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PLANT TOXICITY AND SOIL TRANSFORMATIONS OF SOIL INCORPORATED SULFUR COMPOUNDS

FINAL REPORT

by

W. D. Guenzi, W. E. Beard, R. A. Bowman, and S. R. Olsen

USDA-SEA-Agricultural Research-Western Region
Colorado-Wyoming Area
Fort Collins, Colorado

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The degree of phytotoxicity and the amount of chemical uptake from soil amended p-chlorophenyl methyl sulfide, -sulfoxide, and -sulfone varied among plant species and soil chemical concentrations. Alfalfa was the most susceptible to chemical injury and corn was least susceptible. Bioconcentration occurred in roots and tops, with a much higher level in the tops. Complete degradation of the chemicals to $^{14}CO_2$ in soil was slow, and ranged from 5 to 17% after 160 days of incubation. No translocation of the foliar applied chemicals was detected in corn or sugarbeets.

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EXECUTIVE SUMMARY

Research was conducted to evaluate p-chlorophenyl methyl sulfide, sulfoxide, and sulfone in relation to plant toxicity, chemical uptake by plants from soil, translocation of foliar applied chemicals, and degradation in soil. These three chemicals are closely related and differ only in their oxidation state. Radioactive chemicals were used in the main experiments with ^{14}C being uniformly incorporated in the ring structure. Measurements of degradation, uptake, and translocation were made from total activity measurements of dry combusted soil and plant samples. In addition, the translocation of foliar applied diisopropyl methylphosphonate (DIMP) was determined in corn and sugarbeets.

Soil Degradation

The degradation of sulfide, sulfoxide, and sulfone was determined by amending an Ascalon sandy loam soil at three chemical concentrations (0.5, 5, and 50 ppm), maintaining the soil water content at field capacity, and incubating for 160 days at a constant temperature of 30°C. For all chemicals, there was no effect on total CO_2 production between the control and the 0.5 and the 5 ppm concentrations, but a significant reduction resulted from the 50 ppm treatments. The amount of $^{14}CO_2$ produced from ring cleavage and subsequent oxidation, expressed as percent of initial soil concentration, decreased with increasing soil concentration, and ranged from 5 to 17% after 160 days. However, the rate of compound destruction to $^{14}CO_2$ (nanograms of chemical/day) progressively increased as concentration increased. These average daily rates (ng/day) ranged from 7 to 17 at 0.5 ppm, 30 to 108 at 5 ppm, and 106 to 711 at 50 ppm. Total ^{14}C recovery, residual ^{14}C in soil and $^{14}CO_2$, from the 0.5 and 5 ppm levels of sulfoxide and sulfone ranged from 91 to 97%, whereas at 50 ppm, the recovery was 82%. The low recovery from the sulfide treatments was probably due to volatilization losses of the parent compound during the initial 10 days of incubation.

Foliar Translocation

Absorption and translocation from foliar applied ^{14}C labeled sulfide, sulfoxide, sulfone, and DIMP was determined by plant part analysis following a period of 24 and 72 hours after chemical application. There was no translocation of sulfide, sulfoxide, and sulfone in corn or sugarbeet. A considerable amount of the sulfur compounds volatilized from the target leaf and the remaining ^{14}C activity was found only in the leaf of application. Activity recovered after 24 hours in the target leaf was 0.7, 6.8, and 21.6% in corn, and 8.7, 29.8, and 41.4% in sugarbeets for the sulfide, sulfoxide, and sulfone, respectively. DIMP was not translocated in corn and only 3.7% of the chemical activity was recovered in the target leaf after a 24 hour period. For the sugarbeet, a very small amount was translocated (0.5%), with 91% being volatilized, and 8.5% associated with the target leaf after 24 hours. Even though DIMP was the only chemical translocated, there still could be some concern resulting from accumulation of the chemicals in leaves exposed to contaminated water applied by sprinkler irrigation. Even though large amounts of chemicals would be expected to volatilize from leaf surfaces, repeated sprinkler irrigation during the growing season could result in some accumulation in the exposed leaves, especially with the sulfone.

Plant Toxicity and Uptake

A greenhouse experiment was conducted to determine the effects of varying concentrations in soil of ^{14}C-ring labeled p-chlorophenyl methyl sulfide, sulfoxide, and sulfone on growth and uptake by alfalfa, corn, fescue, sugarbeets, and wheat. All crops were grown in an Ascalon sandy loam whereas wheat was the only crop tested in the Nunn loam soil.

Visual phytotoxic symptoms were the same for all chemicals and similar for all plant species. Initial injury occurred on the tips of older leaves and progressively moved down the leaf with continued growth. Severity increased with increasing soil chemical concentration and varied among plants at a given concentration. No toxicity symptoms were noted for corn, sugarbeets, and alfalfa at the 0.5 ppm level whereas slight injury was noticed in fescue and wheat at the same level. Generally, there was more reduction in root growth than top growth at a given soil concentration, and there were very few differences among chemicals. In order to make comparisons among chemicals and plant species, the soil concentration required for 20% reduction in top dry weight was determined from best fit curves. Soil concentration levels (mean of three chemicals) causing this degree of reduction in top growth were 4.7, 6.3, 7.3, 13.3, 15.5, and 25 (sulfone) ppm for alfalfa, fescue, sugarbeets, wheat (Nunn soil), wheat (Ascalon soil), and corn, respectively.

Chemical concentration in plant tissue increased with increasing concentration of the chemicals in soil. In general, a significant increase in chemical concentration in plant tops occurred between the 5 and 25 ppm treatments for all crops. Chemical concentration in plant tops at a 20% growth reduction was nearly the same for all chemicals for each plant species. Plant top concentrations at a 20% reduction (mean of all chemicals) were 216, 250, 379, 559, 671, and 1320 μg/g for alfalfa, fescue, sugarbeets, wheat (Ascalon soil), wheat (Nunn), and corn, respectively. A close relationship existed between soil chemical concentration and the chemical concentration in roots and tops, the linear correlation coefficient being $r = 0.911^{**}$ for tops and $r = 0.949^{**}$ for roots.

The plant's ability to concentrate a chemical in excess of the level of the chemical found in soil is referred to as bioconcentration. Bioconcentration was found in all crops and for all chemicals. Considering all crops at all soil concentrations, bioconcentration was about the same among chemicals, and varied among crops and within concentrations for a specific crop. The mean bioconcentration values for tops were 28, 34, 37, 44, 48, and 62, and for roots 6, 5, 8, 3, 7, and 5 for corn, alfalfa, wheat (Ascalon soil), fescue, wheat (Nunn soil), and sugarbeets, respectively. These results indicated that all chemicals were absorbed, translocated, and concentrated primarily in the tops of all five plant species.

CONTENTS

TABLES

TABLES

TABLES

I. INTRODUCTION

Three closely related sulfur containing organic compounds were detected in the groundwaters of Rocky Mountain Arsenal located near Denver, Colorado. These waters could conceivably be used for irrigation purposes, and therefore basic research information was needed on these compounds' phytotoxicity and soil persistence. Research was initiated by USDA-SEA-AR-Western Region at Fort Collins, Colorado, under the sponsorship of the U. S. Army Medical Research and Development Laboratory in 1977. The research was designed to evaluate the effects of p-chlorophenyl methyl sulfide, sulfoxide, and sulfone on stability in soil, phytotoxicity, uptake, and foliar translocation.

Since very little information was available, three preliminary studies were conducted to provide information for larger and more detailed experiments. Two separate experiments involved the use of a wide range of soil chemical concentrations to evaluate phytotoxicity and seedling emergence of the proposed test plants. The third study was to determine chemical volatilization from soil and make appropriate adjustments to minimize potential human exposure.

The three main experiments were:

1. Plant accumulation and phytotoxicity of soil-incorporated p-chlorophenyl methyl sulfide, sulfoxide, and sulfone in wheat, corn, alfalfa, fescue, and sugarbeets.

   Objectives:

   a. To evaluate the phytotoxicity and accumulation of ^{14}C from labeled chemicals in wheat, corn, alfalfa, fescue, and sugarbeets from soil amended with 0.5, 5, and 25 ppm of each chemical.

   b. To determine residual ^{14}C activity in soil after plant harvest.

2. Degradation of p-chlorophenyl methyl sulfide, sulfoxide, and sulfone in soil.

   Objectives:

   a. Determine the rate of chemical degradation from soil by the measurement of evolved $^{14}CO_2$.

   b. Evaluate the persistence of test chemicals in soil by measuring total ^{14}C remaining in soil after predetermined incubation periods.

3. Translocation of foliar applied p-chlorophenyl methyl sulfide, sulfoxide, sulfone, and diisopropyl methyl phosphonate to corn and sugarbeets.

Objective:

To determine the extent of translocation of four test chemicals from a foliar application on one leaf surface to other plant parts.

II. PRELIMINARY STUDIES

A. SOIL CHEMICAL CONCENTRATIONS AND PLANT TOXICITY

A preliminary experiment was conducted to determine the effect of three chemicals and concentration of the soil amended chemicals on the growth of five plant species. The main objective was to derive information that could be used in selecting a limited number of concentration levels for larger and more detailed experiments using expensive radioactive chemicals.

Materials and Methods

The two soils used in all phytotoxicity studies were collected in Adams County and are representative of soil types in the area. The Ascalon sandy loam was sampled from a dryland wheat field about 6.5 miles east of Brighton, and the Nunn loam collected from a cultivated field about 28.5 miles east of Brighton, Colorado. Soils were ground to pass through a 0.64-cm screen, dried, mixed, and stored in galvanized containers. Physical and chemical properties of the soils are given in Table 1. Most of the analyses were conducted by the Colorado State University Soil Testing Laboratory using widely accepted methods. Ascalon soil was used in all studies, and the Nunn was only used in the major experiment with wheat.

Separate standard solutions of p-chlorophenyl methyl sulfide (sulfide), sulfoxide, and sulfone were made up in *acetone-n-hexane (2/98 v/v)* at a concentration of 1 mg/ml (1000 ppm). Dilutions required for various concentrations (0.5, 5, 25, 50, and 100 ppm) were made with n-hexane. Concentrations of the chemicals added to soil were based on dry soil weight, and the volume of hexane added with the chemicals was 0.2 ml/g of soil which thoroughly wet the soil but without free standing solvent.

Four hundred grams of air dried Ascalon soil were placed in a glass beaker, 80 ml of appropriate standard added, covered with aluminum foil, and allowed to equilibrate for 30 minutes. The soil was then spread out in a thin layer on aluminum foil, and the hexane evaporated initially in a fume hood and then overnight in a ventilated laboratory. After the soil had dried for 1 day, a 1-ml air sample was taken over the surface of the soil and was analyzed for hexane vapors by GC analysis using a hydrogen flame detector. No evidence of hexane vapors was detected. To assure adequate phosphorous (P) and nitrogen (N) for plant growth in confined pot experiments, 50 μg/g (50 ppm) of P as concentrated superphosphate and 50 μg/g (50 ppm) of N as $(NH_4)_2SO_4$ were added as dry materials to the soil and mixed thoroughly.

The five plants used were alfalfa (Medicago sativa L.), corn (Zea mays L.), tall fescue (Festuca arundinacea), sugarbeets (Beta vulgaris L.), and spring wheat (Triticum aestivum L.). Depending on the crop being tested, a predetermined amount of the treated soil was placed in a 10-cm plastic pot. Seeds were placed on top of the soil, and the remaining soil was placed on

Table 1. Properties of soils used in toxicity studies.

Soil property	Soils	
	Ascalon†	Nunn‡
Texture (%)	sandy loam	loam
sand	68	33
silt	20	42
clay	12	25
Water content (field capacity) (%)	12.8	22.6
pH	6.6	6.6
Conductivity (mmhos/cm)	0.4	1.1
Organic matter (%)	0.8	1.4
Total nitrogen (%)	0.049	0.086
Cation exchange capacity (meq/100 g)	5.2	18.6
Ammonium-N (ppm)	7.0	5.0
Nitrate-N (ppm)	2.0	19.0
DTPA extractable (ppm)		
Zn	1.4	1.3
Fe	16.8	5.3
Cu	0.68	0.77
Mn	15.0	5.2
NH_4^+OAc extractable (ppm)		
Ca	617	2810
Mg	124	294
K	280	361
$NaHCO_3$-P (ppm)	15.5	14.0
Sulfate-S (ppm)	10.0	11.0

† Ascalon is a typic argiustol (sub-group), fine loam mixed mesic family, tertiary outwash (parent material).

‡ Nunn is a typic argiustol (sub-group) fine montmorillonitic (family), aeolean and tertiary outwash (parent material).

top of the seeds. For corn and wheat, the seeds were 2 cm from the surface, and for alfalfa, sugarbeets, and fescue, seeds were 1 cm from the surface. Eight seeds were planted for corn and wheat and then thinned to three and four per pot, respectively. Fifteen seeds were planted for sugarbeets, alfalfa, and fescue, and thinned to 3, 4, and 5, respectively. The soil was wet to field capacity (12.8%), and every morning the pots were weighed and water added (if required) to bring the soil water content back to field capacity.

Plants were grown in a greenhouse with a minimum temperature of 15°C and a maximum of near 25°C. Supplemental lights were used to give a day length of 14 hours. Observations were taken on toxicity symptoms, and colored photographs were taken to record symptoms and concentration effects on plant growth.

Results and Discussion

Wheat

The effect of soil amended with varying concentrations of p-chlorophenyl methyl sulfide, sulfoxide, and sulfone on top growth of wheat is given in Table 2. Top dry weight production was reduced in a nearly linear manner with increased concentration to 50 ppm. The three chemicals had nearly the same phytotoxic effects at equivalent concentrations. Based on dry weight yield after 28 days of growth, a 50% reduction in growth as compared to the control was found at about 27, 30, and 33 ppm for the sulfoxide, sulfone, and sulfide, respectively. These values were obtained from best fit curves of plant growth versus concentration. Plant height measurements showed somewhat less effect as a function of concentration than dry weight values.

Visual phytotoxic symptoms on wheat appeared to be the same for all chemicals. Initial symptoms were a browning or drying on the leaf tips, with time, the drying progressively moved down the leaf. As damage to the leaf continued, there was also a twisting of the leaf. The symptoms were first noticed on the 25 and 50 ppm treatments and later at all concentration levels. The 0.5 ppm treatment showed only a small amount after 28 days.

Corn

Corn responses to incorporated test chemical concentrations in soil are given in Table 3. At chemical concentration up to 25 ppm, all three test chemicals showed dry weight production equal to or greater than the control, and the sulfide and sulfoxide had equivalent or more dry weight production than the control at 50 ppm. The dry weight from test chemicals at concentrations of 0.5 and 5 ppm was considerably more than the control. In general, the toxicity of the chemicals to corn was the sulfone > sulfoxide > sulfide. Based on dry weight after 35 days of growth, a 20% reduction in growth as compared to the control was found at about 50, 73, and 97 ppm for the sulfone, sulfoxide, and sulfide, respectively.

Table 2. Concentration effect of *p*-chlorophenyl methyl sulfide, sulfoxide, and sulfone on top growth of wheat after 28 days.

Chemical	Concentration	Plant response		
		Wet wt.	Dry wt.	Height
	ppm	mg/pot	mg/pot	cm
Control	0	2930	564	26
Sulfide	0.5	3000	598	27
	5	3040	576	28
	25	2150	373	25
	50	324	66	12
	100	0	0	0
Sulfoxide	0.5	2850	572	26
	5	2720	523	27
	25	1700	304	24
	50	382	95	13
	100	98	15	5
Sulfone	0.5	3080	628	27
	5	2640	511	26
	25	1980	356	24
	50	407	105	15
	100	107	27	5

Table 3. Concentration effect of soil incorporated *p*-chlorophenyl methyl sulfide, sulfoxide, and sulfone on top growth of corn after 35 days.

Chemical	Concentration	Plant response		
		Wet wt.	Dry wt.	Height
	ppm	—— mg/pot	——	cm
Control	0	4425	501	22
Sulfide	0.5	4840	693	24
	5	5815	756	25
	25	4893	589	25
	50	5380	594	25
	100	3342	397	20
Sulfoxide	0.5	4618	639	23
	5	4967	688	24
	25	5056	637	25
	50	4352	518	24
	100	2009	279	19
Sulfone	0.5	4633	611	23
	5	4556	583	24
	25	3822	512	23
	50	3477	422	21
	100	1517	199	17

Visual phytotoxic symptoms induced by the chemicals were the same for all three chemicals. Initial symptoms were a browning or drying on the older leaf tips. With increased growth, the browning progressively moved down the leaf from tip to the stem. The symptoms were first noticed for all chemicals at the 100-ppm level after 14 days, at 25, 50, and 100 ppm after 16 days, at 5, 25, 50, and 100 ppm after 20 days, and even a small amount on the 0.5 ppm treatments after 29 days. The degree of browning or drying of the leaves was a function of concentration with more damage at the highest concentration. The symptoms for corn were very similar to wheat except no twisting of the corn leaves was observed.

Sugarbeets

Growth response of sugarbeets from chemically amended soil is given in Table 4. No information was obtained from the 50-ppm treatment of the sulfide and the 25-ppm treatment of the sulfone due to "damping off" of the seedlings. Also, in two cases, 100-ppm sulfide and 50-ppm sulfoxide, only 2 and 1 plant, respectively, remained per pot at the completion of the experiment. The other plants died due to chemical effects. These two treatments are reported in Table 4 as mg/pot as the other treatments with the three plants per pot. Although there was some error in this approach, expressing plant yield in mg/plant also had some error as the plants in pots with fewer plants grew better due to lack of competition. Plant growth expressed as dry weight was reduced in somewhat of a linear response for all chemicals up to 50 ppm. There was some evidence of growth stimulation at the 0.5 and 5 ppm levels for the sulfide and sulfoxide. After 56 days, a 20% reduction in growth as compared to the control was found at about 14, 17, and 19 ppm for the sulfone, sulfoxide, and sulfide, respectively.

Visual phytotoxic symptoms induced by the chemicals were the same for sulfide, sulfoxide, and sulfone. Initial symptoms were a browning or dying of the older leaf tips, and with increased growth, the browning progressively moved down the leaf. Symptoms were first noticed for all chemicals at the 100-ppm level after 14 days, at 50 ppm for the sulfoxide and sulfone after 19 days, at 25 ppm for sulfide and sulfoxide after 20 days, and at 5 ppm for all chemicals after 46 days. No phytotoxic symptoms were observed for any chemical at the 0.5 ppm treatment. Increasing severity of toxicity symptoms was related to increased concentration of the soil incorporated chemicals.

Alfalfa

Alfalfa was the most susceptible crop tested, and the effect of chemicals and concentration on top growth of alfalfa is given in Table 5. Some problems were encountered with "damping off" but there were enough plants remaining so that thinning to 4 plants per pot was possible. The three chemicals had about the same phytotoxic effects at equivalent concentrations and showed a fairly linear response up to 25 ppm. Based on dry weight yield after 63 days of growth, a 20% reduction in growth as compared to the control was found at about 5, 6, and 6 ppm for the sulfoxide, sulfide, and sulfone, respectively.

Table 4. Concentration effect of soil incorporated p-chlorophenyl methyl sulfide, sulfoxide, and sulfone on top growth of sugarbeets after 56 days.

Chemical	Concentration	Plants per pot†	Plant response		
			Wet wt.	Dry wt.	Height
	ppm		mg/pot		cm
Control	0	3	4557	751	12
Sulfide	0.5	3	5780	930	13
	5	3	3726	794	12
	25	3	4493	541	11
	50	0‡	-	-	-
	100	2§	150	29	2
Sulfoxide	0.5	3	5763	910	13
	5	3	4823	843	13
	25	3	3376	448	11
	50	1§	130	29	2
	100	0§	-	-	-
Sulfone	0.5	3	3864	574	11
	5	3	3481	747	13
	25	0‡	-	-	-
	50	3	337	89	5
	100	0§	-	-	-

† Plants remaining at harvest, originally thinned to 3 plants per pot.

‡ Plants lost due to "damping off."

§ Plant(s) died from chemical effects.

Table 5. Concentration effect of soil incorporated p-chlorophenyl methyl sulfide, sulfoxide, and sulfone on top growth of alfalfa after 63 days.

Chemical	Concentration	Plants per pot†	Plant response		
			Wet wt.	Dry wt.	Height
	ppm		mg/pot		cm
Control	0	7	2819	847	21
Sulfide	0.5	7	2603	719	21
	5	8	2499	646	19
	25	5‡	564	145	11
	50	1‡	186	32	8
	100	0‡	-	-	-
Sulfoxide	0.5	7	2813	856	20
	5	9	2344	632	17
	25	5‡	506	114	7
	50	0‡	-	-	-
	100	0‡	-	-	-
Sulfone	0.5	10	2934	798	18
	5	8	2471	650	16
	25	5‡	581	168	10
	50	2‡	232	52	8
	100	0‡	-	-	-

† Originally thinned to 4 plants per pot, these numbers represent total plants per pot at the end of the experiment.

‡ Plants died due to chemical effects.

Phytotoxic symptoms for alfalfa started with the older leaves showing a bleached or white leaf tip, and with further growth the whiteness continued to move down the leaf. After 34 days, all the plants at the 100-ppm treatment turned brown and died. The same symptom was characteristic for all three chemicals. The symptoms were noticed for all chemicals at the 100-ppm level after 12 days, at 50 ppm after 13 days, at 25 ppm after 15 days, and at 5 ppm after 19 days. No phytotoxic symptoms were observed from any of the 0.5 ppm treatments.

Fescue

The effect of chemicals and concentration on top growth of fescue is given in Table 6. The three chemicals had about the same phytotoxic effects at equivalent concentrations. Based on dry weight yield after 68 days of growth, a 20% reduction in growth as compared to the control was observed at about 7, 10, and 10 ppm for the sulfide, sulfoxide, and sulfone.

