Chlordane Uptake and Its Translocation in Food Crops

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Chlordane is a member of the persistent organic pollutants (POPs), a group of chemicals characterized by extremely long residence in the environment after application. Technical chlordane, composed of a large number of components, is a synthetic organochlorine substance that was used primarily as an insecticide. Uptake by root crops of persistent soil residues of chlordane was noted early in the chronology of the material. The present report is the first comprehensive study of the uptake of weathered soil residues of chlordane and its translocation throughout the tissues of food crops under both greenhouse and field conditions. The data show that for all 12 crops chlordane is not limited to root tissue but is translocated from the root to some of the aerial tissues. Chlordane accumulation in edible aerial tissue appears to be dependent on plant physiology. As expected, chlordane was detected in the edible root tissue of the three root crops examined, carrots, beets, and potatoes. In the remaining crops chlordane was detected in the edible aerial tissue of spinach, lettuce, dandelion, and zucchini, whereas it was not detected in edible aerial tissue of tomatoes, peppers, and corn; trace amounts of chlordane were detected in the edible aerial tissue of bush beans and eggplant. Under the conditions of the field trial the data indicate that for weathered chlordane residues, the soil-to-plant uptake route dominates over the air-to-plant uptake route. This is the case even when the soil concentration of the recalcitrant, weathered residues, for which volatilization is expected to be minimal, is as high as it would be directly following application. Greenhouse trials confirm this observation for zucchini, a member of the Cucurbitaceae family, which bioaccumulates weathered chlordane very efficiently in its edible fruits.

Keywords: *Organochlorine pesticides; persistent organic pollutants; weathered pollutant residues; chlordane; pollutant uptake by plants*

INTRODUCTION

The organochlorine pesticides came into widespread use in the United States in the 1940s. Beginning with the insecticide benzene hexachloride (BHC) (Harvey et al., 1950), reports began to appear in the literature in the early 1950s regarding the persistence of these synthetic compounds in soil. Because of this long-term persistence in the environment, insecticides such as DDT, aldrin, dieldrin, heptachlor, chlordane, and other anthropogenic compounds such as polychlorinated biphenyls (PCBs), dioxins (polychlorinated dibenzo-*p*-dioxins; PCDDs), and furans (polychlorinated dibenzofurans; PCDFs), are collectively referred to as persistent organic pollutants (POPs) (Wania et al., 1996). In the 1950s and 1960s E. P. Lichtenstein, an entomologist at the University of Wisconsin, Madison, WI, published extensively on the persistence of chlorinated hydrocarbon insecticides in soil and their translocation in plants (Lichtenstein, 1959, 1960; Lichtenstein and Schulz, 1960, 1965; Lichtenstein et al., 1965a). Most of Lichtenstein's work, as well as that of others (Harris et al., 1967; Ahrens et al., 1968), focused on root crops, although cucumbers (Lichtenstein, 1960; Lichtenstein et al., 1965b), lettuce (Lichtenstein, 1960), alfalfa (King et al., 1966), and soybeans (Bruce et al., 1966) were included in some trials.

In 1990 this laboratory became interested in what appeared to be selective crop uptake of POPs. As part of our annual marketbasket survey of pesticide residues in produce sold in Connecticut, crops from a local farm at which synthetic pesticides had not been used for the preceding decade were analyzed. Chlordane and heptachlor epoxide were detected in summer squash and cantaloupe from this location (Pylypiw et al., 1991). Similarly, in 1996 chlordane was detected in summer and winter squash, as well as in sweet potatoes, from a different Connecticut farm at which synthetic pesticides had not been used for the preceding 20 years (Pylypiw et al., 1997). An examination of the marketbasket data from 1990 through 1997 suggested that certain crops, the Cucurbitaceae (e.g., cucumber, squash, pumpkin) in particular, tended to contain residues of POPs in their edible portion with greater frequency than other crops, including root crops (Pylypiw et al., 1997). As far back as 1965 uptake of aldrin and heptachlor by cucumbers (Lichtenstein et al., 1965b) and chlordane by squash (Thruston, 1965) was reported, and in 1991 squash uptake of DDE was noted (Pylypiw et al., 1991). In 1994 it was remarked that uptake of PCDD/PCDF by a member of the Cucurbitaceae family, zucchini, was "exceptionally high" when compared with other plants (Hülster et al., 1994). This explicit statement regarding Cucurbitaceae had been implicit in Lichtenstein's (Lichtenstein et al., 1965b) work reported almost 30 years earlier.

