United States
Environmental Protection
Agency

Environmental Research
Laboratory
Corvallis OR 97333

Research and Development EPA-600/D-82-272 August 1982

EPA ENVIRONMENTAL RESEARCH BRIEF

Biological Effects and Interactions of Pesticides in a Soil-Plant-Water Microcosm

J. D. Gile
Environmental Research Laboratory, Corvallis OR 97333

Abstract

A soil-plant-water microcosm was used to develop a data base for pesticide transport and metabolism and to determine the effects of varying environmental conditions and/or components on chemical movement in a terrestrial ecosystem. The system was used in a comparative transport study with lindane, fonofos, parathion, phorate, DDT, and carbofuran. The results demonstrated the importance of chemical structure, water solubility, and soil type in predicting comparative chemical behavior. The system was also employed in studies of the effects of crop abundance on chemical movement and the interactions between agricultural chemicals that can affect chemical movement.

Studies were also conducted on the effects of plant type, plant nutrition, soil microorganisms, chemical interactions on pesticide transport, and metabolism. These studies emphasize the importance of ecosystem interactions in determining chemical transport through ecosystems and into food chains.

Introduction

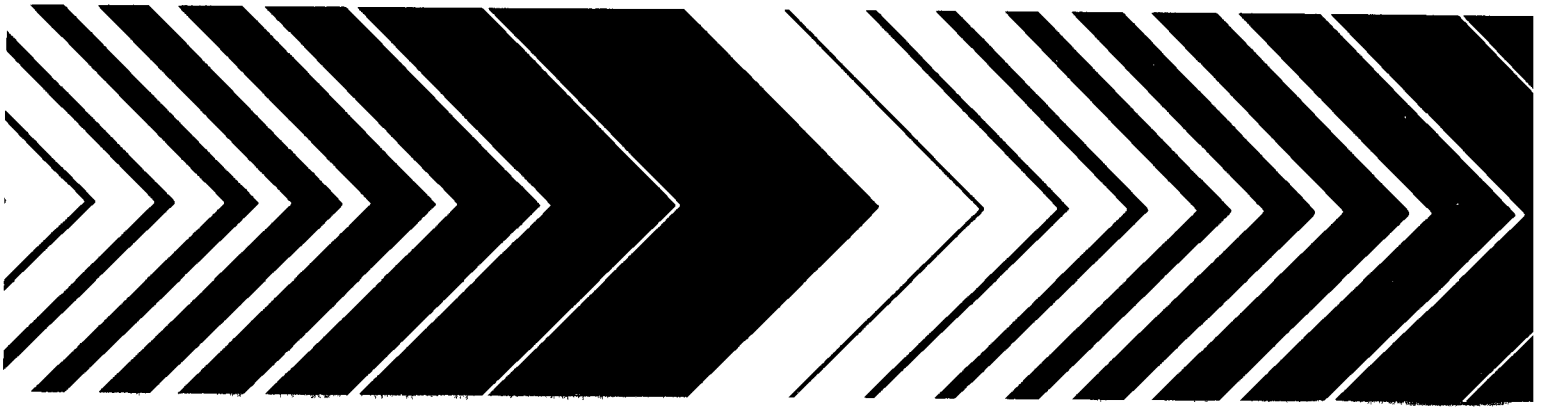
A major portion of applied pesticides end up in soil. Contamination of the soil with pesticides can affect plant growth, contaminate plants and groundwater, and contaminate animals that consume the plants and/or the water. Consideration must be given to the effects of the biotic and abiotic environment on the chemical plus its interactions with other chemicals. The potential movement of pesticides through the food chain was studied by evaluating the relationship between plants, soil, and water. The study consists of research in five related areas: 1) microcosm development; 2) interaction of chemical residues; 3) binding and release of residues in soils; 4) residue fate in flooded soils; and 5) effects of environmental factors and plant type on pesticide uptake and metabolism. This Research Brief summarizes research conducted by Prof. E. Paul Lichtenstein and students in the Department of Entomology, University of Wisconsin, Madison, Wisconsin. For the purposes of this summary, the material will be presented as methods development and data base development with regard to ecosystem interactions and their impact on chemical movement through the food chain. The specific papers that are addressed represent the five related study areas. The research was supported by EPA cooperative agreement CR-804920 and the College of Agriculture and Life Sciences, University of Wisconsin (Project 1387).

Results and Discussion

Methods Development

Traditionally, the transport and effects of chemicals have been studied in isolated laboratory experiments or in field situations. While chemical and physical studies provide key information for use in understanding chemical behavior, they do not account for the complexity of an ecosystem and its attendent interactions which can moderate chemical behavior. Conversely, because of this complexity the results from field studies are often difficult to interpret. Therefore, in parts of this study a model ecosystem or microcosm was used. This approach is an intermediate step, not a complete alternative.