Visual phytotoxic symptoms for fescue were a browning of the older leaf tips, followed by a bending of the dried-up dead tips, and finally, a large section of the leaf would be twisted. Toxic symptoms started from all three chemical treatments at the 25, 50, and 100 ppm level after 18 days and also at the 5 ppm level for the sulfoxide and sulfone. The plants in the 5 ppm sulfide soil showed symptoms after 24 days. There was no apparent difference between the control and the 0.5 ppm treatment.

Summary

The concentration of soil incorporated p-chlorophenyl methyl sulfide, sulfoxide, and sulfone required for 20 and 50% reduction in dry weight production of the five plant species is given in Table 7. For comparative purposes, dry weight yield was plotted against chemical concentration and best fit curves were drawn through the data points. The concentration of soil incorporated chemicals to reduce plant yield 20 and 50% was obtained from the plots. In this growth reduction range and for all plants, except corn, there appeared to be little difference in plant toxicity among chemicals. There is considerable difference in growth response of various plant species as related to chemical concentration. For example, the concentration of sulfide required for a 20% reduction in dry weight was 6, 7, 18, 19, and 97 ppm for alfalfa, fescue, wheat, sugarbeets, and corn, respectively.

B. SEEDLING EMERGENCE FROM CHEMICALLY TREATED SOIL

Seedling emergence of the five test plants was evaluated from soil amended with varying concentrations of the three chemicals. The main purpose of this study was to determine if seedling emergence would be inhibited at the desired soil concentrations that were planned for large scale greenhouse experiments.

Table 6. Concentration effect of soil incorporated p-chlorophenyl methyl sulfide, sulfoxide, and sulfone on top growth of fescue after 68 days.

Chemical	Concentration	Plants per pot†	Plant response		
			Wet wt.	Dry wt.	Height
	ppm		mg/pot	mg/pot	cm
Control	0	13	4304	1200	29
Sulfide	0.5	17	5072	1538	28
	5	16	3883	1100	29
	25	9	2291	429	27
	50	4	392	64	16
	100	3	300	44	20
Sulfoxide	0.5	18	4668	1235	26
	5	17	4372	1212	26
	25	10	2624	580	28
	50	4	198	27	13
	100	2	184	46	19
Sulfone	0.5	19	5182	1364	27
	5	13	4717	1176	33
	25	7	1959	390	25
	50	2	165	18	19
	100	1	70	4	14

† Originally thinned to 5 plants per pot, these numbers represent total plants per pot at the end of the experiment.

Table 7. Concentration of soil incorporated p-chlorophenyl methyl sulfide, sulfoxide, and sulfone required for 20 and 50% reduction in dry weight production of plant tops.

Plant	Growth reduction	Chemicals		
		Sulfide	Sulfoxide	Sulfone
	%	ppm		
Alfalfa	20	6	5	6
	50	14	11	13
Corn	20	97	73	50
	50	-	-	87
Fescue	20	7	10	10
	50	18	24	20
Sugarbeets	20	19	17	14
	50	33	29	30
Wheat	20	18	11	14
	50	33	27	30

Materials and Methods

Seedling emergence of corn, wheat, alfalfa, fescue and sugarbeets was determined by planting seeds in soil separately amended with p-chlorophenyl methyl sulfide, sulfoxide, and sulfone. Separate standard solutions of the sulfide, sulfoxide, and sulfone were made up in acetone-n-hexane (2/98 v/v) at a concentration of 1 mg/ml. Dilutions required for various concentrations (0.5, 5, 25, and 50 ppm) were made with n-hexane. Concentrations of chemicals added to the soil were based on dry soil weight, and the volume of hexane added with the chemicals was 0.2 ml/g of soil which thoroughly wet the soil but without free standing solvent. The same amount of hexane was also added to the control.

Three hundred and fifty grams of Ascalon sandy loam were ground to pass through a 2-mm sieve, and placed in a 150 mm x 25 mm Petri dish. Seventy milliters of the appropriate standard were added to the soil and covered with a Petri dish lid. After a 30-minute equilibration period, the lids were removed and the dishes were placed in a fume hood for 24 hours to evaporate the solvent. Then the soil was removed from the dishes, spread on aluminum foil, and left on laboratory benches for 48 hours. Half of the soil (175 g) was replaced in the Petri dish, 25 seeds were placed on top of the soil, and the remaining soil placed on top of the seeds. Total soil depth was about 24 mm. Soils were wet to 0.1 bar suction (17.6%), covered with a Petri dish cover which had 10 holes (1 mm in diameter), and placed in a constant temperature room at 30°C. After the seedlings emerged (started touching the lid), the lids were removed, and 7 extra ml of water were added by weight difference every morning and late afternoon to allow for evaporation. Seedling emergence counts were made daily and until no more new seedlings emerged. There were three replications with a total of 75 seeds for each test.

Results and Discussion

The effect of p-chlorophenyl methyl sulfide, sulfoxide, and sulfone at four concentrations on seedling emergence of wheat, corn, sugarbeets, alfalfa, and fescue is given in Table 8. For soil incorporated concentrations up to 50 ppm, the analysis of variance for main treatment effects showed no significant differences at the 5% level among chemicals or among concentrations for sugarbeets, alfalfa, and corn. There was a significant difference ($P < 0.05$) among chemicals, and a highly significant difference ($P < 0.01$) among concentrations for wheat. These differences were due to inhibition at the 50 ppm concentration level. There was no significant difference among chemicals for fescue, but a significant difference among concentrations ($P < 0.5$). As was the case with wheat, the significant decrease in fescue emergence was a result of the 50 ppm concentration level.

The results from this study indicated that soils amended with the three test chemicals at concentrations up to 50 ppm would have no effect on seedling emergence of sugarbeets, alfalfa, corn, and fescue. For wheat, there was no inhibitory effect from any chemical at 25 ppm, and a significant reduction from the control with the sulfide and sulfone at 50 ppm. Although

Table 8. Effect of chemicals and chemical concentration from soil incorporated chemicals on seedling emergence at a constant temperature of 30°C. Values are the mean of three replicates (total of 75 seeds).†

Chemical	Chemical concentration (ppm)				
	0	0.5	5	25	50
	Seedlings/Petri dish				
			Wheat		
Sulfide	23.3a‡	24.3a	23.0a	23.0a	19.3b
Sulfoxide	23.3ab	24.0a	22.7ab	21.0b	22.0ab
Sulfone	23.3a	24.0a	24.0a	22.7a	13.7b
			Sugarbeets		
Sulfide	22.3a	23.7a	22.0a	24.0a	21.3a
Sulfoxide	22.3a	24.0a	23.0a	21.0a	21.0a
Sulfone	22.3a	23.0a	23.3a	22.0a	22.0a
			Alfalfa		
Sulfide	18.7a	18.3a	18.0a	20.7a	19.0a
Sulfoxide	18.7a	21.7a	19.7a	21.7a	19.7a
Sulfone	18.7a	18.7a	19.3a	18.0a	20.0a
			Corn		
Sulfide	25.0a	24.7a	25.0a	24.7a	24.7a
Sulfoxide	25.0a	24.7a	25.0a	25.0a	24.7a
Sulfone	25.0a	25.0a	24.7a	25.0a	25.0a
			Fescue		
Sulfide	17.7a	18.0a	17.3a	16.0a	16.3a
Sulfoxide	17.7ab	20.7a	15.7ab	18.0ab	14.3b
Sulfone	17.7a	17.7a	17.3a	17.7a	15.0a

† Values given are the means of emergence after the following number of days: Wheat (6), sugarbeets (7), alfalfa (6), corn (6), and fescue (12).

‡ Means in the same row for each treatment followed by the same letter are not significantly different at the 0.05 level (Tukey's test).

75 seeds are not considered sufficient for a germination test, these results should reflect an expected seedling emergence response of these plant species in chemically amended soil, and a good estimate of germination in the soil-chemical environment.

C. CHEMICAL VOLATILIZATION FROM SOIL

A preliminary experiment was designed to determine the volatilization of *p*-chlorophenyl methyl sulfide, sulfoxide, and sulfone from soil. The experiment was not designed to provide detailed information on volatilization, but to obtain enough information to evaluate potential health hazards and precautions required for the use of radioactive compounds.

Materials and Methods

The Ascalon sandy loam was air dried and ground to pass through a 2-mm sieve. Separate samples of uniformly ring labeled ^{14}C *p*-chlorophenyl methyl sulfide, sulfoxide, and sulfone, along with carrier chemical, were dissolved in *n*-hexane so that 4 ml of standard solution which was added to 20 g of soil contained 0.2 mg of chemical with ^{14}C activity of about 1 μCi. Solvent was removed by passing dry air over the sample at 10 ml/min for 24 hours. Soils were then wet to field capacity and incubated at 30°C for 20 days. The volatilization flask consisted of a 125-ml Erlenmeyer flask with a standard 24/40 male taper ground glass joint fused to its neck. Its top was made by sealing a glass inlet and outlet tube into an outer 24/40 glass joint. The inlet tube extended 2 cm above the soil surface. The soil depth in the flasks ranged from 6 to 9 mm. There were two replicates for each treatment.

The volatilization flasks containing the soils were connected to a moist, CO_2-free air system with flow regulated by a fine metering needle valve at a rate of 5 ml/min. This apparatus was arranged so that the air passed over the soil, through a *n*-hexane trap to collect volatiles, and finally, through 1 *N* KOH to trap CO_2. The hexane traps were replaced every 5 days, and the volume of the hexane solution was reduced to 4 ml by placing the flasks in a 50°C water bath and directing an air stream over the solution surface. The solution was transferred into a scintillation counting vial, and rinsings with counting solvent made a total of 20 ml in the counting vial. The counting solvent contained 4 g of PPO (2,5-diphenyloxazole) and 50 mg of POPOP (1,4-bis[2-(5-phenyloxazolyl)]benzene) in 1 liter of toluene. Barium chloride was added to the CO_2 traps and the excess base was titrated with acid to determine the total amount of CO_2 evolved. The suspension was then filtered and the $BaCO_3$ washed with ethanol and dried. Acid was added to the $BaCO_3$ in a closed system, and the CO_2 was trapped in Hyamine(R) hydroxide and counted by scintillation techniques.

Results and Discussion

Volatilization, $^{14}CO_2$, and total CO_2 from the Ascalon soil amended with ^{14}C labeled sulfide, sulfoxide, and sulfone are given in Table 9. The amount of volatilization was determined by measuring ^{14}C activity in the n-hexane traps after periods of 5, 10, 15, and 20 days. After 5 days, the percent of added activity found in the traps was 41.7, 17.3, and 0.3% for sulfide, sulfoxide, and sulfone, respectively. However, in a later study, it was found that a considerable amount of the sulfide was lost during the evaporation of the solvent in which the chemical was added to the soil. Although the initial loss was concentration dependent, the average sulfide recovery for 10 ppm was calculated to be about 59%. The recoveries of sulfoxide and sulfone averaged 99 and 98%, respectively. Recalculating the percent loss from adjusted initial concentrations, 71% of the sulfide volatilized during the first five days (Table 9). The volatilization losses of sulfide and sulfoxide from soil were very large during the first 5 days, and decreased markedly during subsequent sampling periods. Since 71% of the sulfide volatilized during the first 5 days and only 0.5% during the next 5 days, evidently the immediate large loss resulted from the weakly sorbed material followed by a very slow release of the small amount of remaining chemical. For sulfoxide, the 17% lost during the first five days may have resulted from factors affecting vapor loss from the soil's surface and subsequent low loss due to factors influencing diffusion. The volatilization of sulfone was very low, with only 1.4% of the applied being volatilized after 20 days. This preliminary experiment on volatilization does not give much information on the mechanism, as extensive research would be needed to evaluate the interacting effects of the physical chemical properties of the chemical, sorptive properties of the soil, chemical concentration, soil water, temperature, and diffusion. In this study, the differences in volatility among chemicals from soil were probably due primarily to differences in vapor pressure of the chemicals, and possibly to varying degrees of chemical sorption to soil components.

Total CO_2 and $^{14}CO_2$ production are given in Table 9. The amount of activity recovered as $^{14}CO_2$ resulting from ring cleavage of the parent compound ranged from 2.0 to 2.6% for the three chemicals. Information on the purity of the radioactive chemicals was only available for sulfoxide, which was 99%. Therefore some of the $^{14}CO_2$ could have resulted from the degradation of impurities. Total CO_2 production appeared to be about the same for all chemicals. More information on $^{14}CO_2$ and total CO_2 will be presented in a more detailed experiment included in this report.

Table 9. Volatilization, CO_2, and $^{14}CO_2$ from soil amended with 10 ppm of ^{14}C labeled p-chlorophenyl methyl sulfide, sulfoxide, and sulfone.

Chemical	Incubation period†	Volatilization	$^{14}CO_2$	Total CO_2
	days	% of applied		mg C/20 g
Sulfide	0-5	41.68 (70.65)‡	0.20 (0.34)‡	2.04
	5-10	0.30 (0.51)	0.34 (0.57)	0.27
	10-15	0.18 (0.30)	0.67 (1.13)	0.81
	15-20	0.15 (0.25)	0.33 (0.57)	1.68
	Total	42.31 (71.71)	1.54 (2.61)	4.80
Sulfoxide	0-5	17.25	0.27	2.24
	5-10	1.27	0.35	0.54
	10-15	0.25	0.96	0.71
	15-20	0.38	0.70	1.74
	Total	19.15	2.28	5.23
Sulfone	0-5	0.33	0.21	1.61
	5-10	0.41	0.32	0.54
	10-15	0.30	0.86	0.67
	15-20	0.34	0.62	1.31
	Total	1.38	2.01	4.13

† Volatilization and CO_2 production during the time period indicated.

‡ Percentage of initial ^{14}C concentration expected in soil at start of the experiment based on initial recoveries in a later experiment.

III. DEGRADATION OF P-CHLOROPHENYL METHYL SULFIDE, SULFOXIDE AND SULFONE IN SOIL

A laboratory study was designed to determine the amount of degradation of ^{14}C labeled p-chlorophenyl methyl sulfide, sulfoxide, and sulfone in soil during a 160-day period. The main objectives were: (1) to determine the rate of degradation in soil by measuring evolved $^{14}CO_2$ and (2) evaluate the persistence of the test chemicals in soil by measuring total ^{14}C remaining in soil after predetermined incubation periods. In addition, a broad measure of the effect of these chemicals on total microbial activity was determined from total CO_2 production.

The experiment was confounded because some of the sulfide was lost during the addition of the chemical to soil. Instead of the applied concentrations of 0.5, 5 and 50 μg/g, the determined initial concentration of sulfide prior to incubation was 0.36, 3.0 and 23.9 μg/g. The initial measured concentrations of the sulfoxide and sulfone were basically the same as that applied. These values were 0.47, 4.77 and 47.4 μg/g for sulfoxide and 0.48, 4.77 and 48.9 μg/g for sulfone. All values in the text are based on the initial measured concentrations. Even though the initial sulfide concentrations were considerably lower than the other two chemicals, statistical analysis is valid because the wide concentration range was maintained.

Materials and Methods

The soil was an Ascalon sandy loam collected from a dryland wheat stubble field, air dried, and ground to pass through a 2-mm sieve. Separate standard solutions of p-chlorophenyl methyl sulfide, sulfoxide and sulfone were made up in acetone-n-hexane (0.1 ml acetone/mg of chemical). Uniformly ring labeled ^{14}C chemicals without carrier were used for the 0.5 ppm (0.5 μg/g soil) treatment, and nonlabeled carrier chemicals were added to ^{14}C labeled materials to give the required concentrations of 5 and 50 ppm for the other two treatments. The specific activity of the ^{14}C chemicals was about 5mCi/mmol. Dilutions required for various concentrations were made with n-hexane, and the volume of standard solution was 0.2 ml/g of soil which thoroughly wet the soil but without free standing solvent.

Twenty grams of air dried soil were placed in cut-off test tubes (22 x 70 mm), and 4 ml of the appropriate standard was added, covered with aluminum foil, equilibrated for 30 minutes, and then spread on aluminum foil to allow hexane evaporation. After about 16 hours, the soils were mixed and replaced in the same glass container, and wet to field capacity. Four glass vials, each containing a 20 g soil sample, were placed in a larger glass bottle for incubation. Each of the soil vials was weighed so that water evaporated during the experiment could be replaced.

Incubation bottles were placed in a constant temperature room (30°C ± 0.50), and continuously flushed with moist, CO_2-free air at a rate of 4 to

6 ml/min. Exhaust gases were first passed through a n-hexane trap and then a 0.25 N KOH trap. The n-hexane trap was used to collect any volatile components to eliminate radioactive contamination, but the apparatus contained rubber stoppers and tubing which adsorbed some of the vapors and prevented quantitative use of the data. The carbonates in the base trap were precipitated with $BaCl_2$ and the excess base was titrated with standard acid to determine CO_2 production. After titration, the contents were filtered and the $BaCO_3$ was washed with ethanol and dried at 105°C for 30 minutes. The $BaCO_3$ was then placed in a small vial and placed in a larger glass container along with a scintillation vial containing Hyamine hydroxide. The larger container was sealed and acid was added to the $BaCO_3$ through a rubber septum and the evolved CO_2 and $^{14}CO_2$ were trapped in the Hyamine. Cocktail was added to the Hyamine and analyses of $^{14}CO_2$ were made by scintillation counting.

After designated incubation periods, soils were spread on aluminum foil, dried, mixed, and a representative sample ground to pass through a 100-mesh sieve. A 0.5 gram sample, weighed accurately to four places, was combusted in a Coleman nitrogen analyzer (adapted for CO_2 analysis), and the evolved CO_2 was trapped in Hyamine and counted. Each treatment was replicated three times.

Results and Discussion

Total CO_2 Production

The effect of p-chlorophenyl methyl sulfide, sulfoxide, and sulfone on total CO_2 production from an Ascalon soil is given in Table 10, and replicate data given in Appendix Tables A-1, A-2, and A-3. There was a significant difference among chemicals ($P < 0.05$), and the significance was probably due to higher CO_2 production from the sulfide treatment and very little difference between the sulfoxide and sulfone. The higher CO_2 values for the sulfide may have been the result of lower initial concentrations. Soil chemical concentrations of 0.5 and 5 ppm had no effect on CO_2 production ($P > 0.05$). The only exception was a decrease during the 80-160 day period with the 5 ppm level of sulfone (Table 10). Although the 50 ppm treatment showed no effect during the first 40 days, the main effect including all chemicals was a significant decrease ($P < 0.05$) in CO_2 production during 40-80 and 80-160 day incubation periods at the 50 ppm level as compared to all other treatments. These data suggest that the high chemical treatment caused a delayed inhibitory effect on CO_2 production.

$^{14}CO_2$ Production

The amount of $^{14}CO_2$ produced from ring cleavage and subsequent oxidation from sulfide, sulfoxide, and sulfone is summarized in Table 11 and replicate data given in Appendix Tables A-1, A-2, and A-3. The percent recovery value is based on initial ^{14}C measurements of the soil prior to incubation. The amount of chemical degradation based on percent of initial soil concentration ranged from 4.9 to 16.7% after a 160 day incubation. On

Table 10. Total CO_2 production from an Ascalon soil amended with ring labeled ^{14}C p-chlorophenyl methyl sulfide, sulfoxide, and sulfone during a 160 day incubation period.

Chemical	Incubation period	Total CO_2 production at soil concentrations (µg/g)† of			
		0	0.5	5	50
	days	mg C/20 g soil			
Sulfide	0-10	3.19a‡	3.23a	3.31a	3.22a
	10-20	2.02a	2.27a	2.01a	1.83a
	20-40	2.76a	3.01a	2.62a	1.99a
	40-80	4.77a	5.17a	4.44a	3.15b
	80-160	8.01a	8.40a	7.83a	4.66b
	Total	20.75	22.08	20.21	14.85
Sulfoxide	0-10	3.19a	3.42a	3.24a	3.20a
	10-20	2.02a	2.19a	1.93a	1.63a
	20-40	2.76a	2.88a	2.37a	2.03a
	40-80	4.77a	4.94a	4.35a	2.53b
	80-160	8.01a	8.27a	7.12a	3.19b
	Total	20.75	21.70	19.01	12.58
Sulfone	0-10	3.19a	3.33a	3.28a	3.30a
	10-20	2.02a	2.22a	2.03a	2.01a
	20-40	2.76a	3.02a	2.60a	2.34a
	40-80	4.77a	4.91a	4.28a	2.78b
	80-160	8.01a	7.72a	5.64b	3.44c
	Total	20.75	21.20	17.83	13.87

† Concentration of chemical applied, but initial ^{14}C measurements showed concentrations to be 0.36, 3.00, and 23.9 µg/g for sulfide, 0.47, 4.77, and 47.4 µg/g for sulfoxide, and 0.48, 4.77, and 48.9 µg/g for sulfone.

‡ Means in the same row for each treatment followed by the same letter are not significantly different at the 0.05 level (Tukey's test).

Table 11. $^{14}CO_2$ production from an Ascalon soil amended with ring labeled ^{14}C p-chlorophenyl methyl sulfide, sulfoxide, and sulfone during a 160-day incubation period.

