 ± 0.01 (0.5)	ND	23.8 ± 9.87
11	14.8 ± 8.54 (82.2)	2.75 ± 1.13 (15.3)	0.26 ± 0.10 (1.4)	0.14 ± 0.04 (0.8)	ND	18.0 ± 9.68
15	9.87 ± 8.60 (74.8)	2.90 ± 0.74 (22.0)	0.31 ± 0.06 (2.3)	0.15 ± 0.03 (1.1)	trace[d]	13.2 ± 9.23
43	3.09 ± 1.39 (43.0)	3.57 ± 1.72 (49.7)	0.39 ± 0.15 (5.4)	0.14 ± 0.02 (1.9)	trace	7.19 ± 2.53
106	0.28 ± 0.16 (31.5)	0.47 ± 0.12 (52.8)	0.11 ± 0.03 (12.4)	0.04 ± 0.01 (4.5)	trace	0.89 ± 0.24
114	0.12 ± 0.08 (13.5)	0.60 ± 0.38 (67.4)	0.17 ± 0.05 (19.1)	trace	trace	0.89 ± 0.51
121	0.09 ± 0.07 (13.6)	0.45 ± 0.19 (68.2)	0.14 ± 0.05 (21.2)	trace	trace	0.66 ± 0.26
129	0.10 ± 0.08 (25.0)	0.21 ± 0.06 (52.5)	0.08 ± 0.03 (20.0)	trace	ND	0.40 ± 0.15
149	0.05 ± 0.02 (17.2)	0.17 ± 0.08 (58.6)	0.07 ± 0.03 (24.1)	trace	ND	0.29 ± 0.07

[a] Key: TS = terbufos; TSO = terbufos sulfoxide; TSO_2 = terbufos sulfone; TOASO = terbufos oxon sulfoxide; $TOASO_2$ = terbufos oxon sulfone. [b] Percent of total residue (TS + TSO + TSO_2 + TOASO + $TOASO_2$). [c] ND = not detectable at the limit of detection of 0.002 ppm (dry weight). [d] trace = less than 0.01 ppm (dry weight).

dures for the quantification of the two sulfones as described were reliable even in the presence of the two sulfoxides at 100 times the concentrations. Under the chromatographic conditions described, the absolute retention times were 0.99 and 1.16 min for terbufos oxon and terbufos and 3.20 and 3.93 min for their corresponding sulfones. The percentage recoveries of terbufos and its toxic oxidative metabolites ranged from 82.9% to 111% for soil and plant tissues (Table II). Injection of 0.2 ng of the sulfones and 0.04 ng of the parent compound and its oxon produced approximately 40% to 50% of full-scale response. Since aliquots equivalent to 5 g of soil and 1 g of plant tissue were cleaned up and the final volumes were adjusted to 0.5 mL for GLC analysis, the limits of detection were at least 0.002 ppm (dry weight for soil and fresh weight for plant tissues; based on 4–5% full-scale response produced by 5-μL sample injection).

The mean concentration of terbufos residues in soil and its standard deviation at various intervals after application are given in Table III. In order to ascertain that the standard deviation reflected the actual variability among the four replicates of the treatment, four subsamples from each replicate were analyzed individually for soil samples collected 6 days after application. The results were within ±5% of the mean of the four analyses, indicating that standard deviations given in Table III indeed reflected the variability among replicates.