The microcosm utilized in parts of this project was designed to examine chemical movement in both terrestrial and aquatic ecosystems. The focus in the terrestrial portion was on plant uptake and movement through the soil column to groundwater; in the aquatic portion emphasis was placed on chemical introduction via groundwater and subsequent partitioning between the biotic and abiotic components of the simulated pond (Figure 1). The dimensions of the terrestrial portion are 49 cm high, 39 cm deep, and 26 cm wide. Individual components consist of two soil containers, each 10 cm high, 22



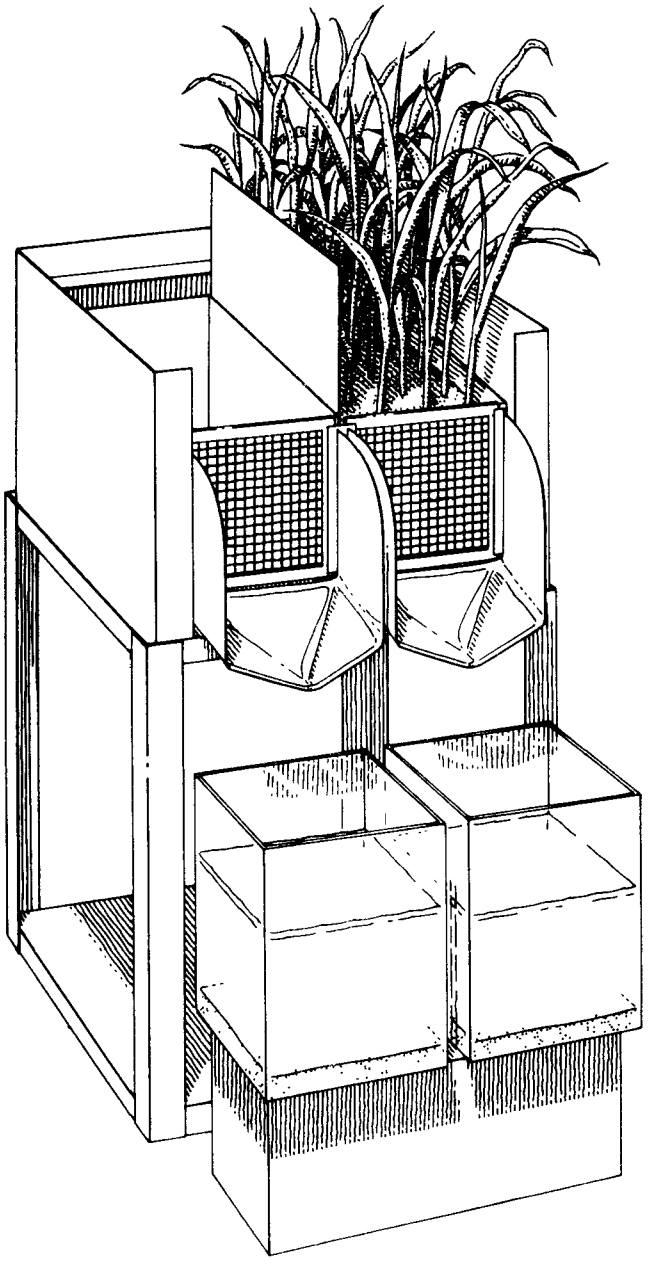


Figure 1. Schematic diagram of soil-plant-water microcosm.

cm deep, and 10 cm wide which are used for plant growth and can be individually placed under different environmental conditions in growth chambers. When rainfall or irrigation are being simulated, the two soil containers are placed into the "runoff container" (10 cm high, 32 cm deep, 21 cm wide) having a divider 20 cm high. This container in turn fits into another (18 cm high, 31 cm deep, and 25.5 cm wide) which by means of an adjustable wingnut screw makes it possible to lift the container at one end. In this way, different slopes are obtained, thus affecting the amount of runoff during irrigation.

Runoff water containing soil was channeled into the aquarium shown in Figure 1. Based on the size of these aquaria and the slope of the soil, the amount of "rain" was adjusted accordingly. To create more realistic conditions, a layer of lake bottom mud was placed into the aquaria before runoff water with soil entered them. When the water appeared clear after settling of the soil, organisms such as water plants, fish or insect larvae were introduced into the aquatic part of this microcosm. Both the containers of the terrestrial part and the aquaria can be placed into climatic chambers with different environmental conditions.

This microcosm can be used to study the effects of rainfall and other environmental conditions on the fate, movement, the potential bioaccumulation, and interaction of one or several test compounds after their application to soils and crops. Thus, problems related to a particular test chemical can be studied in fallow or plant-covered soil, in crop plants grown in this soil, in runoff water containing soil particles, in lake mud deposits, and in various organisms within the aquatic part of this microcosm.

A model experiment using the microcosm was conducted with [^{14}C]phorate as the test compound because of previous experience with phorate in a "model soil-plant ecosystem" (Lichtenstein *et al.*, 1974). Results obtained with the terrestrial and aquatic portions of the microcosms are partially presented in Table I. The total amounts of radiocarbon in the various microcosm components were determined by combustion. With freshly deposited insecticide residues, 94% (91% terrestrial and 3% aquatic) of the applied radiocarbon was recovered as opposed to 82% with aged residues. This difference of 12% was noticed in the terrestrial portions. It is possible that during the first 28 days of the experiment some compounds were lost due to volatilization from the fallow soil.

With the freshly deposited insecticide, the aquatic insecticide residues resulted from two "rainfalls", each of which yielded a soil-water runoff containing 1.5% of the totally applied radiocarbon. Two-thirds of the ^{14}C recovered from the aquaria was associated with the soil lake mud mixture. Within the terrestrial part, most of the ^{14}C residues were recovered from the soil (65% of applied) while 26% was recovered from the corn. Two-thirds of the total radiocarbon content was contained in the leaves.