Chemical	Incubation period	$^{14}CO_2$ from soil concentrations (µg/g)† of					
		0.5		5		50	
		Rate	Total	Rate	Total	Rate	Total
	days	ng/day‡	% of Init.	ng/day‡	% of Init.	ng/day‡	% of Init.
Sulfide	0-10	9	1.29a§	59	0.99a	277	0.58a
	10-20	15	2.06a	64	1.07a	488	1.02a
	20-40	9	2.35a	41	1.38ab	222	0.93b
	40-80	7	3.77a	34	2.24b	132	1.10b
	80-160	7	7.26a	30	4.02b	106	1.77c
	Total		16.73		9.70		5.40
Sulfoxide	0-10	9	0.94a	74	0.83a	294	0.31a
	10-20	16	1.65a	108	1.21a	711	0.75a
	20-40	9	1.97a	66	1.48a	583	1.23a
	40-80	10	4.27a	56	2.52b	436	1.84b
	80-160	9	7.28a	52	4.63b	238	2.01c
	Total		16.11		10.67		6.14
Sulfone	0-10	10	1.06a	66	0.69a	352	0.36a
	10-20	17	1.81a	95	1.00a	587	0.60a
	20-40	9	1.91a	63	1.31a	381	0.78a
	40-80	8	3.46a	56	2.34ab	303	1.24b
	80-160	7	5.39a	43	3.60b	235	1.92c
	Total		13.63		8.94		4.90

† Concentration of chemical applied, but initial ^{14}C measurements showed concentrations to be 0.36, 3.00, and 23.9 µg/g for sulfide, 0.47, 4.77, and 47.4 µg/g for sulfoxide, and 0.48, 4.77, and 48.9 µg/g for sulfone.

‡ Calculated average degradation rate (ng of chemical/day) from $^{14}CO_2$ data.

§ Means in the same row for each treatment followed by the same letter are not significantly different at the 0.05 level (Tukey's test).

a percentage basis, the larger amount of degradation occurred at lowest soil chemical concentration treatment and progressively decreased with higher concentration levels. For example, the $^{14}CO_2$ evolved from the sulfoxide treatment after 160 days was 16.1, 10.7, and 6.1% for 0.5, 5, and 50 ppm levels, respectively. Statistical analysis on percent of $^{14}CO_2$ recovered after various incubation periods showed a significant difference among chemicals ($P < 0.05$), and among soil chemical concentrations ($P < 0.01$). The difference among chemicals was due to the slightly lower total $^{14}CO_2$ production in the sulfone treatment and no difference between the sulfide and sulfoxide.

The amount of chemical degraded to $^{14}CO_2$, expressed as percent, decreased with increasing soil chemical concentration; however, the degradation rate, expressed as ng of chemical/day from $^{14}CO_2$ data, progressively increased with increasing concentration for all chemicals (Table 11). The highest rate of $^{14}CO_2$ evolution occurred during the 10 to 20 day period, and decreased with time. For example, sulfoxide destruction to $^{14}CO_2$ during the 10 to 20 day period was 16, 108, and 711 ng/20 g soil/day and during the 80-160 day period the rate was 9, 52, and 238 ng/20 g/day for the 0.5, 5, and 50 ppm levels, respectively. Since there was a decrease in rate of $^{14}CO_2$ produced with time, there appears to be no indication of a specific microbial population developing a mechanism to degrade these chemicals.

A significant correlation existed for the combined data of the three chemicals and all incubation periods between total CO_2 (mg C) and ng of chemical lost as $^{14}CO_2$ for the 0.5 ($r = 0.928^{**}$) and 5 ($r = 0.813^{**}$) ppm treatments. No correlation ($r = 0.132$) existed for the 50 ppm treatment. The association of total CO_2 and degradation implies to some extent a microbial mechanism involved in the degradation of these compounds at low soil concentration levels.

Persistence

The persistence of ^{14}C in soil from ring labeled sulfide, sulfoxide, and sulfone was determined by measuring the ^{14}C activity remaining by dry combustion of soil after predetermined incubation periods. These recovery values for the three chemicals are summarized in Table 12 and replicate data given in Appendix Tables A-4, A-5, and A-6. The recovery of ^{14}C from soil amended with sulfoxide and sulfone was not significantly different, but the recovery from sulfide was significantly less ($P < 0.01$) than the other two. The recovery values for sulfide, sulfoxide, and sulfone after 160 days at the 5 ppm level were 60.6, 84.5, and 82.5%, respectively. There was a significant difference among concentrations ($P < 0.01$) due primarily to the lower recoveries at the 50 ppm level and no difference ($P > 0.05$) for any chemical between the 0.5 and 5 ppm treatments.

The decrease in residual ^{14}C activity in soil with time was accounted for in the $^{14}CO_2$ evolved for the 0.5 and 5 ppm treatments of sulfoxide and sulfone (Table 12). At the 50 ppm level for these same compounds, only 83% of the applied activity was recovered as residual soil ^{14}C and $^{14}CO_2$. The

Table 12. Residual ^{14}C activity in soil and total ^{14}C recovered from an Ascalon soil amended with ring labeled ^{14}C p-chlorophenyl methyl sulfide, sulfoxide, and sulfone during a 160 day incubation period.

Chemical	Incubation	Recovery of ^{14}C from soil concentration (μg/g)† of					
		0.5		5		50	
		Soil	Total‡	Soil	Total‡	Soil	Total‡
	days	% of initial					
Sulfide	10	98.7a§	99.99	92.3a	93.29	81.6b	82.18
	20	82.3a	85.65	78.0a	80.06	57.7b	59.30
	40	80.3a	86.00	72.6a	76.04	51.4b	53.93
	80	73.6a	83.07	67.4a	73.08	48.9b	52.53
	160	65.7a	82.43	60.6a	70.30	45.3b	50.70
Sulfoxide	10	98.4ab	99.34	106.2a	107.03	93.1b	93.41
	20	95.0a	97.59	97.6a	99.64	90.8a	91.86
	40	98.0ab	102.56	99.8a	103.32	89.9b	92.19
	80	86.8a	95.63	90.4a	96.44	82.1a	86.23
	160	80.6a	96.71	84.5a	95.17	76.1a	82.24
Sulfone	10	101.9a	102.96	100.2a	100.89	101.3a	101.66
	20	95.3a	98.12	96.9a	98.59	97.0a	97.96
	40	96.6a	101.38	99.1a	102.10	94.4a	96.14
	80	86.1a	94.34	89.8a	95.14	87.6a	90.58
	160	82.4a	96.03	82.5a	91.44	77.9a	82.80

† Concentration of chemical applied, but initial ^{14}C measurements showed concentrations to be 0.36, 3.00, and 23.9 μg/g for sulfide, 0.47, 4.77, and 47.4 μg/g for sulfoxide, and 0.48, 4.77, and 48.9 μg/g for sulfone.

‡ Total ^{14}C activity recovered after the period, including residual soil ^{14}C and $^{14}CO_2$.

§ Means in the same row for each treatment followed by the same letter are not significantly different at the 0.05 level (Tukey's test).

total recovery from the sulfide treatment decreased from 82% at 0.36 ppm level to 51% at the 24 ppm level. The larger losses from the sulfide compared to sulfone and sulfoxide were probably due to volatilization during the initial 10 day incubation period.

Summary

Sulfide, sulfoxide, and sulfone degraded slowly in soil incubated at 30°C and at field capacity moisture content. Soil chemical concentrations of all chemicals at 0.5 and 5 ppm had no effect on total CO_2 production, but a significant reduction was found at the 50 ppm levels. Almost all of the inhibitory effects of chemicals at the high concentration on CO_2 production occurred during the 40 to 160 day incubation period. The amount of $^{14}CO_2$ produced from ring cleavage and subsequent oxidation expressed as percent of initial concentration decreased with increasing soil chemical concentration. However, the rate of $^{14}CO_2$ production progressively increased with increasing concentration for all chemicals. The extent of degradation after 160 days as measured by $^{14}CO_2$ ranged from 5 to 17%. In some cases, a near complete recovery of activity was achieved while in other cases only 51% was recovered. Total ^{14}C recovery from the 0.5 and 5 ppm levels of sulfoxide and sulfone ranged from 91 to 97% whereas at the 50 ppm level the recoveries were 82% after 160 days. The ^{14}C activity not recovered for sulfoxide and sulfone was probably lost as volatile metabolites while most of the unaccountable activity from the sulfide was lost by volatilization of the parent compound during the initial 10 days of incubation.

IV. TRANSLOCATION OF FOLIAR APPLIED CHEMICALS TO CORN AND SUGARBEETS

A greenhouse experiment was conducted to evaluate translocation of ^{14}C labeled p-chlorophenyl methyl sulfide, sulfoxide, and sulfone, and diisopropyl methyl phosphonate (DIMP) from a foliar application on one leaf surface to other plant parts of corn and sugarbeets. Plants absorb chemicals mainly through their root system, and to a lesser extent through their leaves. Generally, elements or compounds that become easily fixed or unavailable through soil applications, are applied directly on the leaves. However, this foliar uptake mechanism is not necessarily restricted to needed elements as toxic chemicals may enter the plant system by this same mechanism. Since the test chemicals are present in low concentrations in some ground waters, this experiment was designed to simulate the effect of the chemicals that could be applied by sprinkler irrigation and possibly absorbed and translocated by a foliar mechanism.

Materials and Methods

An Ascalon sandy loam soil was used in the greenhouse translocation studies. Soil was air-dried and ground to pass through a 0.64 cm sieve. Two kg of soil were amended with 100 µg N/g as $(NH_4)_2SO_4$ and 50 µg P/g as $Ca(H_2PO_4)_2 \cdot H_2O$, and mixed thoroughly in a twin-shelled blender. The soil was then potted in a one-half gallon paper container lined with a plastic bag. Additional nitrogen as KNO_3 and $(NH_4)_2SO_4$ was added as required.

An excess of corn and sugarbeet seeds were added to pots in April for the sulfur studies and in November for DIMP. After initial growth, the pots were thinned to 2 plants per pot for each crop. Soil moisture was kept near field capacity for the duration of the experiment. Greenhouse temperature and relative humidity were monitored continuously, and a 14-hour day length was maintained with 400 watt Na-incandescent lamps.

Sulfur compounds were applied to corn on May 16, 41 days after planting, and on May 30 to the sugarbeets, 55 days from planting. Because of the cooler temperatures during the winter season, DIMP was applied 71 days after planting for both sugarbeets and corn.

Test chemicals were applied to the youngest fully expanded leaf. A 100 µl micro-syringe was used to apply the ^{14}C labeled material in small adjacent droplets on the target leaf. These droplets averaged about 2 mm in diameter. The volume of standard solution added to each leaf was 0.2 ml which represented about 0.6 µCi and 20 µg of chemical. The standards were made up in water using 0.1% Tween 80 as the emulsifying agent. Suspensions were continuously stirred during the foliar application process.

Foliar applications were made at about 7 a.m. in the sunlight of the greenhouse and the amount of translocation of ^{14}C was determined after 24 hours in one set of plants, and after 72 hours in another set. After the translocation period, the plants were separated into a number of components. Each sugarbeet was sectioned into 8 components: (1) leaf of initial chemical application (target ^{14}C leaf); (2) petiole from application leaf (petiole ^{14}C); (3) crown; (4) upper half of root (root-top); (5) lower half of root (root-bottom); (6) youngest fully expanded leaf on opposite side from application (new leaf); (7) old leaf on opposite side from application (old leaf); (8) remaining plant top that was not sampled (other). The corn plant was sectioned into 7 components: (1) leaf of initial chemical application (target ^{14}C leaf); (2) stem from application leaf (stem); (3) crown; (4) roots; (5) new leaf; (6) old leaf; (7) remaining plant top that was not sampled (other).

Plant parts were dried in a 60°C oven, weighed, and ground in a Wiley mill to pass through a 40-mesh sieve. In some cases with small amounts of sample, the material was ground using an agate mortar and pestle. A small sub-sample generally ranging from 40 to 60 mg was weighed accurately to four places and dry combusted to determine total ^{14}C activity from the trapped $^{14}CO_2$.

Experimental design consisted of four chemicals, p-chlorophenyl methyl sulfide, sulfoxide, and sulfone, and DIMP, two test crops (corn and sugarbeets), two sampling periods (24 and 72 hrs), and three replications. Radioactivity measurements on samples that were less than 50 DPM over background were not considered significant, and these values were not listed in the regular tables; but are given in the Appendix Tables.

Results and Discussion

The extent of absorption and translocation of the three sulfur compounds and DIMP in corn and sugarbeets was evaluated by applying small droplets of a water suspension containing standard ^{14}C compounds. Chemicals were added during the early morning hours to take advantage of the cooler temperatures to minimize the rate of droplet evaporation. Depending on temperature and relative humidity, the droplets evaporated in the time period from 2 to 4 hours.

Sulfide, Sulfoxide, and Sulfone

Corn -- Experimental and environmental conditions during the translocation periods of p-chlorophenyl methyl sulfide, sulfoxide, and sulfone in corn is given in Table 13. Environmental conditions were very good for plant growth including clear skies the first and third day and overcast the second day.

Under the imposed experimental conditions, there was no translocation and very little absorption of the three sulfur containing compounds in corn (Table 14). All of the recovered activity was in the target ^{14}C leaf and the amount varied among chemicals. The activity recovered as percent of applied after 24 hours was 0.67, 6.78, and 21.57% for sulfide, sulfoxide, and sulfone, respectively. The same type of relationship existed for the

Table 13. Summary of experimental conditions for foliar applied ^{14}C p-chlorophenyl methyl sulfide, sulfoxide, and sulfone in corn plants.

Environmental conditions	Absorption period (hr)		
	24	48	72
Cloud cover	Clear	Overcast	Clear
Temperature (°C)			
High	41	30	33
Low	16	16	16
Weighted avg.	28	19	24
Relative humidity (%)			
High	90	90	86
Low	25	60	28

Additional Information

Time of application: 16 May 1978, 0730 hrs.

Temp. and R.H. at application: 24°C, 70%

Plant age: 41 days

Plant height (avg.): 94 cm with leaf fully extended

Plant top weight (avg.): 10.6 g ± 0.6 (SE)

Table 14. Absorption and distribution of foliar applied ^{14}C p-chlorophenyl methyl sulfide, sulfoxide, nd sulfone in corn plants.

Plant part	Absorption period (hr)			
	24		72	
	Activity recovered	Plant concentration†	Activity recovered	Plant concentration†
	%	μg/g	%	μg/g
			Sulfide	
Target ^{14}C leaf	0.67	0.17	0.87	0.20
Stem	-‡	-	-	-
Crown	-	-	-	-
Roots	-	-	-	-
New leaf	-	-	-	-
Old leaf	-	-	-	-
Other§	-	-	-	-
			Sulfoxide	
Target ^{14}C leaf	6.78	1.49	7.99	1.47
Stem	-	-	-	-
Crown	-	-	-	-
Roots	-	-	-	-
New leaf	-	-	-	-
Old leaf	-	-	-	-
Other§	-	-	-	-
			Sulfone	
Target ^{14}C leaf	21.57	4.09	15.24	2.43
Stem	-	-	-	-
Crown	-	-	-	-
Roots	-	-	-	-
New leaf	-	-	-	-
Old leaf	-	-	-	-
Other§	-	-	-	-

† Calculated chemical concentration based on ^{14}C measurements assuming activity remained as parent compound.

‡ Radioactive counts in sample were less than 50 DPM after natural background was subtracted out.

§ Includes plant top material remaining after specific parts were removed.

72 hour absorption period. Although the experiment showed no translocation in corn, the results showed large losses of the chemicals by volatilization ranging from 99% for the sulfide to 78.4% for sulfone after 24 hours. A complete listing of all data including plant part weight, sample size analyzed, and ^{14}C counts are given in Appendix Tables B-1, B-2, and B-3.

Sugarbeets -- The environmental conditions during the 72 hour period were more conducive to foliar uptake in sugarbeets than those found earlier with corn (Table 15). The first 24 hour period was cooler, thus providing the sugarbeet plants with greater time for absorption since the evaporative processes were reduced. The clear days and temperatures for the rest of the period were ideal for translocation to occur once the chemicals were absorbed. Information on plant part weights, sample size analyzed, ^{14}C counts per sample are given in Appendix Tables B-4, B-5, and B-6.

There was no translocation of the three sulfur containing compounds in sugarbeets as measured by ^{14}C activity in plant parts (Table 16). Although there were some very small amounts detected in some plant parts of the sulfoxide and sulfone treatments, the values were insignificant compared to the total applied, and to the total found in the ^{14}C target leaf. Considerably more chemical was absorbed in the target ^{14}C leaf for sugarbeets than with corn. The percent absorbed by the target leaf after 24 hours was 8.7, 29.8, and 41.4% for the sulfide, sulfoxide, and sulfone, respectively.

DIMP

The greenhouse temperatures and relative humidity for the foliar experiment with DIMP were considerably lower than those for the sulfur chemicals. However, average day temperatures seemed adequate for absorption and translocation of DIMP in corn and sugarbeets (Table 17). Additional data on plant weights, sample size, and counts for individual replicates can be found in Appendix Tables B-7 and B-8.

Corn -- The application of ^{14}C DIMP to the youngest fully expanded corn leaf showed no movement of ^{14}C to other plant parts after 24 or 72 hour periods (Table 18). Only a small portion of the amount applied was absorbed in the target leaf, 3.7% for the 24 hour period and 3.0% after 72 hours. This indicated that 96 to 97% was volatilized from the leaf surface and remaining chemical was not translocated.

Sugarbeets -- Foliar applied DIMP was translocated within the sugarbeet plant (Table 18). Although the majority of the chemical was volatilized from the leaf of application (about 91%), detectable amounts of activity were detected in all plant parts except the old leaf after 24 hours, and all plant parts except the new leaf after 72 hours. The amount of activity in the old and new leaf for both time periods is probably insignificant. Converting the data from activity measurements to plant concentration (μg/g) assuming the activity remained as the parent compound, the concentrations decrease from

Table 15. Summary of experimental conditions for foliar applied ^{14}C p-chlorophenyl methyl sulfide, sulfoxide, and sulfone in sugarbeet plants.

Environmental conditions	Absorption period (hr)		
	24	48	72
Cloud cover	Clear	Clear	Clear
Temperature (°C)			
High	32	27	30
Low	16	15	16
Weighted avg.	22	18	17
Relative humidity (%)			
High	84	80	90
Low	40	46	52

Additional Information

Time of application: 30 May 1978, 0715 hrs.

Temp. and R.H. at application: 21°C, 75%

Plant age: 55 days

Plant height (avg.): 31 cm with leaf fully extended

Plant top weight (avg.): 2.35 g ± 0.2 (SE)

Plant root weight (avg.): 1.03 g ± 0.09 (SE)

Table 16. Absorption and distribution of foliar applied ^{14}C p-chlorophenyl methyl sulfide, sulfoxide, and sulfone in sugarbeet plants.

Plant part	Absorption period (hr)			
	24		72	
	Activity recovered	Plant concentration†	Activity recovered	Plant concentration†
	%	µg/g	%	µg/g
		Sulfide		
Target ^{14}C leaf	8.74	8.57	9.80	6.05
Petiole ^{14}C	-	-	-	-
Crown	-	-	-	-
Root (top half)	-	-	-	-
Root (bottom half)	-	-	-	-
New leaf	-	-	-	-
Old leaf	-	-	-	-
Other§	0.68	0.06	1.02	0.07
Total	9.42		10.82	
		Sulfoxide		
Target ^{14}C leaf	29.77	28.63	29.49	25.53
Petiole ^{14}C	-	-	0.06	0.16
Crown	0.22	0.07	-	-
Root (top half)	-	-	-	-
Root (bottom half)	-	-	-	-
New leaf	-	-	0.06	0.04
Old leaf	-	-	-	-
Other§	-	-	0.74	0.07
Total	29.99		30.35	
		Sulfone		
Target ^{14}C leaf	41.37	32.70	30.33	21.66
Petiole ^{14}C	0.06	0.13	0.09	0.18
Crown	0.21	0.07	-	-
Root (top half)	-	-	-	-
Root (bottom half)	-	-	-	-
New leaf	-	-	-	-
Old leaf	-	-	-	-
Other§	-	-	0.61	0.05
Total	41.64		31.03	

† Calculated chemical concentration based on ^{14}C measurements assuming activity remained as parent compound.

‡ Radioactive counts in sample were less than 50 DPM after natural background was subtracted out.

§ Includes plant top material remaining after specific parts were removed.

Table 17. Summary of experimental conditions for foliar applied ^{14}C diisopropyl methyl phosphonate (DIMP) in corn and sugarbeet plants.

Environmental conditions	Absorption period (hr)		
	24	48	72
Cloud cover	Clear	Clear	Clear
Temperature (°C)			
High	27	31	27
Low	16	14	13
Weighted avg.	20	21	18
Relative humidity (%)			
High	42	40	42
Low	30	28	28

Additional Information

Time of application: 3 January 1979, 0730 hrs.

Temp. and R.H. at application: 16°C, 42%

Corn and sugarbeet plant age: 71 days

Plant height (avg.): Corn 94 cm and sugarbeet 23 cm with leaf fully extended

Plant top weight (avg.): Corn 12.4 g ± 0.2 (SE) and sugarbeets 2.8 g ± 0.3 (SE)

Plant root weight (avg.): Corn 4.7 g ± 0.5 (SE) and sugarbeets 0.9 ± 0.2 (SE)

Table 18. *Absorption and distribution of foliar applied ^{14}C diisopropyl methyl phosphonate (DIMP) in corn and sugarbeet plants.

Plant part	Absorption period (hr)			
	24		72	
	Activity recovered	Plant concentration†	Activity recovered	Plant concentration†
	%	μg/g	%	μg/g
		Corn		
Target ^{14}C leaf	3.71	0.84	2.97	0.70
Stem	- ‡	-	-	-
Crown	-	-	-	-
Roots	-	-	-	-
New leaf	-	-	-	-
Old leaf	-	-	-	-
Other§	-	-	-	-
		Sugarbeets		
Target ^{14}C leaf	8.50	7.30	6.62	4.27
Petiole ^{14}C	0.13	0.24	0.46	0.67
Crown	0.07	0.05	0.40	0.16
Root (top half)	0.15	0.04	0.76	0.18
Root (bottom half)	0.03	0.04	0.19	0.22
New leaf	0.02	0.02	-	-
Old leaf	-	-	0.04	0.02
Other§	0.12	0.02	0.64	0.07
Total	9.02		9.11	

† Calculated chemical concentration based on ^{14}C measurements assuming activity remained as parent compound.