The experiments reported here were designed to investigate the apparent selectivity of the uptake of

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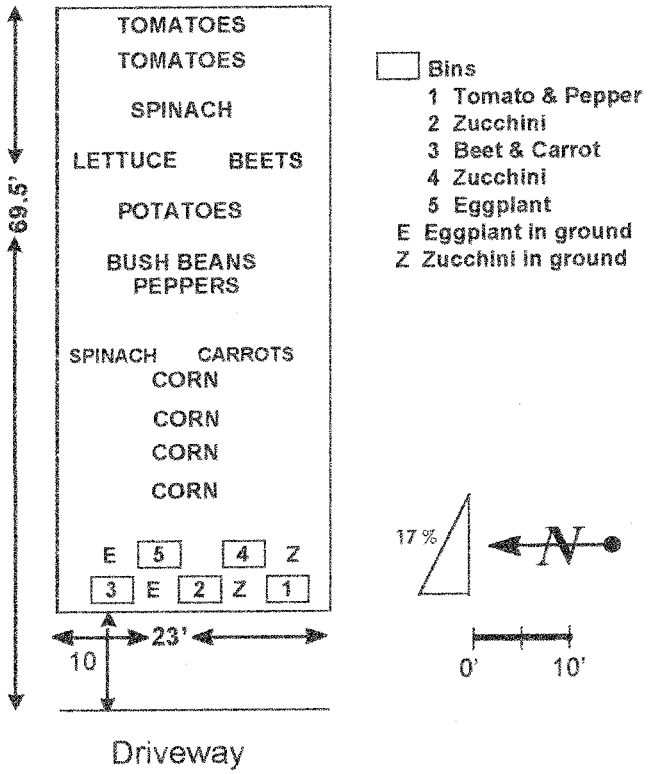

Figure 1. Schematic of field trial.

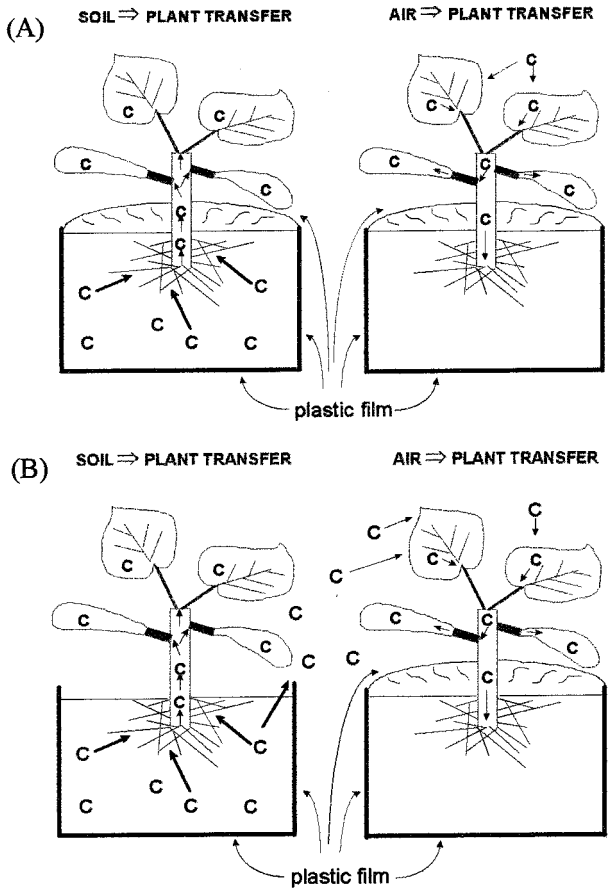

Figure 2. Schematic of greenhouse trials.

weathered chlordane residues in soil. Twelve food crops were grown in the field in soil containing weathered chlordane, and the chlordane concentration in different plant tissues was determined for each of the 12 crops. The relative importance of the soil-to-plant uptake pathway versus the air-to-plant uptake pathway was also assessed for several crops in the field trial and for zucchini, a member of the Cucurbitaceae, in greenhouse experiments.