Corn plants from soils containing "aged" residues had considerably less radiocarbon (19% of applied) than plants from soils containing "fresh" residues (26% of applied). Expressed on a per gram dry weight basis, corn leaves from soil with "aged" residues contained 1.9% of the applied radiocarbon while leaves from soils with "fresh" residues contained 3.1%. Since roots from both soils contained similar amounts of ^{14}C, quantitative differences were observed with leaves of plants grown in the differently aged phorate-treated soils. The amount of test compound transported via soil runoff is likely a function of the physiochemical properties of the chemical itself, such as vapor pressure, volatilization, and water solubility. Moreover, factors such as soil type, slope of the terrain, cover crop (presence and kind), and rain (amount, duration, and intensity) are probably all directly related to the mobility of the particular chemical. The fate and metabolism of a test compound and its potential interaction with other environmental chemicals can easily be studied under different conditions (e.g., various temperatures or light exposures). These results provide additional support for the use of model ecosystems as research tools to aid in the overall understanding of chemical behavior in the environment.

Table I. Fate and Movement of "Aged" and "Freshly" Deposited [^{14}C]phorate Soil Residues in a Plant-Soil Water Microcosm[a]

Recovered From	^{14}C Recovered in Percent of Applied[b] to Soil			
	"Fresh" Residues		"Aged" Residues	
	Total Sample	Per g Wt[c]	Total Sample	Per g Wt
Terrestrial Part				
Soils (S)	65.6 ± 0.5	0.17	60.6 ± 0.4	0.15
Corn (C)				
Leaves	16.9 ± 0.6	3.12	9.8 ± 0.4	1.92
Roots	8.7 ± 0.1	0.80	9.0 ± 0.5	0.86
Total (C)	25.6		18.8	
Total (S + C)	91.2		79.4	
Runoff 1				
Water (W)	0.4 ± 0.1	0.0006	0.2 ± 0	0.0003
Soil (S)	1.1 ± 0.1	0.08	1.1 ± 0.1	0.08
Total (W + S) 1	1.5		1.4	
Runoff 2				
Water (W)	0.5 ± 0.1	0.0008	0.3 ± 0	0.0005
Soil (S)	1.0 ± 0.1	0.08	1.1 ± 0.1	0.08
Total (W + S) 2	1.5		1.4	
Total (1 + 2)	3.0		2.7	
Aquatic Part				
Soil and Lake Mud (S)	2.0 ± 0	0.03	1.5 ± 0.1	0.02
Water (W)	0.8 ± 0.1	0.0008	0.6 ± 0.1	0.0005
Guppies (G)	0.02 ± 0	0.08	0.01 ± 0	0.04
Salvinia (P)	0.2 ± 0.1	0.29	0.1 ± 0	0.18
Total (S, W, G, P)	3.2		2.21	
Total				
Terrestrial (T)	91.2		79.4	
Aquatic (A)	3.02		2.21	
T + A	94.22		81.61	

[a] Results determined by combustion to $^{14}CO_2$, except water, are averages of duplicated tests.
[b] Applied [^{14}C]phorate at 4 ppm to 450 g of soil (9.83 μCi).
[c] Per gram of dry weight of per milliliter of water.

Data Base Development

Agricultural chemicals rarely, if ever, exist in isolation in the environment. The transport of the chemical between ecosystem components, its effects and its degradation are affected by environmental conditions (e.g., temperature, moisture, and soil type), the presence of other chemicals, the presence and type of plants as well as numerous other factors. The balance of this project was dedicated to exploring certain interactions that occur in ecosystems and how they effect the movement of chemicals in particular into plants as the first step in a food chain to man.

Comparative Chemical Transport and Metabolism

It has been commonly accepted that certain chemical properties can aid in predicting the environmental behavior of chemicals; however, most environmental studies have dealt only with the behavior of one or two compounds at a time. These studies have provided a large volume of data on environmental fate and behavior of individual compounds. However, the comparative behavior of different compounds is difficult to assess since the environmental conditions associated with the various studies can differ considerably.

One of the major areas in this project was the comparative examination of the persistence, translocation and metabolism of six different insecticides in two different soil types under identical environmental conditions. The insecticides used in order of increasing water solubility were [^{14}C]DDT, [^{14}C]*lindane*, [^{14}C]*fonofos*, [^{14}C]*parathion*, [^{14}C]*phorate*, and [^{14}C]carbofuran. These six chemicals represent three major classes of insecticides; organochlorine, organophosphorus and carbamate. The soil plant test system consisted of either Plano silt loam or Plainfield sand and oats *(Avena sativa)* maintained in the University of Wisconsin Biotron. Table II provides a summary of the results from this study. Total amounts of ^{14}C residues recovered from insecticide-treated loam soils plus oats grown in these soils were similar with DDT and carbofuran. They were also higher than those observed with the other insecticides. While most of the [^{14}C]DDT residues remained in the soils, most of the [^{14}C]carbofuran residues were recovered from oat leaves in the form of carbofuran and 3-hydroxycarbofuran. ^{14}C residues of all insecticides were more persistent in loam than in sandy soil and sand-grown oats took up more ^{14}C insecticide residues than loam-grown oats. The more water-soluble insecticides [^{14}C]phorate and [^{14}C]carbofuran were more mobile and were metabolized to a greater extent than insecticides of lower water solubilities. Unextractable (bound) ^{14}C residues in loam soil ranged from 2.8 to 29.1% of the applied doses of [^{14}C]DDT and [^{14}C]parathion, respectively.