‡ Radioactive counts in sample were less than 50 DPM after natural background was subtracted out.

§ Includes plant top material remaining after specific parts were removed.

the target leaf (7.3), petiole (0.24), crown (0.05), root-top (0.04), to root-bottom (0.04) for the 24 hour period. The same trend existed for the 72 hour except more translocation was evident by the decrease in concentration in the target leaf with increases in other plant parts. Thus, ^{14}C DIMP was translocated from the target leaf to the petiole, down to the crown and roots as evidenced by activity measurements, and further substantiated by higher activity values in plant parts after 72 hours translocation as compared to a 24 hour period.

Summary

Absorption and translocation of ^{14}C DIMP, sulfide, sulfoxide, and sulfone was determined from a foliar application and subsequent plant part analysis after periods of 24 and 72 hours. Experiments were conducted on corn and sugarbeets grown under greenhouse conditions. There was no translocation of any chemical in corn, and no translocation of the sulfur compounds in sugarbeets. DIMP was translocated in the sugarbeet from the target leaf to the root with 27.3% of the total activity added being recovered in plant parts other than the target leaf. The amount of chemical remaining in the target leaf after translocation periods up to three days varied from less than 1% for sulfide on corn to 41.4% for sulfone on sugarbeets. Even though DIMP was the only chemical translocated, there still could be concern resulting from accumulation of the chemicals in leaves exposed to contaminated water applied by a sprinkler irrigation system. Although a large amount of the chemicals would be expected to be volatilized from leaf surfaces, repeated sprinkler irrigation during the growing season could result in some accumulation in the exposed leaves, especially with the sulfone.

V. PLANT ACCUMULATION AND PHYTOTOXICITY OF SOIL INCORPORATED p-CHLOROPHENYL METHYL SULFIDE, SULFOXIDE, AND SULFONE IN WHEAT, CORN, ALFALFA, FESCUE, AND SUGARBEETS

A greenhouse experiment was conducted to determine the effect of soil concentration levels (0.5, 5, and 25 ppm) of ^{14}C-ring labeled p-chlorophenyl methyl sulfide, sulfoxide and sulfone on growth and uptake by alfalfa, corn, fescue, sugarbeets, and wheat in an Ascalon soil, and also wheat in a Nunn soil. Since a considerable amount of the sulfide was lost during solvent evaporation of the chemically treated soil, initial soil concentrations for all treatments were measured prior to initiation of the experiment (Appendix Tables C1-C6). The initial recovery values for sulfoxide and sulfone were about the same as the amount applied, but sulfide losses were sizeable and variable among crops. Therefore, all values in the tables are expressed as percent or calculated values of the initial measured concentration.

Materials and Methods

The Ascalon sandy loam was used for all test crops, and the Nunn loam was used only for wheat. The soils were collected in September 1977, ground to pass through a 0.64-cm screen, and stored in galvanized containers in an unheated storage building. Separate standard solutions of p-chlorophenyl methyl sulfide, sulfoxide, and sulfone were made up in acetone-n-hexane (0.1 ml acetone/1 mg chemical). Uniformly ring labeled chemicals without carrier were used for the 0.5 ppm (0.5 μg/g soil) treatment, and nonlabeled carrier chemicals were added to ^{14}C labeled materials to give the required concentrations of 5 and 25 ppm for the other two treatments. The specific activity of the ^{14}C chemicals was about 5 mCi/mmol. Dilutions required for various concentrations were made with n-hexane, and the volume of hexane added with the chemicals was 0.2 ml/g of soil which thoroughly wet the soil but without free standing solvent.

Air dried soil (2050 g) was placed in a two-liter glass beaker, standard solutions added, covered with aluminum foil, and equilibrated for 30 minutes. The soil was then spread out in a thin layer on aluminum foil, placed on top of an aluminum serving tray, and the hexane evaporated initially in a fume hood overnight and then in a ventilated laboratory. To assure adequate phosphorous (P) and nitrogen (N) for plant growth in confined pot experiments, 50 μg/g (50 ppm) of P as concentrated superphosphate and 50 μg/g of N as $(NH_4)_2SO_4$ were added as dry materials to the soil. To obtain uniform distribution of test chemicals and fertilizer within the soil, the soil was mixed thoroughly in a twin-shell blender for 5 minutes. Then the soil was spread out in a thin layer and a total of 50 g of soil was removed as small subsamples for initial ^{14}C analysis. These samples were stored in a freezer for future analyses.

The remaining 2000 g of treated soil were placed in one-half gallon ice cream cartons in which a plastic liner had been inserted. Corn and wheat were planted 2 cm from the surface, and alfalfa, sugarbeets, and fescue were planted 1 cm from the soil surface. The number of seeds planted for each crop was 20, 20, 15, 12, and 9 for fescue, alfalfa, sugarbeets, wheat, and corn, respectively. After seedling establishment the plants were thinned to 5, 5, 5, 3, and 2 for fescue, alfalfa, wheat, corn, and sugarbeets, respectively.

Seed treatment, Manzate-200, was used on the sugarbeet and alfalfa seeds to eliminate any "damping off" effects during germination and seedling establishment. The initial water added to the soil to bring the soil water content to field capacity also contained an additional 50 ppm N as KNO_3. Every morning each pot was weighed and water added to bring the soil water content back to field capacity. Depending on the stage of growth and daytime temperatures, additional water had to be applied to assure adequate soil water for plant growth. Plants were grown in a greenhouse and supplemental lights were used to give a day length of 14 hours.

Results and Discussion

Wheat

Toxicity Symptoms -- The effect of concentration and soil incorporated ^{14}C labeled p-chlorophenyl methyl sulfide, sulfoxide, and sulfone were evaluated from the growth response of wheat in an Ascalon sandy loam and a Nunn loam. The first visual phytotoxicity symptom was a browning of the older leaf tip followed by the browning or drying progressively moving down the leaf. Later stages of damage included the twisting of the leaf. Symptoms were the same for all chemicals in both soils. Using a rating scale of 0 to 5, with 0 having no symptoms and 5 being a dead plant, the ranking for wheat grown in the Ascalon soil was 1 for all chemicals at the 0.5 ppm level, 1^+ for sulfide and 2 for sulfoxide and sulfone at 5 ppm, and 3 for sulfide and 3^+ to 5 for sulfoxide and sulfone at 25 ppm. For wheat grown in the Nunn soil, ratings were the same for all chemicals at each concentration with 1 for 0.5 ppm, 2 for 5 ppm, and 3 for 25 ppm.

Plant Growth -- The effects of chemicals and concentration on wheat growth parameters are given in Table 19 for the Ascalon soil and Table 20 for the Nunn soil. For both soils, there was no significant difference ($P > 0.05$) among chemicals on plant height, and the dry weight of roots and tops. A highly significant difference ($P < 0.01$) existed among concentrations for the same parameters which resulted from lower root and top growth at the high concentration level for the sulfoxide and sulfone in the Ascalon and all chemicals in the Nunn soil. The non-significant root and top reduction in dry weight from the high sulfide concentration level in the Ascalon soil was due to the lower initial soil concentration (10.5 ppm) as compared to the Nunn soil with 18.2 ppm, and about 24 ppm for the other chemicals in both soils. There was no difference ($P > 0.05$) between the control plants and the 0.5 and 5 ppm treatment levels for all chemicals and in both soils on plant height, and root and top dry weight. Plant height differences at the highest concentration probably resulted from slightly taller plants be-

Table 19. Concentration effect of soil incorporated ^{14}C labeled p-chlorophenyl methyl sulfide, sulfoxide, and sulfone on wheat grown in the Ascalon soil after 47 days.

Chemical	Initial soil concentration	Plants per pot†	Tops			Roots
			Height	Wet wt.	Dry wt.	Dry wt.
	— μg/g —		cm	———	g/pot	———
Sulfide	0	45	35a‡	47.3	12.4a	9.0a
	0.37	43	37b	48.6	13.2a	9.6a
	2.93	41	35a	48.6	12.7a	8.9a
	10.50	39	40ab	50.8	12.2a	8.4a
Sulfoxide	0	46	35a	51.2	13.4a	9.1a
	0.48	49	35a	52.1	14.3a	9.7a
	5.02	43	36a	50.1	13.7a	10.9a
	23.90	23	39a	35.3	7.7b	4.8b
Sulfone	0	50	35a	51.2	14.0a	9.4a
	0.46	44	35a	46.0	12.8a	9.2a
	4.76	44	37a	51.1	13.6a	10.9a
	23.70	19	39a	27.4	6.8b	3.7b

† Originally thinned to 5 plants per pot--these numbers represent total plants at the end of the experiment.

‡ Means followed by the same letter in each column within each chemical are not significantly different at 0.05 level (Tukey's test).

Table 20. Concentration effect of soil incorporated ^{14}C labeled p-chlorophenyl methyl sulfide, sulfoxide, and sulfone on wheat grown in the Nunn soil after 47 days.

Chemical	Initial soil concentration	Plants per pot†	Tops			Roots
			Height	Wet wt.	Dry wt.	Dry wt.
	µg/g		cm	g/pot		
Sulfide	0	39	38a‡	59.0	16.2a	8.8a
	0.42	41	39a	57.6	15.3a	7.8a
	4.07	32	40a	61.9	15.9a	6.7a
	18.20	22	43b	38.5	9.2b	3.4b
Sulfoxide	0	39	39a	57.8	15.0a	7.6a
	0.46	43	38a	57.5	15.4a	7.5a
	4.62	40	39a	56.4	15.0a	8.1a
	22.80	20	41a	41.5	9.2b	4.0b
Sulfone	0	42	39a	62.01	16.4a	9.3a
	0.47	39	38a	56.7	15.4a	7.9a
	4.71	35	38a	55.9	14.6a	7.1a
	24.20	20	42b	34.9	8.3b	3.2b

† Originally thinned to 5 plants per pot--these numbers represent total plants at the end of the experiment.

‡ Means followed by the same letter in each column within each chemical are not significantly different at 0.05 level (Tukey's test).

cause of less competition from fewer plants per pot, since tillering was considerably reduced.

In order to make comparisons among chemicals and between soils, an arbitrary 20% reduction of top dry weight as compared to the control was determined from best fit curves. For the Ascalon soil, the soil chemical concentration required for a 20% reduction was about 16 and 15 ppm for the sulfoxide and sulfone, respectively. The high soil concentration of the sulfide treatment (10.5 ppm) did not cause a 20% reduction in top growth. In the fine textured Nunn soil, the concentration for the same reduction was 13, 14, and 12 ppm for sulfide, sulfoxide, and sulfone, respectively. These values reflect the similarity of the chemicals in their phytotoxic effects on the growth of wheat.

Uptake of ^{14}C -- Total chemical uptake in tops and roots was calculated from ^{14}C measurements of plant material. Chemical uptake in the Ascalon and Nunn soils showed similar responses as related to chemical and concentrations, except significantly more ($P < 0.05$) was taken up from the Nunn than from the Ascalon soil (Tables 21 and 22 and Appendix Tables C-7 and C-8). Uptake by both tops and roots was significantly larger ($P < 0.05$) with each increasing soil concentration level. For example, the uptake of sulfoxide from the Ascalon soil at concentrations of 0.5, 5, and 25 was 214, 2,480, and 6,644 μg for tops and 46, 257, and 679 μg for roots, respectively. Total uptake (tops and roots), expressed as a percentage of the initial soil concentration, ranged from 15 to 32% for the Ascalon soil and from 22 to 43% for the Nunn soil. These results indicated that substantial amounts of the chemicals were absorbed by the roots from soil and were translocated to the tops. There was a significant difference ($P < 0.05$) among chemicals due to lower initial soil concentration levels in the sulfide treatment. There was no difference between the sulfoxide and sulfone chemicals on total uptake.

Chemical concentration in plant roots and tops increased with increasing soil concentrations (Tables 21 and 22). These calculations were made from total ^{14}C measurements assuming the activity remained as the parent compound. For wheat grown in the Nunn soil, there was a significant difference ($P < 0.05$) in root and top concentrations among soil concentrations within each chemical. In the Ascalon soil, root and top concentrations were statistically the same ($P > 0.05$) at the 0.5 and 5 ppm levels, and significantly higher at the 25 ppm level for sulfoxide and sulfone. The relationship between reduced root and top growth and chemical concentration in the plant material suggests that the chemicals are more toxic to roots than tops at a given soil concentration. For example, the sulfoxide treatment at the 25 ppm level in the Nunn soil showed a 38.7% reduction in top growth with the plant material containing 1091 μg/g of chemical, and the roots had a 47.4% reduction with a concentration level of 122 μg/g.

Total ^{14}C Recovery -- Total recovery values include residual ^{14}C in soil and ^{14}C activity in plant roots and tops. Recovery of ^{14}C in the Ascalon system showed a significant difference among chemicals ($P < 0.05$)

Table 21. Recovery of ^{14}C from plants and soils and the calculated concentration of the chemical in wheat after 47 days growth in an Ascalon soil amended with p-chlorophenyl methyl sulfide, sulfoxide, and sulfone.

Initial soil concentration†	Recovery of ^{14}C in soil	Total ^{14}C recovery	Total chemical uptake in plants		Chemical conc. in plants‡	
			Tops	Roots	Tops	Roots
— µg/g —	— % of initial —		— µg —		— µg/g —	
		Sulfide				
0.37	38.9	67.2a§	172	38	13.3a	4.2a
2.93	26.9	58.9b	1647	231	142ab	27.7b
10.50	28.9	48.9c	3780	410	312b	49.2b
		Sulfoxide				
0.48	39.9	67.0a	214	46	15.1a	4.7a
5.02	26.8	54.1b	2480	257	182a	23.9a
23.90	38.9	54.2b	6644	679	872b	142b
		Sulfone				
0.46	36.1	64.0a	197	60	15.5a	7.0a
4.76	29.8	58.2b	2409	296	176a	27.7a
23.70	47.9	62.6ab	6494	450	1007b	126b

† Concentration of chemicals applied were 0.5, 5, and 25 µg/g of soil with 2000 g of soil in each pot. These values represent the initial concentrations as determined by ^{14}C measurement of a combusted soil after solvent evaporation.

‡ Calculated chemical concentration based on ^{14}C measurements assuming activity remained as parent compound.

§ Means followed by the same letter in each column within each chemical are not significantly different at 0.05 level (Tukey's test).

Table 22. Recovery of ^{14}C from plants and soils and the calculated concentration of the chemical in wheat after 47 days growth in a Nunn soil amended with p-chlorophenyl methyl sulfide, sulfoxide, and sulfone.

Initial soil concentration†	Recovery of ^{14}C in soil	Total ^{14}C recovery	Total chemical uptake in plants		Chemical conc. in plants‡	
			Tops	Roots	Tops	Roots
— μg/g —	— % of initial —		— μg —		— μg/g —	
		Sulfide				
0.42	43.0	80.3a§	280	33	18.2a	4.3a
4.07	23.8	65.2b	3215	157	202b	23.6b
18.20	25.5	47.8c	7826	284	847c	85.6c
		Sulfoxide				
0.46	45.1	80.7a	289	39	18.9a	5.3a
4.62	24.7	67.5b	3761	197	251b	24.7b
22.80	28.8	52.0c	10008	483	1091c	122c
		Sulfone				
0.47	43.3	76.7a	274	39	17.9a	5.1a
4.71	26.4	68.9b	3787	217	259b	30.3b
24.20	33.9	58.9c	11616	489	1413c	156c

† Concentration of chemicals applied were 0.5, 5, and 25 μg/g of soil with 2000 g of soil in each pot. These values represent the initial concentrations as determined by ^{14}C measurement of a combusted soil after solvent evaporation.

‡ Calculated chemical concentration based on ^{14}C measurements assuming activity remained as parent compound.

§ Means followed by the same letter in each column within each chemical are not significantly different at 0.05 level (Tukey's test).

with a higher recovery from the sulfone treatment (Table 21). Concentration effects were highly significant ($P < 0.01$) and were not consistent among chemicals. In the Nunn soil, concentration ($P < 0.01$) and chemicals ($P < 0.05$) were significantly different and showed a definite trend of decreasing recovery with increased soil concentration levels (Table 22). The mean recovery values for all chemicals and concentrations were 59.5% from the Ascalon and 66.4% from the Nunn. After the 47 day cropping with wheat, residual ^{14}C soil activity was decreased to a range from 48 to 24% of the initial concentration.

Fescue

Toxicity Symptoms -- Visual phytotoxicity symptoms of fescue grown in the Ascalon soil amended with the test chemicals were an initial browning of the older leaf tips, followed by a bending of the dried-up dead tip, and finally a large section of the leaf would be twisted. Visual toxicity symptoms were the same for the three chemicals. Using a rating scale of 0 to 5, with 0 having no symptoms and 5 being a dead plant, the ranking was 1 for all chemicals at 0.5 ppm, 2 to 3 for 5 ppm, 3 for sulfide at 25 ppm, and a range of 3 to 5 for sulfoxide and sulfone at 25 ppm.

Plant Growth -- The effect of chemicals and concentrations on growth response of fescue is given in Table 23. Plant height was the same ($P > 0.05$) for all chemicals and concentrations, except for the 25 ppm level for sulfoxide and sulfone where there was a significant ($P < 0.05$) decrease in plant height as well as reduced tillering. Dry weight production of roots and tops generally decreased with increasing soil concentration levels in a near linear relationship. Statistically, there was a highly significant difference ($P < 0.01$) among concentrations for roots and tops, and a significant difference ($P < 0.01$) among chemicals in top weight. The significance among chemicals was due to the actual low concentration (10.5 ppm) of sulfide at the high concentration level as compared to 25 ppm for the other two chemicals. The significances among concentration levels resulted from a large decrease in root and top growth ($P < 0.05$) at the high concentration level, and generally no difference ($P > 0.05$) among the controls and the 0.5 and 5.0 ppm levels. Chemicals were more toxic to root growth than top growth by about 7%. Based on dry weight top production, a 20% reduction as compared to the control was found at 6, 7, and 6 ppm and for a 50% reduction at 13, 15, and 15 ppm for sulfide, sulfoxide, and sulfone, respectively. These values taken from best fit curve plots indicate that all chemicals have the same toxic effect on top growth.

Uptake of ^{14}C -- Total chemical uptake in roots and tops increased with increasing soil concentration levels (Table 24 and Appendix Table C-9). Total uptake data are somewhat misleading because of the rather severe toxicity of the sulfoxide and sulfone at the 25 ppm level which reduced root and top uptake and resulted in no difference ($P > 0.05$) between the 5 and 25 ppm levels for all chemicals. In addition, there was no difference

Table 23. Concentration effect of soil incorporated ^{14}C labeled p-chlorophenyl methyl sulfide, sulfoxide, and sulfone on fescue growth after 61 days.

Chemical	Initial soil concentration	Plants per pot†	Tops			Roots
			Height	Wet wt.	Dry wt.	Dry wt.
	— µg/g —		cm	————	g/pot	————
Sulfide	0	52	41a‡	39.5	11.3a	6.1a
	0.34	49	43a	34.1	10.2a	6.1a
	2.82	45	46a	30.7	9.7a	4.3ab
	10.50	37	44a	24.3	6.8b	2.9b
Sulfoxide	0	50	44a	35.2	10.3a	5.8a
	0.52	48	42a	32.5	11.3a	5.9a
	5.06	52	45a	30.0	9.5a	5.2a
	24.80	17	23b	4.4	1.5b	0.6b
Sulfone	0	51	41a	37.9	11.3a	7.1a
	0.50	48	41a	33.2	10.5a	5.9ab
	4.89	52	41a	28.0	9.0a	5.0b
	24.50	17	26b	6.1	2.0b	0.7c

† Originally thinned to 5 plants per pot, these numbers represent total plants at the end of the experiment.

‡ Means followed by the same letter in each column within each chemical are not significantly different at 0.05 level (Tukey's test).

Table 24. Recovery of ^{14}C from plants and soils and the calculated concentration of the chemical in fescue after 61 days in an Ascalon soil amended with p-chlorophenyl methyl sulfide, sulfoxide, and sulfone.

Initial soil concentration†	Recovery of ^{14}C in soil	Total ^{14}C recovery	Total chemical uptake in plants		Chemical conc. in plants‡	
			Tops	Roots	Tops	Roots
— μg/g —	— % of initial	—	— μg	—	— μg/g	—
		Sulfide				
0.34	34.2	56.2a§	144	6	14.0a	1.0a
2.82	22.6	41.3b	1032	20	107ab	4.6a
10.50	19.0	34.2b	3129	53	456b	18.0b
		Sulfoxide				
0.52	30.7	47.7a	170	7	15.0a	1.2a
5.06	21.5	41.8a	2014	43	214a	8.4a
24.80	43.3	48.2a	2376	69	1454b	126b
		Sulfone				
0.50	34.0	54.0a	193	7	18.4a	1.1a
4.89	26.9	43.7b	1604	42	180a	8.5a
24.50	47.7	54.5a	3244	93	1786b	128b

† Concentration of chemicals applied were 0.5, 5, and 25 μg/g of soil with 2000 g of soil in each pot. These values represent the initial concentrations as determined by ^{14}C measurement of a combusted soil after solvent evaporation.

‡ Calculated chemical concentration based on ^{14}C measurements assuming activity remained as parent compound.

§ Means followed by the same letter in each column within each chemical are not significantly different at 0.05 level (Tukey's test).

($P > 0.05$) between the 0.5 and 5 ppm levels but a significant difference ($P < 0.05$) between the 0.5 and 25 ppm levels. Uptake among chemicals was the same ($P > 0.05$) even though the initial soil concentration of sulfide was about one half the amount for the other two chemicals. This probably resulted from less plant toxicity in the sulfide treatment at lower concentration balancing out a higher soil concentration with the other two chemicals only with more plant injury. Based on a percentage of initial soil concentration, the amount recovered ranged from 15.2 to 22% for sulfide, 4.9 to 20.3% for sulfoxide, and 6.8 to 20% for sulfone.