Terbufos (TS) oxidized in soil to its sulfoxide (TSO) and sulfone (TSO_2). Terbufos oxon (TOA) was never detected in any of the samples. Only low concentrations of terbufos oxon sulfoxide (TOASO), ranging from trace (<0.01 ppm dry weight) to 0.23 ppm, and traces of the terbufos oxon sulfone ($TOASO_2$) were detected in a few samples of soil. These results indicated that the major transformation products of terbufos in soil were its sulfoxide and sulfone. Terbufos sulfoxide and terbufos sulfone increased steadily in percent of the total residue while the residue of terbufos itself decreased. Our findings are in general agreement with those reported by Chapman and Harris (1980) and

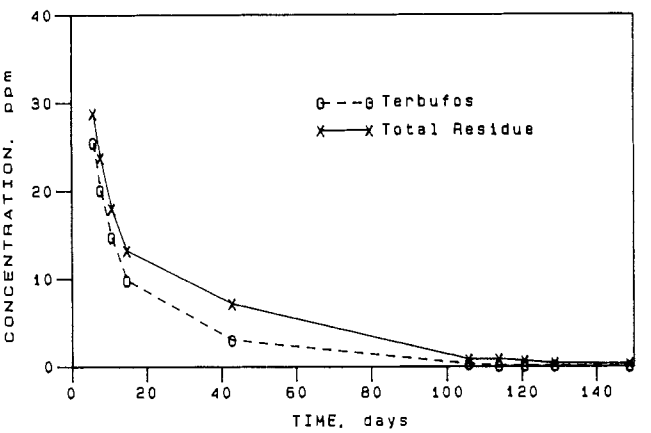

Figure 1. Concentrations of terbufos and total residue (terbufos + oxidative metabolites) in soil after application at 1.9 g of AI/10-m row.

Chapman et al. (1982). Biochemical and chemical transformations of terbufos to its sulfoxide and sulfone were observed by the workers cited, in soils incubated under laboratory conditions and under field weathering. The rates of disappearance of terbufos and total residue (terbufos plus oxidative metabolites) were relatively fast in the first 15 days but slowed considerably thereafter (Figure 1). Residue concentrations were transformed to logarithms before analysis, and then all the soil data were subjected to analysis of variance. Linearity of the relationship between log concentration and time was observed in terbufos (n = 10, r = −0.995*) and in total residues (n = 10, r = −0.996*), and there were no statistically significant deviations from linearity. Therefore, a first-order process was assumed. The calculated rate constants and half-lives and their 95% confidence limits were −0.0196 (range −0.0227 to −0.0165, SE = 0.0015) and 15.4 days (range 13.3 to 18.2 days) for terbufos and −0.0135 (range −0.0149 to −0.0120, SE = 0.00071) and 22.4 days (range 20.2 to 25.1 days) for the total residues. Ahmad et al. (1979)

Table IV. Terbufos Residues in Broccoli Tissues[a]

posttreat interval, days	residues, ppm (fresh wt, $\bar{X} \pm SD$, $n = 4$)[b] (total residue,[c] %)					
	TS	TSO	TSO_2	TOASO	$TOASO_2$	total
22	0.47 ± 0.41 (5.7)	5.19 ± 1.60 (62.9)	1.34 ± 0.55 (16.2)	1.22 ± 0.49 (14.8)	0.13 ± 0.04 (1.6)	8.25 ± 2.99
29	0.30 ± 0.29 (4.7)	3.90 ± 1.81 (60.8)	1.13 ± 0.31 (17.6)	0.95 ± 0.55 (14.8)	0.13 ± 0.05 (2.0)	6.41 ± 2.59
36	0.12 ± 0.05 (2.8)	2.71 ± 1.97 (63.6)	0.92 ± 0.31 (21.6)	0.44 ± 0.44 (10.3)	0.07 ± 0.02 (1.6)	4.26 ± 2.61
43	0.10 ± 0.07 (4.6)	0.91 ± 0.58 (41.9)	0.70 ± 0.29 (32.3)	0.34 ± 0.15 (15.7)	0.12 ± 0.04 (5.5)	2.17 ± 1.11
50	ND[d]	1.15 ± 0.86 (51.8)	0.55 ± 0.48 (24.8)	0.45 ± 0.23 (20.3)	0.07 ± 0.05 (3.2)	2.22 ± 1.61
57	ND	0.18 ± 0.19 (41.9)	0.13 ± 0.09 (30.2)	0.10 ± 0.07 (23.3)	0.02 ± 0.01 (4.7)	0.43 ± 0.36
64	ND	0.14 ± 0.17 (34.1)	0.12 ± 0.17 (29.3)	0.11 ± 0.12 (26.8)	0.04 ± 0.05 (9.6)	0.41 ± 0.51
90	ND	trace[e]	trace	trace	trace	trace