Table II. Summary of Uptake, Translocation, Distribution, and Metabolism of Six ^{14}C Insecticides in Oat Plants Grown in Insecticide-Treated Soils

Extraction Phases[a]		Radiocarbon Recovered in Percent of ^{14}C Insecticides Applied to Soils From					
		Loam Soil[b]			Sandy Soil[c]		
		Soil	Oat Roots	Oat Tops	Soil	Oat Roots	Oat Tops
				p,p'-DDT			
Extractable	LSC	95.4 ± 0.3	0.4 ± 0.1	0.2 ± 0.2	83.3 ± 3.0	4.2 ± 0.7	0.2 ± 0.0
	TLC						
	DDT	90.4[d]	0.2[d]	NA[e]	80.4[d]	4.2[d]	NA
	DDE	3.4[d]	0.0	NA	2.2[d]	0.2[d]	NA
	Other[f]	1.7	0.0	NA	1.4	0.2	NA
Bound[g]	LSC	2.8 ± 0.4	0.0 ± 0.0	0.1 ± 0.0	0.7 ± 0.3	0.1 ± 0.0	0.1 ± 0.0
				Lindane			
Extractable	LSC	62.1 ± 1.5	0.4 ± 0.2	0.4 ± 0.0	45.6 ± 3.6	2.4 ± 1.0	1.8 ± 0.2
	TLC						
	Lindane	53.5[d]	0.5[d]	0.3[d]	33.8[d]	2.5[d]	1.2[d]
	Unknown[h]	6.8	0.0	0.0	5.5	0.4	0.0
	Other	1.7	0.0	0.0	2.0	0.3	0.0
Bound	LSC	4.6 ± 1.2	0.1 ± 0.0	0.1 ± 0.0	1.3 ± 0.2	1.0 ± 0.2	0.2 ± 0.0
				Fonofos			
Extractable	LSC	49.4 ± 4.0	0.4 ± 0.0	2.5 ± 0.1	37.9 ± 4.2	1.9 ± 0.4	3.2 ± 0.2
	TLC						
	Fonofos	42.8[d]	0.1[d]	0.0	29.4[d]	0.8[d]	0.1[d]
	-oxon	0.5[d]	0.0	0.0	1.1[d]	0.1[d]	0.2[d]
	Other	5.4	0.0	0.4	1.7	0.2	0.1
Bound	LSC	15.6 ± 0.3	1.2 ± 0.1	0.2 ± 0.0	9.3 ± 0.8	4.7 ± 0.8	0.4 ± 0.0
				Parathion			
Extractable	LSC	43.2 ± 2.2	0.2 ± 0.0	0.4 ± 0.0	55.3 ± 4.3	2.5 ± 0.1	2.6 ± 0.4
	TLC						
	Parathion	40.0[d]	0.1[d]	0.1[e]	50.8[d]	1.1[d]	0.8[d]
	-oxon	0.5[d]	0.0	0.0	2.4[d]	0.1[d]	0.6[d]
	Other	1.6	0.0	0.0	0.4	0.4	0.1
Bound	LSC	29.1 ± 1.0	0.7 ± 0.1	0.3 ± 0.0	6.0 ± 1.7	5.3 ± 0.7	1.2 ± 0.1
				Phorate			
Extractable	LSC	56.4 ± 4.0	0.2 ± 0.1	6.3 ± 0.7	22.2 ± 1.2	0.8 ± 0.1	26.7 ± 1.6
	TLC						
	phorate	2.4	0.0	0.0	3.7	0.0	0.0
	-sulfoxide	24.0[d]	0.1[d]	0.4[d]	12.1[d]	0.2[d]	7.3[d]
	-sulfone	26.1[d]	0.1[d]	0.5[d]	3.5[d]	0.2[d]	3.6[d]
	Other	1.2	0.0	0.9	1.7	0.0	4.4
Bound	LSC	13.1 ± 0.8	0.3 ± 0.1	0.8 ± 0.1	4.5 ± 0.1	2.7 ± 0.1	3.2 ± 0.4
				Carbofuran			
Extractable	LSC	30.6 ± 0.6	0.7 ± 0.1	51.7 ± 5.1	10.4 ± 3.2	2.8 ± 0.6	61.1 ± 4.0
	TLC						
	Carbofuran	23.5[d]	0.1[d]	5.1[e]	5.7[d]	0.3[d]	7.9[d]
	3-keto-	2.5	0.0	1.6	0.8	0.1	2.7
	3-hydroxy-	1.0	0.1[d]	24.9[d]	1.6[d]	0.3[d]	27.1[d]
	Other	1.8	0.0	8.7	0.9	0.3	8.4
Bound	LSC	10.4 ± 1.0	1.0 ± 0.2	3.0 ± 0.2	0.8 ± 0.1	2.8 ± 0.1	2.5 ± 0.1

[a] Analyses of the extraction phases were conducted by LSC and TLC. For metabolism studies, compounds were separated by TLC, eluted, and quantitated by LSC.
[b] Applied 4 ppm (2.2 - 5.5 μCi) of ^{14}C insecticides to 550 g of silt loam soil. Results are means ± SD for three replicates.
[c] Applied 2 ppm (2.8 - 7.0 μCi) of ^{14}C insecticides to 700 g of Plainfield sand. Results are means ± SD for three replicates.
[d] Identity confirmed by GLC.
[e] Not analyzed.
[f] Compounds included in "other" are described in text.
[g] Unextracted radiocarbon remaining in soils or plant pulp determined by combustion to $^{14}CO_2$.
[h] Unknown; suspected to be γ-PCCH based on report by Yule *et al.* (1967). No authentic reference compound available for comparison.