Chemical concentration in fescue roots and tops (μg/g) increased as soil concentrations increased (Table 24). In all cases for roots and tops (except for the tops from the 2.8 ppm level), the 0.5 and 5 ppm levels showed no difference ($P > 0.05$), but considerably higher ($P < 0.05$) plant concentrations were found at the 25 ppm soil levels (10.5 ppm for sulfide). Plant concentration levels in the range from 1450 to 1790 μg/g for tops and 127 μg/g for roots coincided with severe visual toxicity symptoms, and a dry weight reduction of 83% for tops and 90% for roots.

Total ^{14}C Recovery -- Total recovery of ^{14}C from soil and plant material after a 61 day cropping with fescue is given in Table 24. Recovery values showed no consistent trends with respect to chemicals or concentration, and ranged from a low of 34% for the sulfide to 56%, also for the sulfide. Statistically, there were differences ($P < 0.01$) among chemicals, concentrations, and their interaction. The differences among chemicals were due to higher recoveries from the sulfone treatment with little difference between the sulfide and sulfoxide. In the treatments with sulfoxide and sulfone at 25 ppm, plant growth was severely reduced with only 5 to 7% of the chemical absorbed and 43 to 48% remaining in the soil. This showed that about half of these two chemicals were lost from the system with only a minimal amount of plant uptake.

Corn

Toxicity Symptoms -- Visual phytotoxicity symptoms induced by the chemicals were the same for the sulfide, sulfoxide, and sulfone. Initial symptoms were a browning or drying on the older leaf tips. With increased growth, the browning progressively moved down the leaf from tip to the stem. Using a rating scale of 0 to 5, with 0 having no symptoms and 5 being a dead plant, the ranking for corn after 34 days of growth was 0 for all chemicals at 0.5 ppm level, 1 for sulfide and sulfoxide and 2 for sulfone at the 5 ppm level, and 2 for sulfide and 3 for sulfoxide and sulfone at 25 ppm.

Plant Growth -- Plant height and dry weight production of roots and tops were the same ($P > 0.05$) for all chemicals (Table 25). Soil concentration levels had no effect ($P > 0.05$) on plant height for the three chemicals, but there was a significant difference ($P < 0.05$) among concentrations on dry weight yield which was due primarily to the low weight from

Table 25. Concentration effect of soil incorporated ^{14}C labeled p-chlorophenyl methyl sulfide, sulfoxide, and sulfone on corn growth after 34 days.

Chemical	Initial soil concentration	Tops			Roots
		Height	Wet wt.	Dry wt.	Dry wt.
	— µg/g —	cm	—	g/pot	—
Sulfide	0	70a†	84.3	12.8a	9.7a
	0.31	72a	86.8	13.2a	8.7a
	3.00	74a	89.4	13.4a	8.1a
	14.60	74a	84.7	12.3a	5.8b
Sulfoxide	0	70a	83.0	12.2a	8.6a
	0.49	69a	85.9	13.1a	9.2a
	5.05	74a	90.5	13.4a	8.3a
	26.30	74a	81.9	12.1a	5.4b
Sulfone	0	71a	84.7	12.9a	8.6a
	0.52	70a	85.4	13.0a	9.5a
	5.13	73a	87.6	13.1a	8.4a
	24.90	73a	69.5	10.2b	4.4b

† Means followed by the same letter in each column within each chemical are not significantly different at 0.05 level (Tukey's test).

the 25 ppm sulfone treatment. Increasing soil concentration levels of all chemicals consistently decreased root growth with the 25 ppm treatment (14.6 ppm for sulfide) being significantly less than the control and the other two concentration levels. From dry weight growth values and curve fitting, a 20% growth reduction as compared to the control was found at 25 ppm for the sulfone with the sulfide and sulfoxide not showing a 20% reduction at the soil concentrations used.

Uptake of ^{14}C -- Total chemical uptake in roots and tops increased with increasing soil concentration levels ($P < 0.01$), and was significantly different among chemicals ($P < 0.01$) (Table 26 and Appendix Table C-10). The soil concentration effect on chemical uptake was the same for the 0.5 and 5 ppm levels, but was significantly ($P < 0.05$) increased from the 25 ppm treatment. The differences among chemicals was due to lower plant uptake from the sulfide treatment because of the lower initial soil concentrations compared to the other chemicals. The amount of activity taken up by plant roots and tops expressed as percents of initial soil concentration ranged from 12 to 21% for sulfide, 13 to 23% for sulfoxide, and 15 to 26% for sulfone. These similar percentage uptake values for the three chemicals suggest the chemicals have the same absorption-translocation mechanism or the sulfide and sulfoxide are rapidly oxidized in soil and thus the plant response is influenced by only the sulfone in all cases.

Chemical concentration in corn roots and tops increased as soil chemical concentrations increased (Table 26). For all chemicals, there were no significant differences ($P > 0.05$) between 0.5 and 5 ppm treatments on chemical concentration in roots and tops. A significantly higher ($P < 0.05$) plant concentration existed for all chemicals at the high soil treatment level. Chemical concentration in plant material was also related to the chemical incorporated in the soil, as a significant difference ($P < 0.01$) existed among chemicals with the order of increasing plant concentration being sulfide, sulfoxide, and sulfone. As was the case with other crops, a considerably higher concentration was found in the tops than the roots. The ratio of tops to roots was fairly consistent for all chemicals with an average of 2.9 for all 0.5 levels and 5.4 for the 5 and 25 ppm levels.

Total ^{14}C Recovery -- Total recovery of ^{14}C from soil and plant material after 34 days of corn growth showed different trends for each chemical as a function of concentration (Table 26) even though there was no difference ($P > 0.05$) among chemicals. For sulfide, a significant decrease ($P < 0.05$) in recovery was obtained with each higher soil concentration level, while with the sulfone, no differences ($P > 0.05$) were found among soil concentrations. For sulfoxide, the 0.5 and 5 ppm treatments had the same recovery and there was a significant ($P < 0.05$) decrease at the high soil concentration level.

Table 26. Recovery of ^{14}C from plants and soils and the calculated concentration of the chemical in corn after 34 days in an Ascalon soil amended with p-chlorophenyl methyl sulfide, sulfoxide, and sulfone.

Initial soil concentration†	Recovery of ^{14}C in soil	Total ^{14}C recovery	Total chemical uptake in plants		Chemical conc. in plants‡	
			Tops	Roots	Tops	Roots
— µg/g —	— % of initial	—	— µg	—	— µg/g	—
		Sulfide				
0.31	57.9	70.2a§	60	17	4.5a	1.9a
3.00	42.6	63.6b	1146	113	85.8a	14.0a
14.60	33.0	53.8c	5519	564	453b	98.7b
		Sulfoxide				
0.49	51.7	64.8a	104	24	7.9a	2.6a
5.05	41.5	61.0a	1757	211	132a	25.6a
26.30	29.9	52.8b	10993	1052	903b	197b
		Sulfone				
0.52	48.0	62.8a	125	29	9.6a	3.0a
5.13	40.0	60.4a	1888	205	144a	24.3a
24.90	37.0	63.4a	12250	896	1323b	225b

† Concentration of chemicals applied were 0.5, 5, and 25 µg/g of soil with 2000 g of soil in each pot. These values represent the initial concentrations as determined by ^{14}C measurement of a combusted soil after solvent evaporation.

‡ Calculated chemical concentration based on ^{14}C measurements assuming activity remained as parent compound.

§ Means followed by the same letter in each column within each chemical are not significantly different at 0.05 level (Tukey's test).

Sugarbeets

Toxicity Symptoms -- Phytotoxic symptoms were the same for the three chemicals. Initial symptoms were a browning or dying of the older leaf tips, and with increased growth, the browning progressively moved down the leaf. No phytotoxic symptoms were noticed on the 0.5 ppm treatments, 1 to 1^{+} for the 5 ppm, and a range from 3 to 5 for the 25 ppm treatment with mostly 5's for sulfoxide and sulfone.

Plant Growth -- Plant height showed a significant difference ($P < 0.01$) among chemicals which was due to more growth at the high soil concentration level from the sulfide treatment (11.6 ppm) as compared to 25 ppm for the sulfoxide and sulfone (Table 27). No differences ($P > 0.05$) were found among chemicals in dry weight production of roots and tops, and highly significant differences ($P < 0.01$) among concentrations. The concentration effect was consistent for plant height, top weight, and root weight with no differences between the control and the 0.5 and 5 ppm levels, and 25 ppm level (11.6 ppm for sulfide) showing a significant ($P < 0.05$) decrease in all three parameters. Based on dry weight yield of top growth and curve fitting, a 20% reduction as compared to the control was found at about 4, 8, and 10 ppm and a 50% reduction required about 9, 15, and 16 ppm for sulfide, sulfoxide, and sulfone, respectively. These plots were near linear, and the values obtained from these plots indicate considerably more toxicity from the sulfide and about the same effect from the sulfoxide and sulfone.

Uptake of ^{14}C -- Total chemical uptake by roots and tops was concentration dependent (Table 28 and Appendix Table C-11). Chemical uptake in tops from the 5 ppm treatment was significantly ($P < 0.05$) larger than that at 0.5 level for all chemicals, with no difference among chemicals. At the high soil concentration levels, there was no sugarbeet growth in the sulfoxide treatment (25 ppm), very little growth and very little uptake of sulfone at 25 ppm, and more total top uptake of sulfide at the 11.6 ppm level than the lower soil concentration levels.

Chemical concentration increased with increasing soil concentration levels (Table 28). Concentration levels in the tops were not significantly different ($P > 0.05$) between the 0.5 and 5 ppm levels for all chemicals, but there was a substantial ($P < 0.05$) increase at the high soil concentration for sulfide (11.6 ppm) and sulfone (25 ppm). Root concentrations were significantly ($P < 0.05$) increased from the 0.5 to the 5 ppm level with no difference among chemicals. The ratio of concentration of tops to roots was fairly consistent among chemicals with an average of 11.2.

Total ^{14}C Recovery -- Total recovery of ^{14}C from soil and plant materials after 51 days of sugarbeet growth ranged from 40 to 65% with no differences ($P > 0.05$) among chemicals (Table 28). Within chemicals, recoveries were the same for all sulfide concentrations, and for sulfoxide and sulfone, higher recoveries ($P < 0.05$) were obtained from the 0.5 and 25 ppm levels than from

Table 27. Concentration effect of soil incorporated ^{14}C labeled p-chlorophenyl methyl sulfide, sulfoxide, and sulfone on sugarbeet growth after 51 days.

Chemical	Initial soil concentration	Tops			Roots
		Height	Wet wt.	Dry wt.	Dry wt.
	µg/g	cm	g/pot		
Sulfide	0	23a†	39.9	6.9a	2.5a
	0.41	22a	41.5	8.0a	4.0a
	3.41	21a	38.6	6.3a	2.8a
	11.60	15b	15.5	2.3b	0.5b
Sulfoxide	0	23a	44.5	7.9a	3.8a
	0.49	23a	46.9	8.2a	3.6a
	5.02	22a	42.6	6.9a	2.7a
	24.20	3b	-‡	0.1b	0.0b
Sulfone	0	21a	40.2	7.1a	3.4a
	0.49	24a	44.9	7.8a	4.1a
	5.02	23a	44.8	7.5a	3.0a
	25.50	7b	-‡	0.4b	0.0b

† Means followed by the same letter in each column within each chemical are not significantly different at 0.05 level (Tukey's test).

‡ Plants died and dried in the pots.

Table 28. Recovery of ^{14}C from plants and soils and the calculated concentration of the chemical in sugarbeets after 51 days in an Ascalon soil amended with p-chlorophenyl methyl sulfide, sulfoxide, and sulfone.

Initial soil concentration†	Recovery of ^{14}C in soil	Total ^{14}C recovery	Total chemical uptake in plants		Chemical conc. in plants‡	
			Tops	Roots	Tops	Roots
— µg/g —	— % of initial —		— µg —		— µg/g —	
		Sulfide				
0.41	34.5	59.6a§	197	9	26.1a	2.5a
3.41	28.6	47.6a	1248	49	207a	19.2b
11.60	43.4	51.4a	1833	14	883b	20.1b
		Sulfoxide				
0.49	30.5	58.7a	266	10	32.2a	3.0a
5.02	22.6	39.6b	1647	60	245a	22.8b
24.20	65.2	65.2a	-	-	-	-
		Sulfone				
0.49	30.8	59.7a	273	10	35.1a	2.5a
5.02	23.6	41.3b	1717	64	230a	21.7b
25.50	55.7	57.0a	663	-	1481b	-

† Concentration of chemicals applied were 0.5, 5, and 25 µg/g of soil with 2000 g of soil in each pot. These values represent the initial concentrations as determined by ^{14}C measurement of a combusted soil after solvent evaporation.

‡ Calculated chemical concentration based on ^{14}C measurements assuming activity remained as parent compound.

§ Means followed by the same letter in each column within each chemical are not significantly different at 0.05 level (Tukey's test).

the 5 ppm level. The overall average recovery was 53.3% which included a 65.2% recovery for the sulfoxide (25 ppm) where there was no plant uptake.

Alfalfa

Toxicity Symptoms -- Visual phytotoxic symptoms were the same for the sulfide, sulfoxide, and sulfone. The first symptoms started with the older leaves showing a bleached or white tip, and with further growth, the whiteness continued to move down the leaf. Using a ranking scale of 0 to 5, with 0 having no symptoms and 5 being a dead plant, the ranking of symptoms was 0 for the 0.5 ppm treatment, 2 for sulfide and 3 for sulfoxide and sulfone at 5 ppm, and mostly 5's for the 25 ppm level.

Plant Growth -- Plant height and dry weight production of roots and tops showed no significant differences ($P > 0.05$) among chemicals and a highly significant difference ($P < 0.01$) among concentrations (Table 29). The general trend was a decrease in plant height with increasing soil concentration. There were no significant differences ($P > 0.05$) among the control, 0.5, and 5 ppm treatments on plant height for sulfide and sulfone, but a significant difference between the 5 and 25 ppm level for the sulfoxide. At 25 ppm (17.3 ppm for sulfide), all chemicals had shown a drastic reduction in plant height. Dry weight of tops and roots was the same ($P > 0.05$) for the control and 0.5 ppm treatment, with a significant decrease from the 0.5 to the 5ppm level, and a further decrease ($P > 0.05$) from the 5 to 25 ppm level. From top weight yield and curve fitting, a 20% reduction as compared to the control was found at about 5, 3, and 6 ppm and for a 50% reduction at about 10, 7, and 11 ppm for sulfide, sulfoxide, and sulfone, respectively. These plots were fairly linear, and these values suggest that the chemicals behaved similarly with possibly a little more toxicity from the sulfoxide.

Uptake of ^{14}C -- Total chemical uptake in tops was less ($P < 0.05$) from the sulfide treatment than the sulfoxide and sulfone which was probably due in part to the lower initial soil concentration level (Table 30 and Appendix Table C-12). For root uptake, there was no difference ($P > 0.05$) among chemicals. Total uptake values for the high soil concentration levels are meaningless because of their extreme toxicity to root and top growth which resulted in 0.1 g or less in dry matter production. Significant increases ($P < 0.05$) in chemical uptake were found in tops and roots for all chemicals from the 0.5 and 5 ppm treatment.

Chemical concentration in roots and tops increased with increasing soil concentration levels with a range of 9 μg/g from a 0.5 ppm level to 641 μg/g for a high treatment level (Table 30). Plant top concentrations were the same for the 0.5 and 5 ppm treatments, with an increase ($P < 0.05$) in concentration at the 25 ppm level over the 0.5 ppm treatment. For plant roots, an increase ($P < 0.05$) in concentration was found from the 0.5 to 5 ppm level with insufficient samples for analysis of the high treatment level.

Table 29. Concentration effect of soil incorporated ^{14}C labeled *p*-chlorophenyl methyl sulfide, sulfoxide, and sulfone on alfalfa growth after 51 days.

Chemical	Initial soil concentration	Plants per pot†	Tops			Roots
			Height	Wet wt.	Dry wt.	Dry wt.
	— µg/g —		cm	———	g/pot	———
Sulfide	0	12	42a‡	24.5	6.6a	3.9a
	0.40	10	41a	24.5	6.9a	3.6a
	3.76	10	38a	21.0	5.7b	2.4b
	17.30	5	5b	0.3	0.1c	0.02c
Sulfoxide	0	11	44a	25.8	6.8a	3.9a
	0.47	11	41a	24.4	6.8a	3.7a
	4.81	11	34b	15.2	4.1b	1.7b
	23.70	5	4c	0.1	0.1c	0.0c
Sulfone	0	10	40a	24.3	6.3ab	3.8a
	0.48	10	41a	25.3	7.3a	3.3a
	4.84	11	35a	20.2	5.6b	2.0b
	23.90	5	4b	0.3	0.1c	0.1c

† Originally thinned to 5 plants per pot--these numbers represent total plants at the end of the experiment.

‡ Means followed by the same letter in each column within each chemical are not significantly different at 0.05 level (Tukey's test).

Table 30. Recovery of ^{14}C from plants and soils and the calculated concentration of the chemical in alfalfa after 51 days in an Ascalon soil amended with p-chlorophenyl methyl sulfide, sulfoxide, and sulfone.

Initial soil concentration†	Recovery of ^{14}C in soil	Total ^{14}C recovery	Total chemical uptake in plants		Chemical conc. in plants‡	
			Tops	Roots	Tops	Roots
— µg/g —	— % of initial	—	— µg	—	— µg/g	—
		Sulfide				
0.40	41.6	49.9ab§	60	7	8.9a	1.9a
3.76	29.1	42.4a	963	41	169a	17.3b
17.30	58.9	59.1b	59	0	641b	0
		Sulfoxide				
0.47	39.0	48.3a	78	9	11.7a	2.5a
4.81	30.1	44.8a	1356	55	335ab	33.0b
23.70	65.0	65.1b	52	-	419b	-
		Sulfone				
0.48	38.8	46.8a	69	7	9.4a	2.1a
4.84	31.0	42.9a	1113	39	203ab	20.5b
23.90	68.9	69.0b	57	-	541b	-

† Concentration of chemicals applied were 0.5, 5, and 25 µg/g of soil with 2000 g of soil in each pot. These values represent the initial concentrations as determined by ^{14}C measurement of a combusted soil after solvent evaporation.

‡ Calculated chemical concentration based on ^{14}C measurements assuming activity remained as parent compound.

§ Means followed by the same letter in each column within each chemical are not significantly different at 0.05 level (Tukey's test).

Total ^{14}C Recovery -- Total recovery of ^{14}C from soil and plant material calculated as a percentage of initial soil concentration is given in Table 30. Highly significant differences ($P < 0.01$) existed among concentrations, but there were no differences ($P > 0.05$) among chemicals. Total recovery values were fairly consistent for all chemicals with the highest recovery from the 25 ppm (17.3 ppm for sulfide) treatment (average of 64.4%), which was essentially without plant growth, to the lowest recovery from the 5 ppm level (average of 43.4%).

Plant Bioconcentration

The plant's ability to absorb and concentrate chemicals in excess of the soil chemical concentration is termed bioconcentration. In this study the bioconcentration factor was calculated by dividing the chemical concentration of the plant tissue by the initial soil chemical concentration. Bioconcentration was found in all crops and for all chemicals (Table 31). Considering all crops at all soil concentration levels, there was very little difference among chemicals on bioconcentration. A considerable amount of variability existed among crops and within concentrations for a specific crop. The consistent trend was much larger bioconcentration in plant tops than in the roots. Considering all plants and chemicals, the bioconcentration factor was 7.5 times higher for tops than roots. The mean bioconcentration values for tops were 28, 34, 37, 44, 48, and 62, and for roots 6, 5, 8, 3, 7, and 5 for corn, alfalfa, wheat (Ascalon soil), fescue, wheat (Nunn soil), and sugarbeets, respectively. These results indicate that all three chemicals were absorbed, translocated, and concentrated primarily in the tops of all five plant species. The bioconcentration values were obtained from the chemical concentration in plant material which was determined from total ^{14}C recovery from a dry combustion measurement. Therefore, there is no assurance that the activity is associated with the parent compound or as metabolites.

Soil Concentration and Plant Top Concentration

The evaluation of chemicals and soil concentration levels on top growth reduction and chemical concentration of the tops was made from plots of top growth and plant concentration as a function of initial soil concentrations. From these curves, the soil concentration required for a given top reduction (20 and 50%), and the corresponding chemical concentration of the tops at these same reduction levels were determined. After finding the soil concentration for a specific reduction, then using that value and reading off a soil concentration versus plant chemical concentration curve, the chemical concentration of the tops was obtained for a specific reduction level (Table 32). These data show that similar soil concentration levels of each chemical within the same crop species caused the same reduction in top growth and a correspondingly similar chemical concentration in the plant top. There was a considerable difference in the soil concentration required for a given top reduction among plant species. For example, alfalfa (the most sensitive crop) showed a 20% top reduction from a soil concentration of about 5 ppm

Table 31. Root and top bioconcentration factors calculated by dividing plant concentration by initial soil concentration for five crops at three soil concentration levels.