EXPERIMENTAL PROCEDURES

Field Trial. In April 1960 technical chlordane was applied to a portion of the lawn at the New Haven campus of The Connecticut Agricultural Experiment Station (CAES) to investigate its herbicidal efficacy. The rate and location of application were recorded at the time (Mattina et al., 1999). In April 1998 the turf was removed from a portion of the chlordane-treated area and the soil was fertilized and rototilled. Beginning in April 1998 crops were planted in the experimental plot on our New Haven campus at the locations shown in Figure 1 with the exception of dandelion, which was opportunistic. Spinach plants were both direct seeded in the field ("direct spinach" in Figure 4) or started in Pro-mix (Premier Horticulture, Riviere-du-Loup, PQ, Canada) and transplanted to the field plot ("trans spinach" in Figure 4). The entire plot was covered with a straw mulch and watered as required. During the next several months aerial plant tissue was harvested and roots were collected at the final destructive harvest of each crop. Edible tissue was harvested for all crops at marketable size.

Five plastic bins measuring 30 in. × 20 in. × 15 in. deep were filled with a 2 in. layer of marble chips, which was covered with a sheet of fiberglass screening, and filled with "clean" soil to within 1 in. of the bin top. The bins were buried in the soil of the plot to within 1 in. of their top edge. The soil around each bin on the east-facing side was scooped away, several 1 in. diameter drainage holes were punctured in this side of each bin, and the drainage trough was lined with straw mulch. After a trickle hose was laid over the soil in the bins, each bin was covered with a sheet of clear 4 mil plastic. The purpose of the plastic covering was to reduce or eliminate contamination of the "clean" soil by the contaminated surrounding soil and by atmospheric deposition. The plastic was cut minimally so that the crops noted in Figure 1 could be planted in the bins.

Greenhouse Trials. Five adjacent bays, each measuring 1 ft × 3 ft × 3.5 ft, were constructed on a cement greenhouse trough. The construction assured isolation of the soil, plant roots, and irrigation water in each bay from those in adjacent bays. Alternate bays were filled with chlordane-contaminated soil or "clean" soil. The soil in each bay was fertilized, and trickle hosing was laid on top of the soil for irrigation. The minimum greenhouse temperature maintained was 20 °C; natural light was supplemented with sufficient artificial light to achieve conditions adequate for growth.

Greenhouse Trial 1. This trial was conducted from October 1997 to January 1998 and is shown schematically in Figure 2A. Once the bays were filled with soil, the contaminated soil in bays 1, 3, and 5 and the "clean" soil in bays 2 and 4 were covered with plastic. The purpose of the plastic covering was again to reduce or eliminate contamination of the "clean" soil by the contaminated soil in adjacent bays and to minimize soil outgassing of chlordane. A small opening was cut in the plastic covering, permitting four to five zucchini plants to be direct seeded or transplanted into the soil in each bay. The cuts in the top plastic were sealed with duct tape around the plants to minimize the size of the opening. When it became apparent that the plants in bay 5 would not survive, these plants were removed and the soil in bay 5 was covered with plastic for the remainder of trial 1. After the appearance of flowers, the plants were hand pollinated with a small brush. The leaves from all zucchini plants, those growing in contaminated as well as clean soil, intermingled during the growing period. Each plant in a given bay was labeled and was analyzed individually. Fruits were harvested when they were of edible size or close to edible size, and only leaves in good condition were analyzed.