Bound ^{14}C residues were higher in oats grown in the sandy soil than in loam-grown oats. The oxygen analogue metabolites of the organophosphorus insecticides were most abundant in the sandy soil and in oats grown therein. Data illustrate the importance of chemical structure, water solubility, and soil type in predicting the comparative environmental behavior of pesticides.

Chemical Interactions

Effects of Parathion Residues in Soil on the Fate of [^{14}C] Parathion

Pretreatment of cranberry soils with parathion or p-nitrophenol considerably increased the degradation of [ring-^{14}C]parathion. This is indicated by the increase in the evolution of $^{14}CO_2$, as shown in Figure 2. The effects of soil pretreatment were in particular evident one day after soil treatment with [^{14}C]parathion. While in controls only 2% of the applied radiocarbon had been released as $^{14}CO_2$, this figure amounted to 34% and 39% with soils pretreated with p-nitrophenol or parathion, respectively.

Effects of Selected Fungicides on the Fate of [Ring-^{14}C]Parathion in Cranberry Soils

As shown in Table III, the degradation of [^{14}C]parathion was considerably inhibited by captafol, since 66% of the applied insecticide was still present in these soils, as opposed to only 3% in controls. The decreased metabolism of the insecticide is also indicated by a significant reduction in bound radiocarbon. Captafol apparently inhibited these soil microorganisms which are usually responsible for the degradation of the insecticide. The effects of captafol on the biodegradation of [^{14}C]parathion were similar to those observed with autoclaved soils.

Maneb also inhibited $^{14}CO_2$ evolution from [^{14}C]parathion but not the total degradation of the insecticide. As shown in Table III, only 8% of the applied insecticide was recovered; yet considerably more benzene-soluble radiocarbon (23%) was still present. Thin-layer chromatography of the benzene extraction phase revealed the presence of p-amino[^{14}C]phenol

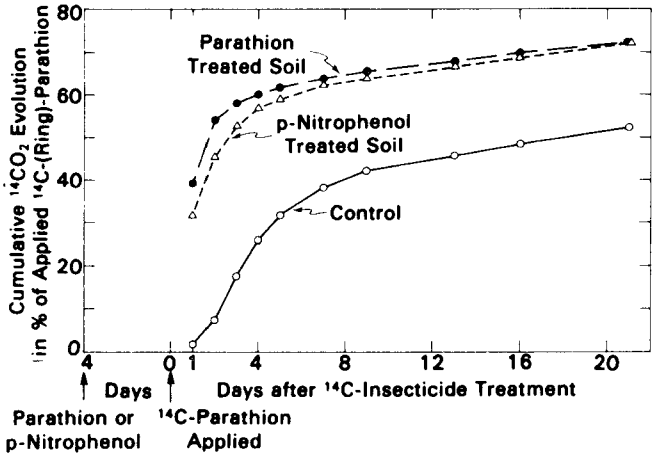


Figure 2. Effect of parathion or p-nitrophenol in soil on the evolution of $^{14}CO_2$ from soil-applied [ring-^{14}C] parathion. Results are means of duplicate tests and represent accumulated $^{14}CO_2$ evolution.

in addition to [^{14}C]parathion. As demonstrated by Katan and Lichtenstein (1977), binding of parathion residues to soils occurs after the insecticide has been reduced to amino compounds. Thus, in the presence of maneb, 66% of the soil-applied radiocarbon was unextractable as opposed to 38% with control soils. It appears, therefore, that maneb did not affect soil microorganisms which are responsible for the reduction of parathion in cranberry soils.

Benomyl affected [^{14}C]parathion degradation, although to a lesser extent than did captafol and maneb. Thus, in benomyl-treated soils the amount of $^{14}CO_2$ evolved was only 18% of the applied radiocarbon. As with maneb, the presence of benomyl in the soil resulted in recoveries of larger amounts of benzene-soluble radiocarbon and in increased binding of ^{14}C-labeled compounds.

The fungicide PCNB did not affect the fate of [^{14}C]parathion in cranberry soils. This fungicide is not harmful to bacteria; in some cases, it increases their number in soils.

Effects of Selected Herbicides on the Fate of [^{14}C]Parathion in Cranberry Soils

Results obtained in experiments with 2,4-D and [^{14}C]parathion showed that the persistence of parathion in cranberry soils was increased in the presence of the herbicide, 2,4-D. Thus, after three weeks of incubation, only 2.09 ± 0.31% of the applied [^{14}C]parathion could be recovered from control soils, but 12.2 ± 2.3% of the applied [^{14}C]parathion was recovered from 2,4-D-treated soils. This suggests that 2,4-D may have inhibited the reduction of [^{14}C]parathion by affecting the activity of nitroreductase-producing microorganisms.