Plant	Soil concentration†	Plant bioconcentration factor					
		Sulfide		Sulfoxide		Sulfone	
		Tops	Roots	Tops	Roots	Tops	Roots
Alfalfa	L	22	5	25	5	20	4
	M	45	5	70	7	42	4
	H	37	-‡	18	-	23	-
Corn	L	15	6	16	5	19	6
	M	29	5	26	5	28	5
	H	31	7	34	8	53	9
Fescue	L	41	3	29	2	37	2
	M	38	2	42	2	37	2
	H	43	2	59	5	73	5
Sugarbeets	L	64	6	66	6	72	5
	M	61	6	49	5	46	4
	H	76	2	-	-	58	-
Wheat							
Ascalon soil	L	36	11	32	10	34	15
	M	49	10	36	5	37	6
	H	30	5	37	6	43	5
Nunn soil	L	43	10	41	12	38	11
	M	50	6	54	5	55	6
	H	47	5	48	5	58	7

† Soil concentration for sulfoxide and sulfone were: L = 0.5 μg/g, M = 5.0 μg/g, and H = 25 μg/g, and for the sulfide the range was L = 0.31-0.42 μg/g, M = 2.82-4.07 μg/g, and H = 10.5-18.2 μg/g.

‡ Insufficient sample.

Table 32. Soil and plant top concentration required for 20 and 50% reduction in dry weight production of plant tops.

Plant	Chemical	Concentration required for growth reduction of --			
		20%		50%	
		Soil	Tops	Soil	Tops
		µg/g			
Alfalfa	Sulfide	5	212	10	390
	Sulfoxide	3	200	7	390
	Sulfone	6	235	11	370
Corn	Sulfide	-†	-	-	-
	Sulfoxide	-	-	-	-
	Sulfone	25	1320	-	-
Fescue	Sulfide	6	247	13‡	556‡
	Sulfoxide	7	296	15	669
	Sulfone	6	206	15	635
Sugarbeets	Sulfide	4	270	9	612
	Sulfoxide	8‡	491‡	15‡	788‡
	Sulfone	10	375	16	694
Wheat					
Ascalon soil	Sulfide	-	-	-	-
	Sulfoxide	16	560	28‡	966‡
	Sulfone	15	557	26‡	1044‡
Nunn soil	Sulfide	14	642	20	911
	Sulfoxide	14	685	29‡	1179‡
	Sulfone	12	685	26‡	1479‡

† Soil chemical concentration not high enough to cause top growth reduction.

‡ Values obtained from extrapolated curves.

with a plant concentration of 216 μg/g. Whereas corn (the least sensitive crop) showed a 20% top reduction from a soil sulfone concentration of 25 ppm with a plant concentration of 1320 μg/g. This indicates that there was not only a relationship between soil concentration and plant concentration, but also the levels of plant concentration varied widely between plant species for a given growth reduction.

A linear relationship exists between soil chemical concentration and plant root and top concentrations. A highly significant correlation coefficient for these two parameters was $r = 0.911$ for tops and $r = 0.949$ for roots. The basic linear regression equation was $y = mx + b$ with y = plant chemical concentration (μg/g), m = slope, x = soil chemical concentration, and b = intercept. Using all crops and all soil concentrations, the predictive equation for plant tops is $y = 45.84(x) - 8.21$ and for roots $y = 6.17(x) - 4.41$. This close relationship between soil concentration and plant concentration, using data from all crops, makes it possible to predict plant concentrations from a soil of known chemical concentration. Soils of different physical and chemical properties would no doubt have some effect as shown in the growth of wheat in an Ascalon sandy loam and Nunn loam in this study.

The similarity of the sulfide, sulfoxide, and sulfone on a number of plant growth responses suggests the chemicals exhibit the same mechanism for plant toxicity and uptake or the sulfide and sulfoxide are rapidly converted to the sulfone. In the latter case, the plants would actually be responding to only one chemical, the sulfone. The soil from one replicate of the 25 ppm treatment of sulfide, sulfoxide, and sulfone after sugarbeet harvest was extracted and the compounds were separated by thin layer chromatography. From the sulfide treated soil, 92% of the activity was detected as the sulfone with only background levels of sulfide and sulfoxide. The extract from the sulfoxide treated soil contained 95% sulfone, 3.1% sulfoxide, and below background for the sulfide. The sulfone treatment consisted of only the sulfone in the soil extract. These few extracts with only semiquantitative results showed near complete conversion of the sulfide and sulfoxide to the sulfone during the 51 day growth period, but the rate of conversion remains unanswered.

Summary

A greenhouse experiment was conducted to determine the effect of soil concentration levels of ^{14}C-ring labeled p-chlorophenyl methyl sulfide, sulfoxide, and sulfone on growth and ^{14}C uptake by alfalfa, corn, fescue, sugarbeets, and wheat. The amount of uptake was determined by a measurement of ^{14}C activity, and the data expressed as a function of the initial soil concentration measured after chemical application. Visual phytotoxic symptoms were similar for all plant species with initial injury appearing on the tip of the older leaves and progressively moving down the leaf with continued growth. Phytotoxic symptoms were the same for all chemicals.

Generally, there was more reduction in root responses as a function of chemicals and soil concentrations than in tops; but these differences were not always reflected at the 95% statistical confidence level. Significant decreases ($P < 0.05$) were found in dry weight top production for all chemicals at the 25 ppm level for wheat, fescue, and sugarbeets, at 5 ppm for alfalfa, and at 25 ppm for corn in only the sulfone treatment. Soil concentration levels for significant ($P < 0.05$) decreases in root production were the same as for tops in wheat, sugarbeets, and alfalfa, but a significant decrease in corn root production occurred at 25 ppm with all chemicals. In order to make comparisons among chemicals and plant species with respect to soil concentration levels, the soil concentration levels required for 20 and 50% reduction in top growth were determined from best fit curves. The 20% reduction in top growth appears to be representative of the level where significant differences ($P < 0.05$) occurred. Soil concentration levels (mean of three chemicals) causing a 20% reduction in top growth were 4.7, 6.3, 7.3, 13.3, 15.5, and 25 (sulfone) ppm for alfalfa, fescue, sugarbeets, wheat (Nunn soil), wheat (Ascalon soil), and corn, respectively.

Chemical concentration in plant tissue increased with increasing soil chemical concentration. In general, a significant increase ($P < 0.05$) in chemical concentration of plant tops occurred between the 5 and 25 ppm treatments for all crops except for wheat grown in the Nunn soil where a significant increase occurred between the 0.5 and 5 ppm levels. The same trend existed in roots for wheat, fescue, and corn, but a significant increase was found from the 0.5 and 5 ppm treatments for sugarbeets and alfalfa. Chemical concentration in plant tops at a 20% reduction in top growth was nearly the same for all chemicals within each plant species. Plant top concentrations at a 20% reduction in growth (mean of all chemicals) were 216, 250, 379, 559, 671, and 1320 ppm for alfalfa, fescue, sugarbeets, wheat (Ascalon soil), wheat (Nunn soil), and corn, respectively. A definite relationship existed between soil chemical concentration and the chemical concentration in plant tops and roots. The linear correlation coefficient for these two parameters was $r = 0.911^{**}$ for tops and $r = 0.949^{**}$ for roots.

The ability of plants to take up and concentrate chemicals at a level higher than the soil concentration is referred to as bioconcentration. All plants at all soil concentrations accumulated the three chemicals in tops and roots. The mean bioconcentration values for tops were 28, 34, 37, 44, 48, and 62, and for roots 6, 5, 8, 3, 7, and 5 for corn, alfalfa, wheat (Ascalon soil), fescue, wheat (Nunn soil), and sugarbeets, respectively.

VI. CONCLUSIONS

Research was conducted to study p-chlorophenyl methyl sulfide, sulfoxide, and sulfone in relation to degradation in soil, plant toxicity and uptake and translocation of the foliar applied chemicals. Translocation of foliar applied diisopropyl methyl phosphonate (DIMP) was also evaluated in corn and sugarbeets.

Sulfide, sulfoxide, and sulfone applied at soil concentrations of 0.5 and 5 ppm had no effect on total CO_2 production, but a significant reduction resulted from the 50 ppm treatments. The amount of complete degradation of the chemicals was determined by measuring evolved $^{14}CO_2$ from ^{14}C ring labeled compounds. The rate of degradation determined from $^{14}CO_2$ evolved and expressed as nanograms of chemical/day ranged from 7 to 17 at 0.5 ppm, 30 to 108 at 5 ppm, and 106 to 711 at 50 ppm. However, the total amount of $^{14}CO_2$ evolved during the 160 day period decreased with increasing concentration and ranged from 5 to 17%.

There was no translocation of foliar applied sulfide, sulfoxide, and sulfone in corn or sugarbeets. A considerable amount of the chemicals was volatilized and the remaining ^{14}C activity was associated with the target leaf. After 24 hours, the activity recovered from the target leaf was 0.7, 6.8, and 21.6% in corn, and 8.7, 29.8, and 41.4% in sugarbeets for sulfide, sulfoxide, and sulfone, respectively. DIMP was not translocated in corn and only 3.7% of the activity was recovered from the target leaf after 24 hours. For sugarbeets during the same period, a very small amount was translocated (0.5%), 91% being volatilized, and 8.5% associated with the leaf of application.

A greenhouse experiment was conducted to determine the effects of soil concentrations of sulfide, sulfoxide, and sulfone on the growth and uptake by five plant species. Visual phytotoxic symptoms were the same for all chemicals and similar for all plant species. Initial injury occurred on the tip of older leaves and progressively moved down the leaf with continued growth. Severity increased with increasing concentration and varied among plants at a given soil concentration. Generally, there was more reduction in root growth than top growth at a given soil concentration, and there were very few differences among chemicals. Soil and tissue concentrations required for 20% reduction in top growth were determined from best fit curves. Soil concentration levels (mean of three chemicals) causing this degree of reduction in top growth were 4.7, 6.3, 7.3, 13.3, 15.5, and 25 (sulfone) ppm, and the corresponding tissue concentrations were 216, 250, 379, 671, 559, and 1320 μg/g for alfalfa, fescue, sugarbeets, wheat (Nunn soil), wheat (Ascalon soil), and corn, respectively. Chemical concentration in plant tissue increased with increasing concentration of the chemicals in soil and resulted in a highly significant linear correlation coefficient for roots ($r = 0.949$) and tops ($r = 0.911$). In general, a significant increase in chemical concentration in plant tops occurred between the 5 and 25 ppm treatments for all crops. Considering all crops at all soil concentrations, bioconcentration was about the same among chemicals, and varied among crops and within concentrations for a specific crop. The mean bioconcentrations for tops were 28, 34, 37, 44, 48, and 62, and for roots 6, 5, 8, 3, 7, and 5 for corn, alfalfa, wheat (Ascalon soil), fescue, wheat (Nunn soil), and sugarbeets, respectively. These studies showed that the three chemicals amended to soil were absorbed, translocated, and concentrated in the tissue of five plant species. The concentration of the chemicals in soil causing similar growth reduction varied among the five plant species. Alfalfa was most susceptible to injury and corn was least susceptible at a given concentration.

APPENDIX A

CO_2, $^{14}CO_2$, AND RESIDUAL ^{14}C IN SOIL DEGRADATION STUDIES

Table A-1. Total CO_2 and $^{14}CO_2$ production from an Ascalon soil amended with p-chlorophenyl methyl sulfide during a 160-day incubation period.

Incubation Period	Reps	Total CO_2 production at concentrations (μg/g)† of				$^{14}CO_2$ production at concentrations (μg/g)† of		
		0	0.5	5	50	0.5	5	50
days		mg C/20 g soil				% of initial‡		
0-10	1	3.04	3.21	3.73	3.18	1.31	0.73	0.63
	2	3.21	3.49	3.08	3.25	1.01	0.78	0.53
	3	3.33	2.99	3.13	3.23	1.56	1.46	0.59
	Mean	3.19	3.23	3.31	3.22	1.29	0.99	0.58
10-20	1	2.00	2.28	2.06	1.86	2.06	1.04	1.01
	2	2.01	2.33	2.03	1.90	2.12	1.06	0.95
	3	2.04	2.19	1.94	1.73	2.01	1.12	1.09
	Mean	2.02	2.27	2.01	1.83	2.06	1.07	1.02
20-40	1	2.77	2.83	2.70	2.13	2.24	1.34	0.91
	2	2.72	3.29	2.57	2.02	2.64	1.27	0.94
	3	2.78	2.91	2.59	1.82	2.16	1.53	0.94
	Mean	2.76	3.01	2.62	1.99	2.35	1.38	0.93
40-80	1	4.58	5.48	4.82	3.07	3.55	2.01	1.06
	2	5.08	5.31	4.14	3.60	4.73	1.92	1.11
	3	4.66	4.72	4.37	2.78	3.02	2.78	1.12
	Mean	4.77	5.17	4.44	3.15	3.77	2.24	1.10
80-160	1	7.00	9.37	8.69	3.94	6.84	3.75	1.54
	2	9.73	9.29	7.93	6.36	9.39	3.47	1.99
	3	7.29	6.53	6.87	3.69	5.54	4.85	1.77
	Mean	8.01	8.40	7.83	4.66	7.26	4.02	1.77
	Total	20.75	22.08	20.21	14.85	16.73	9.70	5.40

† Concentration of chemical applied, but initial ^{14}C measurements showed initial concentrations to be 0.36, 3.00, and 23.9 μg/g of soil.

‡ Values are percentages of initial concentration in soil.

Table A-2. Total CO_2 and $^{14}CO_2$ production from an Ascalon soil amended with p-chlorophenyl methyl sulfoxide during a 160-day incubation period.

Incubation Period	Reps	Total CO_2 production at concentrations (µg/g)† of				$^{14}CO_2$ production at concentrations (µg/g)† of		
		0	0.5	5	50	0.5	5	50
days		mg C/20 g soil				% of initial‡		
0-10	1	3.04	3.71	3.25	3.40	0.87	0.78	0.32
	2	3.21	3.35	3.42	3.11	1.05	0.79	0.29
	3	3.33	3.20	3.06	3.10	0.91	0.93	0.31
	Mean	3.19	3.42	3.24	3.20	0.94	0.83	0.31
10-20	1	2.00	2.34	1.91	1.67	1.80	1.24	0.82
	2	2.01	2.18	2.01	1.56	1.52	1.11	0.71
	3	2.04	2.04	1.86	1.66	1.62	1.29	0.72
	Mean	2.02	2.19	1.93	1.63	1.65	1.21	0.75
20-40	1	2.77	3.00	2.46	2.03	2.10	1.50	1.22
	2	2.72	2.90	2.41	1.98	2.01	1.45	1.22
	3	2.78	2.75	2.24	2.09	1.80	1.48	1.26
	Mean	2.76	2.88	2.37	2.03	1.97	1.48	1.23
40-80	1	4.58	5.15	4.52	2.43	4.37	2.51	1.92
	2	5.08	4.96	4.86	2.56	5.28	2.71	1.59
	3	4.66	4.71	3.66	2.60	3.17	2.34	2.00
	Mean	4.77	4.94	4.35	2.53	4.27	2.52	1.84
80-160	1	7.00	8.90	7.29	3.14	7.05	4.99	2.09
	2	9.73	8.44	9.33	3.22	9.87	5.18	1.77
	3	7.29	7.46	4.75	3.22	4.91	3.73	2.17
	Mean	8.01	8.27	7.12	3.19	7.28	4.63	2.01
	Total	20.75	21.70	19.01	12.58	16.11	10.67	6.14

† Concentration of chemical applied, but initial ^{14}C measurements showed initial concentrations to be 0.47, 4.77, and 47.4 µg/g of soil.

‡ Values are percentages of initial concentration in soil.

Table A-3. Total CO_2 and $^{14}CO_2$ production from an Ascalon soil amended with *p*-chlorophenyl methyl sulfone during a 160-day incubation period.

Incubation Period	Reps	Total CO_2 production at concentrations (μg/g)† of				$^{14}CO_2$ production at concentrations (μg/g)† of		
		0	0.5	5	50	0.5	5	50
days		mg C/20 g soil				% of initial‡		
0-10	1	3.04	3.30	3.11	3.39	1.10	0.58	0.37
	2	3.21	3.49	3.11	3.32	1.08	0.78	0.36
	3	3.33	3.21	3.61	3.20	1.00	0.73	0.34
	Mean	3.19	3.33	3.28	3.30	1.06	0.69	0.36
10-20	1	2.00	2.32	1.97	1.93	1.77	1.15	0.64
	2	2.01	2.28	2.04	1.94	1.82	0.96	0.56
	3	2.04	2.07	2.07	2.15	1.84	0.90	0.61
	Mean	2.02	2.22	2.03	2.01	1.81	1.00	0.60
20-40	1	2.77	3.12	2.42	2.25	1.80	1.42	0.78
	2	2.72	3.17	2.72	2.35	1.81	1.20	0.76
	3	2.78	2.76	2.66	2.42	2.12	1.30	0.81
	Mean	2.76	3.02	2.60	2.34	1.91	1.31	0.78
40-80	1	4.58	5.02	4.31	2.74	2.71	2.23	1.26
	2	5.08	5.02	4.37	2.76	2.79	2.29	1.20
	3	4.66	4.69	4.16	2.83	4.88	2.51	1.26
	Mean	4.77	4.91	4.28	2.78	3.46	2.34	1.24
80-160	1	7.00	7.21	6.32	3.14	4.15	4.15	1.86
	2	9.73	8.42	5.34	3.35	4.71	3.11	1.69
	3	7.29	7.53	5.26	3.82	7.30	3.54	2.22
	Mean	8.01	7.72	5.64	3.44	5.39	3.60	1.92
	Total	20.75	21.20	17.83	13.87	13.63	8.94	4.9

† Concentration of chemical applied, but initial ^{14}C measurements showed initial concentrations to be 0.48, 4.77, and 48.9 μg/g of soil.

‡ Values are percentages of initial concentration in soil.

Table A-4. Recovery of ^{14}C from an Ascalon soil amended with ring labeled ^{14}C p-chlorophenyl methyl sulfide during a 160-day incubation period.

Incubation	Reps	Recovery of ^{14}C from soil at concentrations (μg/g)† of		
		0.5	5	50
days		% of initial‡		
10	1	102.7	102.2	96.4
	2	99.4	88.9	83.8
	3	93.9	85.7	64.7
	Mean	98.7	92.3	81.6
20	1	84.4	73.3	57.9
	2	81.0	77.3	57.0
	3	81.6	83.5	58.1
	Mean	82.3	78.0	57.7
40	1	80.0	69.3	57.0
	2	76.4	70.9	50.4
	3	84.4	77.7	46.8
	Mean	80.3	72.6	51.4
80	1	75.9	61.7	48.8
	2	66.7	69.0	52.3
	3	78.2	71.5	45.6
	Mean	73.6	67.4	48.9
160	1	70.1	55.9	45.8
	2	58.5	58.6	44.8
	3	68.5	67.4	45.4
	Mean	65.7	60.6	45.3

† Concentration of chemical applied, but initial ^{14}C measurements showed initial concentration to be 0.36, 3.00, and 23.9 μg/g of soil.

‡ Values are percentages of initial concentration in soil.

Table A-5. Recovery of ^{14}C from an Ascalon soil amended with ring labeled ^{14}C p-chlorophenyl methyl sulfoxide during a 160-day incubation period.

Incubation	Reps	Recovery of ^{14}C from soil at concentrations (μg/g)† of		
		0.5	5	50
days		% of initial‡		
10	1	103.2	105.8	95.7
	2	101.2	106.3	93.9
	3	90.9	106.6	89.6
	Mean	98.4	106.2	93.1
20	1	93.0	95.9	93.5
	2	96.8	98.4	88.9
	3	95.1	98.4	90.1
	Mean	95.0	97.6	90.8
40	1	96.1	101.1	87.3
	2	100.6	98.2	93.6
	3	97.3	100.2	88.9
	Mean	98.0	99.8	89.9
80	1	81.1	91.2	83.2
	2	85.9	91.0	82.9
	3	93.4	89.1	80.1
	Mean	86.8	90.4	82.1
160	1	78.2	87.3	75.1
	2	77.8	80.7	74.0
	3	85.9	85.6	79.3
	Mean	80.6	84.5	76.1

† Concentration of chemical applied, but initial ^{14}C measurements showed initial concentration to be 0.47, 4.77, and 47.4 μg/g of soil.

‡ Values are percentages of initial concentration in soil.

Table A-6. Recovery of ^{14}C from an Ascalon soil amended with ring labeled ^{14}C p-chlorophenyl methyl sulfone during a 160-day incubation period.

Incubation	Reps	Recovery of ^{14}C from soil at concentrations (µg/g)† of 0.5	5	50
days		% of initial‡		
10	1	103.5	100.0	101.6
	2	102.9	99.9	103.6
	3	99.4	100.7	98.8
	Mean	101.9	100.2	101.3
20	1	91.8	97.3	97.7
	2	97.3	95.8	95.8
	3	96.8	97.5	97.5
	Mean	95.3	96.9	97.0
40	1	94.9	96.8	94.0
	2	97.8	98.5	93.3
	3	97.1	102.1	96.0
	Mean	96.6	99.1	94.4
80	1	87.4	87.6	87.1
	2	86.0	90.4	90.7
	3	84.8	91.3	85.1
	Mean	86.1	89.8	87.6
160	1	86.9	83.0	83.3
	2	83.7	84.4	76.2
	3	76.5	80.0	74.2
	Mean	82.4	82.5	77.9

† Concentration of chemical applied, but initial ^{14}C measurements showed initial concentration to be 0.48, 4.77, and 48.9 µg/g of soil.

‡ Values are percentages of initial concentration in soil.

APPENDIX B

PLANT PART WEIGHTS, SAMPLE SIZE, AND ACTIVITY COUNTED FROM FOLIAR EXPERIMENTS

Table B-1. Absorption and distribution of foliar applied ^{14}C p-chlorophenyl methyl sulfide in corn plants.