[a] Tissue samples were composites of whole plants for days 22, 29, 36, and 43; leaves for days 50, 57 and 64; and heads for day 90. [b] Key: TS = terbufos; TSO = terbufos sulfoxide; TSO_2 = terbufos sulfone; TOASO = terbufos oxon sulfoxide; $TOASO_2$ = terbufos oxon sulfone. [c] Percent of total residue (TS + TSO + TSO_2 + SO_2 + TOASO + $TOASO_2$). [d] ND = not detectable at the limit of detection of 0.002 ppm (fresh weight). [e] trace = less than 0.01 ppm (fresh weight).

studied soil residues of terbufos in two fields of silty clay loam under South Dakota field conditions. They reported that the half-lives in two fields were 12 and 11 days for terbufos and 39 and 19 days for terbufos oxon sulfone, which represented terbufos with its toxic oxidative metabolites. Our findings were comparable to theirs, and the differences between our values and theirs may have resulted from differences in soil type and environmental conditions of the fields (Felsot et al., 1982).

Terbufos and its toxic oxidative metabolites, except terbufos oxon, were detected in broccoli tissue (Table IV). The highest concentration of total residues was 8.25 ppm (fresh weight) present in the whole plants collected 22 days after seeding at first thinning. The total residues in broccoli tissues declined thereafter as those in the treated soil gradually decreased (Tables III and IV). The makeup of the total residues in broccoli was different from that in soil. Terbufos sulfoxide, terbufos oxon sulfoxide, and terbufos sulfone accounted for 90% or more of the total residues in broccoli, whereas the parent compound and its sulfoxide and sulfone accounted for almost all the total residues in soil. Approximately 5% of the total residues in broccoli was the parent terbufos. This suggests that terbufos and its sulfoxide and sulfone were translocated from soil into plants and they were further oxidized in the plants to terbufos oxon sulfone. The concentration of total residues was highest in young plants collected at the first thinning, i.e. 22 days after seeding. It decreased steadily as the plants matured (Table IV). There were only traces of residues (<0.01 ppm fresh weight) present in marketable broccoli head harvested 90 days after seeding. Similarly, residues ranging from nondetectable to trace were detected in marketable cabbage and cauliflower grown in soil band-treated with terbufos. Sellers et al. (1976) studied residues of terbufos in Iowa corn and soil. They reported that residues in field corn forage ranged from a high of 0.43 ppm 40 days posttreatment with 4.48 kg/ha furrow application to nondetectable residues 60 days posttreatment with 1.12 kg/ha band application. Sweet corn grain and popcorn grain harvested at maturity showed no residue of terbufos even though 10–14 ppm was still in the accompanying soil. It is apparent that terbufos or its sulfoxide and sulfone were readily taken up by plants grown in treated soil, but residues in the plant tissues, including all toxic oxidative metabolites, degraded rapidly.

Our results indicate that band treatment with terbufos at 1.9 g of AI/10-m row applied at seeding was highly effective against the cabbage maggot. Terbufos residues translocated from the treated soil into the cole crops, but the tissue residues degraded rapidly and only traces (<0.01 ppm fresh weight were detected in the marketable produce of broccoli, cabbage, and cauliflower.

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Registry No. TS, 13071-79-9; TSO, 10548-10-4; TSO_2, 56070-16-7; $TOASO_2$, 56070-15-6; fensulfothion, 115-90-2; chlorfenvinphos, 470-90-6; diazinon, 333-41-5.

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