Effects of Fertilizers on the Fate of [^{14}C]Parathion in Cranberry Soils

Some nitrogen fertilizers can indeed inhibit the degradation of [^{14}C]parathion in cranberry soils. Thus, application of $(NH_4)_2SO_4$ to [^{14}C]parathion-treated cranberry soils inhibited the degradation of the insecticide to $^{14}CO_2$, since only 8% of the applied radiocarbon evolved as $^{14}CO_2$ during the 3-week incubation period. In controls, however, this figure amounted to 46%. Potassium nitrate also reduced the formation of $^{14}CO_2$ but not to the extent observed with $(NH_4)_2SO_4$. Addition of NH_4NO_3 or urea to [^{14}C]parathion-treated soils had no apparent effect.

Results obtained after extraction and analyses of fertilizer-treated soils and vapor traps are summarized in Table IV. Although under all experimental conditions the total amounts of ^{14}C recovered were similar, the distribution of ^{14}C-labeled compounds into benzene-soluble, water-soluble, and bound residues was not, thus possibly indicating a drift in the pathway of [^{14}C]parathion degradation. The insecticide was most persistent in soils containing $(NH_4)_2SO_4$. This is demonstrated by a recovery of 29% of the applied radiocarbon in the benzene-soluble form. Analyses by TLC and autoradiography of this benzene extraction phase reversed the presence of [^{14}C]parathion, p-amino [^{14}C]phenol, and amino[^{14}C]parathion. Compared to controls, some increase in bound radiocarbon was also noticeable in the presence of $(NH_4)_2SO_4$. Inhibitory effects of KNO_3 on parathion metabolism were also evident after extraction and analyses of soils and vapor traps (Table IV). All analytical results obtained with fertilizers in the form of NH_4NO_3 or urea were similar to those observed with controls (Table IV).

Table III. Effects of Fungicides[a] on the Fate of [Ring^{14}C]Parathion[c] in Cranberry Soil[b]

	^{14}C Recovered in Percent of Applied [Ring-^{14}C]Parathion in Cranberry Soil Plus:				
	None (Control)	Difolatan (Captafol)	Manzate (Maneb)	Benlate (Benomyl)	Terraclor (PCNB)
Soil					
Extraction Phases					
Benzene^{14}C	7.30 ± 2.03	74.8 ± 10.2[f]	22.9 ± 2.1[f]	16.7 ± 1.78[g]	4.93 ± 0.25
Parathion[d]	2.83 ± 1.01	65.6 ± 14.0	8.00 ± 3.6	4.12 ± 0.88	1.40 ± 0.17
Water	0.69 ± 0.55	1.02 ± 0.02	0.67 ± 0.19	0.47 ± 0.05	0.56 ± 0.04
Bound[e]	37.5 ± 2.1	6.63 ± 2.59[f]	65.6 ± 5.7[g]	56.0 ± 5.9[g]	39.1 ± 1.04
Vapor Traps					
Polyurethane	1.45 ± 0.22	2.83 ± 0.46[g]	2.78 ± 0.20[g]	1.76 ± 0.20[g]	1.61 ± 0.14
KOH ^{14}C	44.5 ± 3.0	7.72 ± 6.78[g]	2.87 ± 1.58[f]	18.4 ± 4.4[g]	44.0 ± 1.7
% of Control	100	17	6.4	41	99
Total	91.4 ± 2.5	93.0 ± 3.5	94.9 ± 2.4	93.3 ± 1.8	90.2 ± 0.05

[a] Captafol (analytical grade) and commercial formulations of Manzate, Benlate, or Terraclor were mixed with soil at 100 ppm of Al on a dry weight basis.
[b] Results obtained after 3 weeks of incubation are means ± SD of triplicate tests.
[c] Applied [ring-^{14}C]parathion (0.34 μCi) at 8.5 μg/cm^2.
[d] Determined by GLC.
[e] Unextractable, bound ^{14}C.
[f,g] Data are significantly different from respective controls (none) at the 0.1%[f] and 1%[g] level (Student's t-test).

Table IV. Effects of Nitrogen Fertilizers[a] on the Fate of [Ring^{14}C]Parathion in Cranberry Soils[b]

	^{14}C Recovered in Percent of Applied [Ring-^{14}C]Parathion[c] in Cranberry Soil Plus:				
	None (Control)	$(NH_4)_2SO_4$	KNO_3	NH_4NO_3	Urea
Soil					
Extraction Phases					
Benzene	5.47 ± 0.39	28.7 ± 9.4	12.1 ± 1.7	5.86 ± 0.55	5.26 ± 0.11
Water	0.37 ± 0.09	0.70 ± 0.28	0.65 ± 0.11	0.57 ± 0.05	0.50 ± 0.36
Bound[d]	33.7 ± 0.06	48.6 ± 10.4	42.4 ± 4.8	31.5 ± 0.7	36.7 ± 1.3
Vapor Traps					
Polyurethane	2.21 ± 0.44	3.90 ± 1.0	3.55 ± 0.39	1.88 ± 0.89	2.10 ± 0.56
KOH	45.8 ± 1.0	7.94 ± 0.83	29.5 ± 0.51	48.7 ± 1.1	45.4 ± 0.07
Total	87.5 ± 0.4	89.8 ± 0.6	88.2 ± 1.7	88.6 ± 0.6	89.9 ± 1.6
Soil pH After:					
No Incubation	5.97 ± 0.02	5.34 ± 0.04	5.24 ± 0.03	5.37 ± 0.03	6.06 ± 0.01
3-Week Incubation	5.64 ± 0.06	5.14 ± 0.15	6.69 ± 0.04	6.06 ± 0.07	6.40 ± 0.06

[a] Mixed with soils at 100 ppm of nitrogen equivalent.
[b] Results obtained after 3 weeks of soil incubation are averages of duplicate tests.
[c] [Ring-^{14}]Parathion (0.81 μCi) was applied to the soil surface at 8 μg/cm^2.
[d] Unextractable, bound ^{14}C.