		Absorption period (hr)					
		24			72		
		Plant sample			Plant sample		
Plant part	Reps	Total	Analyzed	Activity counted†	Total	Analyzed	Activity counted†
		— mg —		DPM	— mg —		DPM
Target ^{14}C leaf	1	565	51.0	527	698	50.2	199
	2	859	50.8	390	1080	50.0	288
	3	946	55.4	132	865	50.0	238
Stem	1	2153	57.7	11	2125	50.9	15
	2	2499	59.1	1	2846	50.0	7
	3	1759	50.4	4	2453	50.5	13
Crown	1	878	55.7	7	995	50.5	24
	2	1043	54.1	0	924	50.2	8
	3	1058	56.8	3	923	50.9	13
Roots	1	2476	50.3	3	2534	50.7	8
	2	2001	57.0	4	3003	50.0	12
	3	2413	57.4	0	2123	50.9	7
New leaf	1	1000	57.3	18	1114	50.7	37
	2	397	55.6	10	755	50.0	23
	3	501	57.5	14	464	50.0	20
Old leaf	1	711	56.6	38	502	50.2	53
	2	995	51.8	15	983	50.8	38
	3	406	52.2	26	428	50.3	25
Other‡	1	2521	54.5	15	1670	50.5	30
	2	1433	55.6	10	1745	50.0	33
	3	2765	53.5	28	2472	50.8	24

† Sample was combusted and CO_2 trapped in 4 mls of Hyamine, and a 2 ml aliquot was counted. This value has been corrected by subtracting out natural background.

‡ Includes plant top material remaining after parts were removed.

Table B-2. Absorption and distribution of foliar applied ^{14}C p-chlorophenyl methyl sulfoxide in corn plants.

		Absorption period (hr)					
		24			72		
		Plant sample			Plant sample		
Plant part	Reps	Total	Analyzed	Activity counted†	Total	Analyzed	Activity counted†
		—— mg ——		DPM	—— mg ——		DPM
Target ^{14}C leaf	1	707	51.7	3935	1120	50.0	648
	2	1320	48.5	3462	1126	50.6	2935
	3	696	47.9	2965	1026	50.0	2508
Stem	1	1822	51.5	3	2751	50.0	13
	2	2346	50.0	6	1969	50.4	26
	3	2326	48.4	1	2909	50.9	21
Crown	1	838	48.6	3	816	50.2	8
	2	985	48.7	0	920	50.5	12
	3	838	49.8	0	1115	50.4	2
Roots	1	4339	50.0	2	2749	50.5	8
	2	2702	49.0	2	2639	50.6	12
	3	3206	48.5	2	2561	50.9	1
New leaf	1	1155	49.7	23	600	50.0	5
	2	833	48.5	16	640	50.3	21
	3	1048	49.5	2	983	50.4	47
Old leaf	1	551	50.7	22	291	50.0	2
	2	979	49.4	13	456	50.0	32
	3	575	48.5	5	818	50.5	41
Other‡	1	2591	50.9	19	-	-	-
	2	1351	50.0	20	3092	50.5	8
	3	1878	51.7	23	2453	50.8	35

† Sample was combusted and CO_2 trapped in 4 mls of Hyamine, and a 2 ml aliquot was counted. This value has been corrected by subtracting out natural background.

‡ Includes plant top material remaining after parts were removed.

Table B-3. Absorption and distribution of foliar applied ^{14}C p-chlorophenyl methyl sulfone in corn plants.

		Absorption period (hr)					
		24			72		
		Plant sample			Plant sample		
Plant part	Reps	Total	Analyzed	Activity counted†	Total	Analyzed	Activity counted†
		mg	mg	DPM	mg	mg	DPM
Target ^{14}C leaf	1	1080	51.6	7938	1032	50.2	6898
	2	1212	50.7	9114	1196	50.4	4441
	3	871	52.3	9735	1543	50.0	2571
Stem	1	2460	49.6	3	2457	50.9	82
	2	2712	51.2	2	1815	50.8	22
	3	2138	50.4	0	3529	50.3	19
Crown	1	725	49.5	0	1096	50.5	31
	2	895	49.6	0	963	50.6	6
	3	905	48.9	0	1176	50.1	12
Roots	1	2132	52.3	0	2708	50.4	16
	2	2423	50.8	0	2790	50.8	6
	3	2444	51.1	0	3199	50.1	14
New leaf	1	655	51.9	8	553	50.0	9
	2	939	51.9	10	704	50.0	12
	3	391	48.6	6	1021	50.4	0
Old leaf	1	911	51.4	8	1178	50.9	35
	2	895	48.8	3	1048	50.9	14
	3	303	49.1	25	1676	50.0	18
Other‡	1	1415	49.3	5	2389	50.6	7
	2	1262	52.5	14	1290	50.7	16
	3	2472	53.7	10	2360	50.9	21

† Sample was combusted and CO_2 trapped in 4 mls of Hyamine, and a 2 ml aliquot was counted. This value has been corrected by subtracting out natural background.

‡ Includes plant top material remaining after parts were removed.

Table B-4. Absorption and distribution of foliar applied ^{14}C p-chlorophenyl methyl sulfide in sugarbeet plants.

Plant part	Reps	24: Plant sample Total	24: Plant sample Analyzed	24: Activity counted†	72: Plant sample Total	72: Plant sample Analyzed	72: Activity counted†
		mg	mg	DPM	mg	mg	DPM
Target ^{14}C leaf	1	174	50.6	10692	400	50.9	2909
	2	241	50.4	4630	242	50.9	9874
	3	196	50.6	8037	331	50.0	6838
Petiole ^{14}C	1	57	50.0	52	116	51.0	24
	2	76	50.0	28	64	50.3	90
	3	77	50.0	41	136	50.0	29
Crown	1	791	50.3	15	519	50.9	9
	2	570	50.9	25	692	50.6	0
	3	671	50.7	16	427	50.3	3
Root-top	1	1093	50.0	20	1234	50.6	0
	2	1425	50.3	16	1382	50.9	11
	3	677	50.0	0	1251	51.0	0
Root-bottom	1	139	50.1	15	100	50.7	10
	2	268	50.0	0	127	50.8	4
	3	115	50.0	4	137	50.7	0
New leaf	1	100	50.0	57	249	50.8	51
	2	268	50.5	53	165	50.7	26
	3	275	50.6	30	543	51.1	0
Old leaf	1	391	50.6	51	466	50.0	30
	2	258	50.4	47	265	50.6	26
	3	303	50.5	37	328	50.0	37
Other‡	1	2185	50.0	74	2846	50.4	159
	2	2985	50.0	46	--	51.3	36
	3	1752	50.8	55	2663	50.1	79

† Sample was combusted and CO_2 trapped in 4 mls of Hyamine, and a 2 ml aliquot was counted. This value has been corrected by subtracting out natural background.

‡ Includes plant top material remaining after parts were removed.

Table B-5. Absorption and distribution of foliar applied ^{14}C p-chlorophenyl methyl sulfoxide in sugarbeet plants.

Plant part	Reps	24: Plant sample Total	24: Plant sample Analyzed	24: Activity counted†	72: Plant sample Total	72: Plant sample Analyzed	72: Activity counted†
		mg	mg	DPM	mg	mg	DPM
Target ^{14}C leaf	1	245	50.0	27877	187	50.0	28766
	2	181	50.6	31882	187	51.2	33179
	3	198	50.0	32320	318	50.0	18145
Petiole ^{14}C	1	63	46.0	1	64	30.0	180
	2	57	41.4	65	51	30.1	91
	3	75	50.0	78	111	50.8	75
Crown	1	590	50.2	153	501	50.0	51
	2	666	50.5	13	458	50.0	41
	3	626	50.9	46	238	51.6	4
Root-top	1	661	50.7	8	590	50.1	8
	2	960	50.7	1	767	51.0	24
	3	571	50.9	0	1927	50.0	0
Root-bottom	1	55	50.0	8	52	50.0	28
	2	81	50.2	7	92	50.0	13
	3	222	50.0	0	57	--	--
New leaf	1	365	50.4	65	199	51.3	57
	2	269	50.0	35	226	50.6	80
	3	271	50.0	33	448	51.6	15
Old leaf	1	406	50.0	54	282	50.1	60
	2	276	50.0	19	303	50.8	52
	3	514	50.0	20	479	50.0	26
Other‡	1	2060	50.6	81	1705	50.0	111
	2	2130	50.3	39	1204	51.1	120
	3	2238	50.0	21	3251	50.0	25

Sample was combusted and CO_2 trapped in 4 mls of Hyamine, and a 2 ml aliquot was counted. This value has been corrected by subtracting out natural background.

[illegible] material remaining after parts were removed.

Table B-6. Absorption and distribution of foliar applied ^{14}C p-chlorophenyl methyl sulfone in sugarbeet plants.

		Absorption period (hr)					
		24			72		
		Plant sample			Plant sample		
Plant part	Reps	Total	Analyzed	Activity counted†	Total	Analyzed	Activity counted†
		mg		DPM	mg		DPM
Target ^{14}C leaf	1	191	50.0	42235	282	50.4	21122
	2	297	50.0	32696	249	51.3	25471
	3	271	50.0	52161	309	50.6	33062
Petiole ^{14}C	1	83	50.9	189	131	50.6	302
	2	103	42.6	47	71	50.1	239
	3	103	50.0	202	108	50.0	153
Crown	1	374	50.1	60	984	50.0	11
	2	599	50.0	103	516	50.2	34
	3	871	50.0	70	1295	50.0	41
Root-top	1	569	50.0	19	939	50.0	7
	2	946	50.9	20	855	50.8	19
	3	977	50.0	20	330	50.0	14
Root-bottom	1	61	47.4	14	198	50.0	0
	2	68	50.0	3	136	50.6	25
	3	269	50.1	6	168	50.1	16
New leaf	1	134	50.8	34	239	50.8	32
	2	243	50.0	22	202	50.5	34
	3	227	50.0	29	157	50.0	27
Old leaf	1	403	50.6	37	296	50.0	28
	2	370	50.1	9	281	51.5	40
	3	466	50.4	20	496	51.0	13
Other‡	1	1635	50.0	45	1838	50.0	56
	2	2979	50.9	49	2416	50.0	53
	3	2905	50.3	35	2615	50.0	65

† Sample was combusted and CO_2 trapped in 4 mls of Hyamine, and a 2 ml aliquot was counted. This value has been corrected by subtracting out natural background.

‡ Includes plant top material remaining after parts were removed.

Table B-7. Absorption and distribution of foliar applied ^{14}C diisopropyl methylphosphonate (DIMP) in corn plants.

Plant part	Reps	24 hr: Plant sample Total	24 hr: Plant sample Analyzed	24 hr: Activity counted†	72 hr: Plant sample Total	72 hr: Plant sample Analyzed	72 hr: Activity counted†
		mg	mg	DPM	mg	mg	DPM
Target ^{14}C leaf	1	940	52.0	1450	900	49.0	1255
	2	920	49.1	2769	720	50.1	1577
	3	790	49.2	1349	920	51.8	1922
Stem	1	4920	50.1	2	4840	49.9	6
	2	4440	50.0	3	4670	50.3	9
	3	4570	50.8	2	4910	50.6	15
Crown	1	1210	50.1	2	2020	50.0	1
	2	1510	50.0	14	2050	50.2	4
	3	1600	50.2	0	2140	50.0	10
Roots	1	3270	50.5	0	6410	50.1	3
	2	4800	49.9	6	3160	50.3	15
	3	5100	50.1	6	5850	50.2	8
New leaf	1	620	50.0	7	520	50.5	3
	2	540	50.2	7	400	50.3	9
	3	410	50.2	19	520	50.2	5
Old leaf	1	700	50.2	6	860	50.4	8
	2	760	50.0	5	960	50.9	9
	3	870	50.2	1	680	49.5	14
Other‡	1	3450	50.0	27	4170	50.9	32
	2	3700	50.3	16	3930	50.1	10
	3	4100	50.0	14	3380	50.9	12

† Sample was combusted and CO_2 trapped in 4 mls of Hyamine, and a 2 ml aliquot was counted. This value has been corrected by subtracting out natural background.

‡ Includes plant top material remaining after parts were removed.

Table B-8. Absorption and distribution of foliar applied ^{14}C diisopropyl methylphosphonate (DIMP) in sugarbeet plants.

		Absorption period (hr)					
		24			72		
		Plant sample			Plant sample		
Plant part	Reps	Total	Analyzed	Activity counted†	Total	Analyzed	Activity counted†
		—— mg ——		DPM	—— mg ——		DPM
Target ^{14}C leaf	1	260	49.9	19900	340	50.0	9367
	2	160	50.0	15402	260	50.2	9716
	3	280	50.0	13534	330	50.5	9825
Petiole	1	120	50.0	436	190	50.6	1242
	2	80	28.4	472	110	50.0	1973
	3	130	49.9	492	110	50.6	1581
Crown	1	250	49.7	65	580	50.1	263
	2	270	50.5	157	400	50.0	520
	3	260	49.9	157	510	50.4	392
Root-top	1	370	50.1	67	770	50.1	218
	2	600	50.3	121	620	50.4	555
	3	1114	50.0	111	1138	49.9	472
Root-bottom	1	90	36.1	62	100	50.0	369
	2	150	50.5	133	110	50.0	704
	3	200	49.9	90	320	50.0	460
New leaf	1	310	49.9	38	560	50.5	34
	2	190	50.7	87	200	50.0	37
	3	260	50.2	26	250	49.6	56
Old leaf	1	190	49.6	23	340	50.4	33
	2	230	50.0	55	280	49.9	46
	3	200	50.4	14	450	50.0	80
Other‡	1	1152	50.5	65	1190	51.1	73
	2	1170	49.0	68	2000	51.4	294
	3	1160	51.4	38	2610	50.7	104

† Sample was combusted and CO_2 trapped in 4 mls of Hyamine, and a 2 ml aliquot was counted. This value has been corrected by subtracting out natural background.

‡ Includes plant top material remaining after parts were removed.

APPENDIX C

UPTAKE OF ^{14}C SULFIDE, SULFOXIDE, AND SULFONE BY PLANT AND RESIDUAL ^{14}C IN SOIL

Table C-1. Initial and final recovery of sulfide, sulfoxide, and sulfone from soil used in a greenhouse experiment to evaluate phytotoxic effects on the growth of wheat in an Ascalon soil. Values resulted from ^{14}C analysis of a dry combusted soil sample.

Sampling time	Reps	Concentration of applied chemical (μg/g soil): 0.5 — Recovery of Applied	0.5 — Recovery of Initial	5 — Recovery of Applied	5 — Recovery of Initial	25 — Recovery of Applied	25 — Recovery of Initial
				Sulfide (%)			
Initial†	1	72.3	100	59.2	100	41.7	100
	2	75.0	100	58.4	100	42.0	100
	3	73.8	100	57.9	100	42.5	100
	Mean	73.8	100	58.5	100	42.1	100
Final‡	1	31.3	43.4	8.6	14.5	12.8	30.7
	2	29.0	38.6	18.3	31.3	10.4	24.8
	3	25.7	34.8	20.2	34.9	13.2	31.1
	Mean	28.7	38.9	15.7	26.9	12.1	28.9
				Sulfoxide (%)			
Initial†	1	96.5	100	104.7	100	96.4	100
	2	98.0	100	97.2	100	94.6	100
	3	94.6	100	99.3	100	95.7	100
	Mean	96.4	100	100.4	100	95.6	100
Final‡	1	39.9	41.4	30.4	29.0	36.8	38.1
	2	40.2	41.0	27.8	28.6	35.1	37.1
	3	35.2	37.3	22.7	22.9	39.6	41.4
	Mean	38.4	39.9	27.0	26.8	37.2	38.9
				Sulfone (%)			
Initial†	1	91.1	100	92.2	100	95.8	100
	2	92.8	100	94.9	100	94.8	100
	3	94.4	100	98.3	100	93.6	100
	Mean	92.8	100	95.1	100	94.7	100
Final‡	1	31.8	34.9	29.6	32.2	44.2	46.1
	2	32.7	35.2	26.1	27.5	44.8	47.3
	3	36.2	38.3	29.1	29.6	46.9	50.2
	Mean	33.6	36.1	28.3	29.8	45.3	47.9

† Sampled immediately after solvent evaporation and a thorough soil mixing in a twin-shelled blender.

‡ Sampled after the crop was harvested (47 days).

Table C-2. Initial and final recovery of sulfide, sulfoxide, and sulfone from soil used in a greenhouse experiment to evaluate phytotoxic effects on the growth of wheat in a Nunn soil. Values resulted from ^{14}C analysis of a dry combusted soil sample.

Sampling time	Reps	0.5 Recovery of Applied	0.5 Recovery of Initial	5 Recovery of Applied	5 Recovery of Initial	25 Recovery of Applied	25 Recovery of Initial
				Sulfide (%)			
Initial†	1	82.3	100	79.6	100	71.7	100
	2	87.1	100	81.7	100	73.8	100
	3	81.4	100	82.6	100	72.7	100
	Mean	83.6	100	81.3	100	72.7	100
Final‡	1	35.6	43.2	16.3	20.4	15.7	21.9
	2	36.2	41.6	20.5	25.0	18.5	25.1
	3	36.0	44.2	21.4	26.0	21.4	29.5
	Mean	35.9	43.0	19.4	23.8	18.5	25.5
				Sulfoxide (%)			
Initial†	1	90.9	100	91.7	100	89.8	100
	2	92.6	100	94.2	100	92.2	100
	3	93.4	100	91.1	100	91.6	100
	Mean	92.3	100	92.3	100	91.2	100
Final‡	1	42.1	46.3	23.7	25.8	23.9	26.6
	2	43.2	46.6	23.2	24.6	27.8	30.2
	3	39.6	42.4	21.5	23.6	27.1	29.6
	Mean	41.6	45.1	22.8	24.7	26.3	28.8
				Sulfone (%)			
Initial†	1	93.6	100	94.3	100	97.4	100
	2	98.0	100	93.7	100	96.0	100
	3	91.4	100	94.5	100	96.4	100
	Mean	94.3	100	94.2	100	96.6	100
Final‡	1	39.1	41.8	23.5	25.0	27.4	28.1
	2	40.5	41.4	24.7	26.3	37.5	39.0
	3	42.6	46.6	26.4	28.0	33.2	34.5
	Mean	40.7	43.3	24.9	26.4	32.7	33.9

Concentration of applied chemical (μg/g soil): 0.5, 5, 25.

† Sampled immediately after solvent evaporation and a thorough soil mixing in a twin-shelled blender.

‡ Sampled after the crop was harvested (47 days).

Table C-3. Initial and final recovery of sulfide, sulfoxide, and sulfone from soil used in a greenhouse experiment to evaluate phytotoxic effects on the growth of fescue in an Ascalon soil. Values resulted from ^{14}C analysis of a dry combusted soil sample.

Sampling time	Reps	Concentration of applied chemical (μg/g soil) 0.5 Recovery of Applied	0.5 Recovery of Initial	5 Recovery of Applied	5 Recovery of Initial	25 Recovery of Applied	25 Recovery of Initial
				Sulfide (%)			
Initial†	1	65.2	100	54.6	100	44.1	100
	2	68.9	100	56.9	100	42.0	100
	3	67.9	100	57.2	100	39.8	100
	Mean	67.3	100	56.2	100	42.0	100
Final‡	1	25.6	39.3	13.3	24.3	8.9	20.2
	2	21.3	30.9	11.6	20.3	6.8	16.1
	3	22.1	32.5	13.3	23.3	8.3	20.8
	Mean	23.0	34.2	12.7	22.6	8.0	19.0
				Sulfoxide (%)			
Initial†	1	99.5	100	102.2	100	101.1	100
	2	105.9	100	100.3	100	98.0	100
	3	104.1	100	101.2	100	98.4	100
	Mean	103.2	100	101.2	100	99.2	100
Final‡	1	29.7	29.9	20.9	20.4	37.6	37.3
	2	34.1	32.3	23.8	23.8	52.9	54.0
	3	31.2	30.0	20.4	20.2	38.0	38.7
	Mean	31.7	30.7	21.7	21.5	42.8	43.3
				Sulfone (%)			
Initial†	1	103.7	100	97.6	100	99.2	100
	2	96.6	100	99.7	100	96.8	100
	3	99.6	100	95.8	100	98.2	100
	Mean	100.0	100	97.7	100	98.1	100
Final‡	1	34.4	33.1	26.9	27.5	56.4	56.9
	2	32.6	33.7	24.6	24.6	33.9	35.1
	3	35.0	35.1	27.5	28.7	50.1	51.0
	Mean	34.0	34.0	26.3	26.9	46.8	47.7

† Sampled immediately after solvent evaporation and a thorough soil mixing in a twin-shelled blender.

‡ Sampled after the crop was harvested (61 days).

Table C-4. Initial and final recovery of sulfide, sulfoxide, and sulfone from soil used in a greenhouse experiment to evaluate phytotoxic effects on the growth of corn in an Ascalon soil. Values resulted from ^{14}C analysis of a dry combusted soil sample.

Sampling time	Reps	Concentration of applied chemical (μg/g soil)					
		0.5		5		25	
		Recovery of Applied	Recovery of Initial	Recovery of Applied	Recovery of Initial	Recovery of Applied	Recovery of Initial
				Sulfide (%)			
Initial†	1	60.4	100	55.6	100	56.4	100
	2	61.9	100	63.1	100	60.0	100
	3	61.3	100	61.4	100	58.7	100
	Mean	61.2	100	60.0	100	58.4	100
Final‡	1	33.5	55.5	26.9	48.4	18.8	33.4
	2	38.2	61.8	26.4	41.8	18.9	31.5
	3	34.5	56.3	23.1	37.7	19.9	34.0
	Mean	35.4	57.9	25.5	42.6	19.2	33.0
				Sulfoxide (%)			
Initial†	1	98.4	100	100.5	100	105.5	100
	2	100	100	102.8	100	103.9	100
	3	95.5	100	99.2	100	105.6	100
	Mean	98.0	100	100.8	100	105.0	100
Final‡	1	50.5	51.3	42.1	42.0	32.2	30.5
	2	51.0	51.0	41.1	39.9	29.5	28.4
	3	50.4	52.8	42.2	42.5	32.4	30.7
	Mean	50.6	51.7	41.8	41.5	31.4	29.9
				Sulfone (%)			
Initial†	1	100.6	100	104.4	100	98.9	100
	2	104.4	100	102.4	100	99.9	100
	3	105.4	100	100.9	100	100.4	100
	Mean	103.5	100	102.6	100	99.7	100
Final‡	1	50.0	49.6	42.6	40.8	42.4	42.9
	2	49.3	47.2	41.2	40.2	35.4	35.4
	3	49.9	47.3	39.4	39.1	32.7	32.6
	Mean	49.7	48.0	41.1	40.0	36.8	37.0

† Sampled immediately after solvent evaporation and a thorough soil mixing in a twin-shelled blender.