Plant/Soil Interactions

In two interrelated studies in soil/plant interactions the following phenomena were examined: 1) effect of plant cover on chemical transport; and 2) comparative chemical uptake by C_3 and C_4 plants.

1) The microcosm described above under "Results and Discussion" was used to evaluate the effect of plants (corn or ryegrass) on the movement and metabolism of a soil-applied ^{14}C fonofos. Fonofos plus its metabolites were least persistent with bare soils and most persistent with ryegrass (Table V). ^{14}C materials transported out of the terrestrial portion of the microcosm were primarily associated with the sediment portion of the runoff and subsequently were found in the lake and sediments. ^{14}C fonofos was the major constituent in both soils and aquatic sediments with the major metabolite identified as the methyl phenyl sulfone. This study emphasizes the considerable effect that the presence of plants as well as type can have on chemical mobility and metabolism.

2) As indicated above, plant type plays an important role in the dispersal of a chemical in an ecosystem. Differences in physiology and/or anatomy can effect uptake and translocation of materials from the surrounding medium. To evaluate the effects of plant physiology on chemical transport, comparative study of water transpiration, and chemical uptake and metabolism by C_3 C_4 plants was conducted. To eliminate possible differences due to plant genera *Atriplex patula* (C_3) and *Atriplex rosea* (C_4) in addition were included as test species as well as other representatives of C_3 (oats, peas, barley, and wheat) and C_4 (corn, sorghum, millet) plants. C_3 plant transpired 2.5 times more water and took up twice as much [^{14}C] phorate residues than did C_4 plants (Table VI), indicating a direct correlation between water transpiration and ^{14}C uptake.

Differences in the metabolism of [^{14}C]phorate in C_3 and C_4 plants are also evident when the amounts of benzene-soluble, water-soluble and unextractable (bound) radiocarbon are compared (Table VII).

Table V. Effects of Cover Crops on the Fate and Movement of ^{14}C-(R)-Fonofos in a Soil-Plant-Water Microcosm (Results are Expressed as Averages of the Amounts of Radiocarbon Recovered from Duplicated Tests)

	Terrestrial Soil Containing ^{14}C-Fonofos[a] Plus					
	Fallow		Corn		Rye Grass	
Recovered From	Total Sample	Per g Wt[b]	Total Sample	Per g Wt	Total Sample	Per g Wt
	^{14}C-Recovered[c] in Percent of Applied to Upper Soil Layer[a]					
Terrestrial Part	19.3 ± 0.9	0.06	31.9 ± 0.5	0.08	58.3 ± 0.0	0.14
Soil (S)	5.5 ± 0.5	0.02	8.4 ± 1.2	0.02	6.4 ± 1.5	0.02
U[a]	24.8		40.3		64.7	
Crops (C)						
Leaves	–		5.5 ± 0.6	0.87	4.8 ± 0.01	1.72
Roots			6.7 ± 0.3	1.67	9.9 ± 0.1	2.29
Total (C)			12.2		14.7	
Total (S + C)	24.8		52.5		79.4	
Runoff 1						
Water (W)	2.4 ± 0.2	0.004	1.5 ± 0.1	0.003	1.0 ± 0.1	0.002
Soil (S)	10.7 ± 0.1	0.19	4.8 ± 0.5	0.21	0.3 ± 0.1	0.11
W + S (1)	13.1		6.3		1.3	
Runoff 2						
Water (W)	1.9 ± 0.2	0.003	0.8 ± 0.1	0.002	1.0 ± 0.1	0.002
Soil (S)	8.4 ± 0.3	0.18	2.9 ± 0.2	0.17	0.3 ± 0.0	0.04
W + S (2)	10.3		3.7		1.3	
Runoff 3						
Water (W)	1.0 ± 0.1	0.002	0.4 ± 0.1	0.001	0.6 ± 0.1	0.001
Soil (S)	8.4 ± 0.3	0.18	2.9 ± 0.2	0.17	0.3 ± 0.0	0.04
W + S (3)	10.3		3.7		1.3	
Total (1 + 2 + 3)						
Water (W)	5.3 ± 0.1		2.7 ± 0.0		2.6 ± 0.1	
Soil (S)	26.8 ± 1.2		10.0 ± 0.7		0.9 ± 0.1	
W + S	32.1		12.7		3.5	
Aquatic Part						
Salvinia (P)	0.24 ± 0.1	0.91	0.11 ± 0.01	0.45	0.06 ± 0.01	0.20
Elodea (E)	0.46 ± 0.02	0.79	0.14 ± 0.01	0.27	0.10 ± 0.01	0.18
Guppies (G)	0.12 ± 0.02	0.34	0.04 ± 0.01	0.09	0.04 ± 0.00	0.09
Water (W)	3.24 ± 0.26	0.002	1.38 ± 0.21	0.001	0.48 ± 0.03	0.001
Soil + Lake Mud (S)	24.5 ± 1.56	0.14	7.63 ± 0.67	0.14	1.54 ± 0.03	0.12
Total (P, E, G, W, S)	28.6		9.30		2.22	
Total						
Terrestrial (T)	24.8		52.5		79.4	
Aquatic (A)	28.6		9.3		2.2	
T + A	53.4		61.8		81.6	

[a] ^{14}C-Ring-Fonofos applied at 4 ppm (5.2 μCi) to upper 200 g Plano silt loam soil layer which was then placed on top of 800 g of untreated soil. Recovery data, however, refer to the upper ½ (U) and the lower ½ (L) layer of soil.
[b] Per g of dry weight or per ml of water.
[c] Except water, all materials were combusted to $^{14}CO_2$.

These data emphasize the importance of plant type with respect to both chemical uptake and metabolism.

Conclusions

1. Chemical behavior in the environment is affected by its interactions with other chemicals.
2. Chemical/environmental component interactions (soil type, plant abundance, and plant type) are of considerable importance in understanding how chemicals move through the food chain.
3. The soil-plant-water microcosm is useful in describing transport and metabolism of chemicals under controlled conditions.

Project Publications and Related Articles

Anderegg, B.N., Lichtenstein, E.P., and Kemp, J.D. Effects of lindane on DNA, RNA and protein synthesis in corn roots. J. Agr. Food Chem. 25(4):923-928 (1977).

Anderegg, B.N., and Lichtenstein, E.P. Effects of light intensity and temperature on the uptake and metabolism of ^{14}C-phorate by oat, pea, and corn plants. From Ph.D. Thesis. Available at University of Wisconsin Library and also on microfilm, Ann Arbor, Michigan. Submitted for publication (1980).

Anderegg, B.N., and Lichtenstein, E.P. A comparative study of water transpiration on the uptake and metabolism of ^{14}C-phorate by C_3 and C_4 plants. J. Agr. Food Chem. 29:733-738 (1981).

Table VI. Influence of Water Transpiration on the Uptake of Radiocarbon from [^{14}C]Phorate-Treated Soil by C_3 and C_4 Plants[a]

Expt.	C_3 Plants	ml of Water Transpired/g Fresh Weight of Greens	C_4 Plants		C_3/C_4[b]
I	*A. patula*	75.4 ± 3.1	*A. rosea*	55.3 ± 3.8	
II	Pats	127.0 ± 12.2[c]	Corn	52.2 ± 4.4	
III	Barley	134.4 ± 1.1	Sorghum	57.0 ± 2.0	
	Wheat	118.5 ± 4.8	Millet	39.5 ± 2.6	
	Average	114.7		51.0	2.25

Expt.	C_3 Plants	Radiocarbon Recovered/g of Plant Tops, Percent of [^{14}C]Phorate Applied to Soil	C_4 Plants		C_3/C_4[b]
I	*A. patula*	4.77 ± 0.35	*A. rosea*	3.90 ± 0.06	
II	Oats	7.59 ± 0.19[d]	Corn	3.14 ± 0.29	
	Peas	6.53 ± 1.12[d]			
III	Barley	10.0 ± 1.20	Sorghum	4.70 ± 0.06[e]	
	Wheat	7.80 ± 0.62	Millet	2.93 ± 0.21[e]	
	Average	7.34		3.67	2.00

[a] Results are means ± SD of triplicate tests (I and II) or averages of duplicate tests (III). Grown in a Plainfield sand treated with [^{14}C]phorate at 1 ppm (4.3 μCi, for experiments I and II) or at 0.5 ppm (2.2 μCi, for experiment III). Growing conditions in experiment I were 32 °C, 50% relative humidity, in experiment II, 28 °C, 35% relative humidity, and in experiment III, 28 °C, 30% relative humidity.
[b] C_3/C_4 = ratio between average milliliters of water transpired or the average ^{14}C recovered from C_3 and C_4 plants, respectively.
[c-e] Within each block (I, II, III), data without a letter in common are significantly different (5% level, Duncan's new multiple range test).

Table VII. Metabolism of [C^{14}C]Phorate in Oat (C_3) and Corn ($_4$) Plants

Extraction Phase	^{14}C Recovered, Percent of [^{14}C]Phorate Applied[a] (per g[b]) Oats (C_3)	Corn (C_4)
Tops		
Benzene	2.92 ± 0.05	1.52 ± 0.32[e]
Water	3.83 ± 0.08	1.27 ± 0.07[d]
Bound[c]	0.84 ± 0.18	0.35 ± 0.04[f]
Total	7.59 ± 0.19	3.14 ± 0.29[d]
Roots		
Benzene	0.09 ± 0.01	0.06 ± 0.01[f]
Water	0.12 ± 0.02	0.11 ± 0.01
Bound	0.95 ± 0.04	0.18 ± 0.02[d]
Total	1.16 ± 0.06	0.35 ± 0.03[d]

[a] Results of triplicate tests.
[b] Per gram of fresh weight.
[c] Unextractable ^{14}C residues as determined by combustion to $^{14}CO_2$.
[d] Significant difference at the 0.1% (students t-test).
[e] Significant difference at the 1.0%.
[f] Significant difference at the 5.0%.

Ferris, I.G., and Lichtenstein, E.P. Interactions Between Agricultural Chemicals and Soil Microflora and Their Effects on the Degradation of [^{14}C]Parathion in a Cranberry Soil. J. Agr. Food Chem. 28(5):1011-1019 (1980).

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☆USGPO: 1982 — 559-092/0497