‡ Sampled after the crop was harvested (34 days).

Table C-5. Initial and final recovery of sulfide, sulfoxide, and sulfone from soil used in a greenhouse experiment to evaluate phytotoxic effects on the growth of sugarbeets in an Ascalon soil. Values resulted from ^{14}C analysis of a dry combusted soil sample.

Sampling time	Reps	Concentration of applied chemical (μg/g soil)					
		0.5		5		25	
		Recovery of Applied	Recovery of Initial	Recovery of Applied	Recovery of Initial	Recovery of Applied	Recovery of Initial
				Sulfide (%)			
Initial†	1	81.1	100	68.1	100	45.8	100
	2	81.8	100	68.1	100	45.7	100
	3	82.6	100	68.3	100	47.5	100
	Mean	81.8	100	68.2	100	46.3	100
Final‡	1	27.7	34.2	20.8	30.6	22.0	48.2
	2	27.5	33.6	18.2	26.8	16.2	35.5
	3	29.5	35.7	19.3	28.3	22.2	46.6
	Mean	28.2	34.5	19.4	28.6	20.1	43.4
				Sulfoxide (%)			
Initial†	1	93.9	100	97.1	100	94.1	100
	2	101.0	100	101.1	100	98.0	100
	3	101.1	100	102.8	100	98.0	100
	Mean	98.7	100	100.3	100	96.7	100
Final‡	1	32.2	34.3	21.2	21.9	63.2	67.2
	2	28.6	28.4	22.2	21.9	64.4	65.7
	3	29.2	28.9	24.6	23.9	61.3	62.6
	Mean	30.0	30.5	22.7	22.6	63.0	65.2
				Sulfone (%)			
Initial†	1	100.3	100	99.0	100	102.1	100
	2	98.7	100	98.0	100	102.6	100
	3	96.6	100	103.9	100	101.6	100
	Mean	98.5	100	100.3	100	102.1	100
Final‡	1	30.5	30.4	26.5	26.8	55.1	63.9
	2	29.6	30.0	22.4	22.9	57.9	56.4
	3	30.9	32.0	21.9	21.1	57.6	56.7
	Mean	30.3	30.8	23.6	23.6	56.9	55.7

† Sampled immediately after solvent evaporation and a thorough soil mixing in a twin-shelled blender.

‡ Sampled after the crop was harvested (51 days).

Table C-6. Initial and final recovery of sulfide, sulfoxide, and sulfone from soil used in a greenhouse experiment to evaluate phytotoxic effects on the growth of alfalfa in an Ascalon soil. Values resulted from ^{14}C analysis of a dry combusted soil sample.

Sampling time	Reps	0.5 Recovery of Applied	0.5 Recovery of Initial	5 Recovery of Applied	5 Recovery of Initial	25 Recovery of Applied	25 Recovery of Initial
				Sulfide (%)			
Initial†	1	79.5	100	78.8	100	68.4	100
	2	79.3	100	73.1	100	71.2	100
	3	82.0	100	73.3	100	68.4	100
	Mean	80.3	100	75.1	100	69.3	100
Final‡	1	33.6	42.2	23.1	29.3	40.1	58.6
	2	33.7	42.5	19.4	26.6	40.3	56.7
	3	33.0	40.2	23.0	31.4	41.9	61.3
	Mean	33.4	41.6	21.8	29.1	40.8	58.9
				Sulfoxide (%)			
Initial†	1	98.3	100	94.7	100	98.3	100
	2	94.4	100	95.6	100	95.6	100
	3	91.8	100	97.9	100	91.0	100
	Mean	94.8	100	96.1	100	95.0	100
Final‡	1	32.6	33.1	29.4	31.0	60.7	61.8
	2	35.9	38.0	27.2	28.4	59.8	62.6
	3	42.1	45.8	30.2	30.9	64.2	70.6
	Mean	36.9	39.0	28.9	30.1	61.6	65.0
				Sulfone (%)			
Initial†	1	91.8	100	96.8	100	98.7	100
	2	98.3	100	95.2	100	95.4	100
	3	95.8	100	98.4	100	92.7	100
	Mean	95.3	100	96.8	100	95.6	100
Final‡	1	34.9	38.0	35.8	37.0	58.0	58.8
	2	39.4	40.1	24.7	26.0	71.0	74.5
	3	36.8	38.4	29.4	29.9	68.0	73.3
	Mean	37.0	38.8	30.0	31.0	65.7	68.9

Concentration of applied chemical (μg/g soil)

† Sampled immediately after solvent evaporation and a thorough soil mixing in a twin-shelled blender.

‡ Sampled after the crop was harvested (51 days).

Table C-7. Uptake of ^{14}C and calculated chemical concentration in wheat from an Ascalon soil amended with ring labeled ^{14}C sulfide, sulfoxide, and sulfone.

Chemical	Chemical concen. in soil† Applied	Chemical concen. in soil† Actual	Reps	Uptake of ^{14}C in plants‡ Tops	Uptake of ^{14}C in plants‡ Roots	Chemical concen. in plants§ Tops	Chemical concen. in plants§ Roots
	— µg/g —			— % —		— µg/g —	
Sulfide	0.5	0.37	1	18.3	3.22	9.3	2.7
			2	24.6	4.48	13.2	2.7
			3	26.7	7.56	17.3	7.3
			Mean	23.2	5.09	13.3	4.2
	5.0	2.93	1	35.7	5.91	230	46.7
			2	27.8	2.81	104	15.8
			3	20.7	3.11	91	20.5
			Mean	28.1	3.94	142	27.7
	25	10.5	1	17.9	1.82	301	42.7
			2	18.0	1.83	326	51.3
			3	18.2	2.19	309	53.5
			Mean	18.0	1.95	312	49.2
Sulfoxide	0.5	0.48	1	20.2	5.38	13.4	5.0
			2	21.7	3.58	15.1	4.0
			3	25.0	5.28	16.7	5.0
			Mean	22.3	4.75	15.1	4.7
	5.0	5.02	1	20.6	2.73	152	29.5
			2	26.2	2.28	183	19.0
			3	27.3	2.67	210	23.3
			Mean	24.7	2.56	182	23.9
	25	23.9	1	15.0	1.48	977	162
			2	12.8	1.60	729	135
			3	13.9	1.19	911	129
			Mean	13.9	1.42	872	142
Sulfone	0.5	0.46	1	25.4	4.49	16.2	3.5
			2	19.0	8.61	15.9	9.5
			3	19.7	6.48	14.4	8.0
			Mean	21.4	6.53	15.5	7.0

(continued)

Table C-7 (continued).

Chemical	Chemical concen. in soil†		Reps	Uptake of ^{14}C in plants‡		Chemical concen. in plants§	
	Applied	Actual		Tops	Roots	Tops	Roots
	μg/g			%		μg/g	
Sulfone (contd.)	5.0	4.76	1	26.4	2.46	176	19.5
			2	24.1	3.12	169	33.6
			3	25.3	3.75	184	30.0
			Mean	25.3	3.11	176	27.7
	25	23.7	1	14.2	0.88	986	108
			2	12.9	0.65	1274	147
			3	14.0	1.31	762	123
			Mean	13.7	0.95	1007	126

† Concentration of chemicals applied were 0.5, 5, and 25 μg/g and an actual chemical concentration in soil was determined after solvent evaporation.

‡ Percent of ^{14}C taken up by plant was based on concentration in the initial soil sample.

§ Calculated chemical concentration based on ^{14}C measurements assuming activity remained as parent compound.

Table C-8. Uptake of ^{14}C and calculated chemical concentration in wheat from a Nunn soil amended with ring labeled ^{14}C sulfide, sulfoxide, and sulfone.

Chemical	Chemical concen. in soil†		Reps	Uptake of ^{14}C in plants‡		Chemical concen. in plants§	
	Applied	Actual		Tops	Roots	Tops	Roots
	μg/g			%		μg/g	
Sulfide	0.5	0.42	1	33.2	4.0	17.3	4.7
			2	34.3	4.2	18.8	4.2
			3	32.3	3.7	18.6	4.0
			Mean	33.3	4.0	18.2	4.3
	5.0	4.07	1	41.1	2.4	192	25.1
			2	42.9	1.7	213	25.7
			3	34.6	1.7	201	20.1
			Mean	39.5	1.9	202	23.6
	25	18.2	1	23.5	0.8	802	73.5
			2	22.0	0.8	892	92.3
			3	18.9	0.8	848	90.9
			Mean	21.5	0.8	847	85.6
Sulfoxide	0.5	0.46	1	31.3	6.0	18.7	5.6
			2	34.1	3.0	20.9	5.8
			3	28.9	3.7	17.1	4.4
			Mean	31.4	4.2	18.9	5.3
	5.0	4.62	1	41.9	2.4	253	22.0
			2	38.8	1.7	230	20.5
			3	41.3	2.3	269	31.7
			Mean	40.7	2.1	251	24.7
	25	22.8	1	23.8	1.2	1125	122
			2	20.3	1.0	1006	112
			3	22.2	1.0	1143	131
			Mean	22.1	1.1	1091	122
Sulfone	0.5	0.47	1	31.7	4.2	18.2	4.2
			2	25.7	4.1	16.8	5.1
			3	30.3	4.2	18.7	6.0
			Mean	29.2	4.2	17.9	5.1

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Table C-8 (continued).

Chemical	Chemical concen. in soil†		Reps	Uptake of ^{14}C in plants‡		Chemical concen. in plants§	
	Applied	Actual		Tops	Roots	Tops	Roots
	μg/g			%		μg/g	
Sulfone (contd.)	5	4.71	1	41.7	2.5	264	31.9
			2	41.5	2.0	253	28.0
			3	37.4	2.4	260	31.1
			Mean	40.2	2.3	259	30.3
	25	24.2	1	27.6	1.2	1317	146
			2	19.9	0.8	1493	160
			3	24.6	1.1	1428	161
			Mean	24.0	1.0	1413	156

† Concentration of chemicals applied were 0.5, 5, and 25 μg/g and an actual chemical concentration in soil was determined after solvent evaporation.

‡ Percent of ^{14}C taken up by plant was based on concentration in the initial soil sample.

§ Calculated chemical concentration based on ^{14}C measurements assuming activity remained as parent compound.

Table C-9. Uptake of ^{14}C and calculated chemical concentration in fescue from an Ascalon soil amended with ring labeled ^{14}C sulfide, sulfoxide, and sulfone.

Chemical	Chemical concen. in soil†		Reps	Uptake of ^{14}C in plants‡		Chemical concen. in plants§	
	Applied	Actual		Tops	Roots	Tops	Roots
	μg/g			%		μg/g	
Sulfide	0.5	0.34	1	23.1	1.01	13.6	0.9
			2	19.1	0.86	12.4	0.9
			3	21.2	0.81	16.0	1.3
			Mean	21.1	0.89	14.0	1.0
	5.0	2.82	1	16.2	0.35	85.9	4.2
			2	20.2	0.37	116	4.5
			3	18.5	0.32	119	5.1
			Mean	18.3	0.35	107	4.6
	25	10.5	1	13.2	0.30	448	22.1
			2	18.1	0.26	469	15.6
			3	13.4	0.18	452	16.3
			Mean	14.9	0.25	456	18.0
Sulfoxide	0.5	0.52	1	13.9	0.56	12.5	1.1
			2	15.6	0.78	14.7	1.4
			3	19.5	0.76	17.7	1.2
			Mean	16.3	0.70	15.0	1.2
	5.0	5.06	1	20.6	0.43	210	7.1
			2	18.2	0.40	237	8.9
			3	20.9	0.44	196	9.1
			Mean	19.9	0.42	214	8.4
	25	24.8	1	7.63	0.16	1928	116
			2	0.79	0.05	968	136
			3	5.96	0.21	1466	125
			Mean	4.79	0.14	1454	126
Sulfone	0.5	0.50	1	20.4	0.75	21.6	1.2
			2	18.5	0.57	17.3	1.0
			3	18.9	0.71	16.4	1.2
			Mean	19.3	0.68	18.4	1.1

(continued)

Table C-9 (continued).

Chemical	Chemical concen. in soil†		Reps	Uptake of ^{14}C in plants‡		Chemical concen. in plants§	
	Applied	Actual		Tops	Roots	Tops	Roots
	—— μg/g ——			—— % ——		—— μg/g ——	
Sulfone (contd.)	5.0	4.89	1	18.3	0.47	173	7.3
			2	14.7	0.49	167	9.6
			3	16.2	0.33	199	8.5
			Mean	16.4	0.43	180	8.5
	25	24.5	1	4.30	0.10	1938	115
			2	11.6	0.35	1477	125
			3	3.96	0.13	1944	145
			Mean	6.62	0.19	1786	128

† Concentration of chemicals applied were 0.5, 5, and 25 μg/g and an actual chemical concentration in soil was determined after solvent evaporation.

‡ Percent of ^{14}C taken up by plant was based on concentration in the initial soil sample.

§ Calculated chemical concentration based on ^{14}C measurements assuming activity remained as parent compound.

Table C-10. Uptake of ^{14}C and calculated chemical concentration in corn from an Ascalon soil amended with ring labeled ^{14}C sulfide, sulfoxide, and sulfone.

Chemical	Chemical concen. in soil†		Reps	Uptake of ^{14}C in plants‡		Chemical concen. in plants§	
	Applied	Actual		Tops	Roots	Tops	Roots
	µg/g			%		µg/g	
Sulfide	0.5	0.31	1	11.0	2.57	5.1	1.9
			2	7.5	2.55	3.4	1.9
			3	10.4	3.00	4.9	1.9
			Mean	9.6	2.71	4.5	1.9
	5.0	3.00	1	18.1	1.93	78.0	15.5
			2	20.3	1.90	97.8	13.3
			3	19.0	1.81	81.5	13.2
			Mean	19.1	1.88	85.8	14.0
	25	14.6	1	23.2	1.99	573	117
			2	17.5	1.82	427	89.4
			3	16.0	1.99	358	89.8
			Mean	18.9	1.93	453	98.7
Sulfoxide	0.5	0.49	1	9.8	2.45	7.1	2.6
			2	11.2	2.54	8.7	2.8
			3	10.7	2.48	7.8	2.5
			Mean	10.6	2.49	7.9	2.6
	5.0	5.05	1	17.7	2.29	146	28.1
			2	16.4	1.84	120	21.7
			3	18.2	2.15	129	27.0
			Mean	17.4	2.09	132	25.6
	25	26.3	1	17.8	2.01	831	212
			2	21.0	1.98	925	181
			3	24.0	2.02	953	198
			Mean	20.9	2.00	903	197
Sulfone	0.5	0.52	1	10.1	2.77	7.7	3.2
			2	13.7	2.78	11.2	2.9
			3	12.1	2.77	9.8	3.0
			Mean	12.0	2.77	9.6	3.0

(continued)

Table C-10 (continued).

Chemical	Chemical concen. in soil† Applied	Actual	Reps	Uptake of ^{14}C in plants‡ Tops	Roots	Chemical concen. in plants§ Tops	Roots
	—— μg/g ——			—— % ——		—— μg/g ——	
Sulfone (contd.)	5.0	5.13	1	19.3	1.89	159	24.1
			2	17.5	2.18	135	25.7
			3	18.5	1.93	139	23.2
			Mean	18.4	2.00	144	24.3
	25	24.9	1	21.0	1.19	1821	294
			2	22.8	2.14	890	181
			3	30.1	2.06	1259	199
			Mean	24.6	1.80	1323	225

† Concentration of chemicals applied were 0.5, 5, and 25 μg/g and an actual chemical concentration in soil was determined after solvent evaporation.

‡ Percent of ^{14}C taken up by plant was based on concentration in the initial soil sample.

§ Calculated chemical concentration based on ^{14}C measurements assuming activity remained as parent compound.

Table C-11. Uptake of ^{14}C and calculated chemical concentration in sugar-beets from an Ascalon soil amended with ring labeled ^{14}C sulfide, sulfoxide, and sulfone.

Chemical	Chemical concen. in soil†		Reps	Uptake of ^{14}C in plants‡		Chemical concen. in plants§	
	Applied	Actual		Tops	Roots	Tops	Roots
	μg/g			%		μg/g	
Sulfide	0.5	0.41	1	34.8	0.85	43.4	3.1
			2	14.1	1.37	13.2	2.7
			3	23.0	1.11	21.6	1.6
			Mean	24.0	1.11	26.1	2.5
	5.0	3.41	1	6.61	0.79	80.4	26.9
			2	29.2	0.84	375	20.4
			3	19.0	0.53	164	10.3
			Mean	18.3	0.72	207	19.2
	25	11.6	1	8.04	0.04	800	20.3
			2	10.2	0.13	685	40.1
			3	5.39	0	1165	0
			Mean	7.88	0.06	883	20.1
Sulfoxide	0.5	0.49	1	28.4	0.83	33.8	3.0
			2	20.7	1.15	26.8	2.7
			3	32.1	1.21	36.0	3.2
			Mean	27.1	1.06	32.2	3.0
	5.0	5.02	1	19.2	0.58	321	26.8
			2	15.1	0.53	206	16.2
			3	14.9	0.69	207	25.3
			Mean	16.4	0.60	245	22.8
	25	24.2	1	0	0	0	0
			2	0	0	0	0
			3	0	0	0	0
			Mean	0	0	0	0
Sulfone	0.5	0.49	1	21.4	0.98	27.9	2.7
			2	22.9	1.11	29.4	2.5
			3	39.3	0.99	48.1	2.3
			Mean	27.9	1.03	35.1	2.5

(continued)

Table C-11 (continued).

Chemical	Chemical concen. in soil†		Reps	Uptake of ^{14}C in plants‡		Chemical concen. in plants§	
	Applied	Actual		Tops	Roots	Tops	Roots
	— μg/g —			— % —		— μg/g —	
Sulfone (contd.)	5.0	5.02	1	16.3	0.71	231	25.1
			2	20.7	0.68	264	21.5
			3	14.4	0.53	194	18.4
			Mean	17.1	0.64	230	21.7
	25	25.5	1	2.10	0	1649	0
			2	0.09	0	1154	0
			3	1.68	0	1641	0
			Mean	1.29	0	1481	0

† Concentration of chemicals applied were 0.5, 5, and 25 μg/g and an actual chemical concentration in soil was determined after solvent evaporation.

‡ Percent of ^{14}C taken up by plant was based on concentration in the initial soil sample.

§ Calculated chemical concentration based on ^{14}C measurements assuming activity remained as parent compound.

Table C-12. Uptake of ^{14}C and calculated chemical concentration in alfalfa from an Ascalon soil amended with ring labeled ^{14}C sulfide, sulfoxide, and sulfone.

Chemical	Chemical concen. in soil†		Reps	Uptake of ^{14}C in plants‡		Chemical concen. in plants§	
	Applied	Actual		Tops	Roots	Tops	Roots
	µg/g			%		µg/g	
Sulfide	0.5	0.40	1	8.8	1.32	11.7	3.1
			2	7.2	0.73	8.0	1.4
			3	6.6	0.48	7.0	1.2
			Mean	7.5	0.84	8.9	1.9
	5.0	3.76	1	11.8	0.53	172	19.0
			2	12.5	0.59	145	14.9
			3	14.0	0.49	190	17.9
			Mean	12.8	0.54	169	17.3
	25	17.3	1	0.18	0	684	0
			2	0.28	0	830	0
			3	0.06	0	410	0
			Mean	0.17	0	641	0
Sulfoxide	0.5	0.47	1	8.0	0.89	12.7	2.4
			2	7.8	0.88	10.4	2.4
			3	9.1	1.13	11.9	2.7
			Mean	8.3	0.97	11.7	2.5
	5.0	4.81	1	14.3	0.64	339	37.9
			2	15.5	0.38	412	30.3
			3	12.4	0.69	253	30.7
			Mean	14.1	0.57	335	33.0
	25	23.7	1	0.17	0	597	0
			2	0.12	0	478	0
			3	0.04	0	182	0
			Mean	0.11	0	419	0
Sulfone	0.5	0.48	1	7.8	1.00	10.1	2.2
			2	6.5	0.56	8.2	1.8
			3	7.2	0.68	9.9	2.3
			Mean	7.2	0.75	9.4	2.1

(continued)

Table C-12 (continued).

Chemical	Chemical concen. in soil†		Reps	Uptake of ^{14}C in plants‡		Chemical concen. in plants§	
	Applied	Actual		Tops	Roots	Tops	Roots
	— μg/g —			— % —		— μg/g —	
Sulfone (contd.)	5.0	4.84	1	12.0	0.38	242	26.3
			2	12.7	0.40	216	18.1
			3	9.9	0.42	150	17.2
			Mean	11.5	0.40	203	20.5
	25	23.9	1	0.25	0	949	0
			2	0.01	0	159	0
			3	0.10	0	515	0
			Mean	0.12	0	541	0

† Concentration of chemicals applied were 0.5, 5, and 25 μg/g and an actual chemical concentration in soil was determined after solvent evaporation.

‡ Percent of ^{14}C taken up by plant was based on concentration in the initial soil sample.

§ Calculated chemical concentration based on ^{14}C measurements assuming activity remained as parent compound.

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