Greenhouse Trial 2. This trial was conducted from January to April 1998 and is shown schematically in Figure 2B. The

clear plastic covering the contaminated soil in bays 1, 3, and 5 was removed, and the "clean" soil in bays 2 and 4 was covered with a fresh double layer of clear plastic in which a small opening was cut in the center. In this manner the "clean" soil remained protected from contamination with the chlordane contaminated soil, but chlordane outgassing from the contaminated soil was possible. Four to five zucchini plants were direct seeded in bays 1−4. In bay 5 one zucchini plant and one tomato plant were grown side by side to compare chlordane concentration in the tissues of an apparent "uptaker", zucchini, with that in the tissues of an apparent "nonuptaker", tomato. The leaves of plants in all bays again intermingled with each other during this trial. In some instances leaves of plants growing in bays 2 and 4 grew directly over the uncovered, contaminated soil in adjacent bays. Hand pollination was also part of this trial.

Vegetation Extraction. All vegetation was rinsed thoroughly with cold tap water to remove soil and debris. Special attention was given to the roots to ensure that all visible soil was rinsed off. Our multiresidue extraction procedure for produce, which has been published elsewhere, was used for all plant tissue (Pylypiw, 1993). Briefly, this consists of blending a portion of the plant matrix with a 2:1 mixture of petroleum ether/2-propanol, filtering the entire mixture through glass wool, back-washing the solution with distilled water, and drying the organic extract over sodium sulfate. A subsample of vegetable matrix was weighed, dried overnight at 95 °C, and reweighed to determine moisture content.

Soil Extraction. Soils from the root region of all crops were collected when aerial tissue was harvested or at the time of destructive harvest. The soil extraction procedure used in our laboratory is detailed elsewhere (Mattina et al., 1999). In brief, this consists of sieving the soil to remove debris and provide uniform soil particles, microwave-assisted extraction of a portion of sieved soil with a mixture of 2:3 hexane/acetone, and solvent exchange of the extract to iso-octane on a hot water bath. Soil moisture content was determined by drying a sieved and weighed soil sample overnight at 95 °C and reweighing.

Air Sampling. Determination of chlordane in greenhouse air was accomplished using a Supelco air sampling apparatus (Supelco, Inc., Bellefonte, PA, model 2-0557) and SKC sampling pump (SKC, Eightyfour, PA, model 224-PCXR3). The polyurethane foam (PUF) plug, quartz filters, and stainless steel screens were cleaned by Soxhlet extraction overnight using 1:1 hexane/acetone. The air sampling apparatus was attached to the pump, and greenhouse air was sampled for 15−20 h at the rate of 5 L/min. The PUF plug and quartz filter were then Soxhlet extracted overnight with 200 mL of 1:1 hexane/acetone. The extract was solvent exchanged to iso-octane over a hot water bath. The iso-octane solution was reduced to 1 mL final volume under nitrogen for analysis by gas chromatography (GC) with mass spectrometric detection (Hewlett-Packard Co., Avondale, PA, model 5970B).

Quantitation. Quantitation of chlordane in both the soil and the vegetation extracts was accomplished using a Hewlett-Packard 5890 GC with a ^{63}Ni electron capture detector (ECD). The column was an SPB-1 (Supelco, Inc.) 30 m × 0.53 mm × 0.5 μm; the GC oven was programmed as follows: initial temperature, 175 °C, ramped at 1 °C/min to 210 °C, then ramped at 2 °C/min to 250 °C, and held for 15 min for a total run time of 70 min. The injection port was kept at 250 °C, and a 2 μL splitless injection was used. Helium was the carrier gas, the makeup gas was 5% CH_4 in Ar, and the ECD was operated at 325 °C. All data were collected and processed using HP ChemStation B.02.05 software.

Stock standards of γ-(*trans*)chlordane, α-(*cis*)chlordane, *trans*-nonachlor, and *p,p′*-DDE in toluene were either prepared from EPA analytical grade standards (U.S. Environmental Protection Agency, Research Triangle Park, NC) or purchased as 100 μg/mL in methanol from Chem Service (West Chester, PA). The stock solution was diluted in iso-octane to prepare the following calibration solutions: 200, 100, 50, 20, 10, 5, 2, and 0.2 ng/mL. The limits of quantitation (LOQ) were 0.4 ng/g for all vegetation except roots and 0.8 ng/g for soil and roots. For these limits the area of the selected component peak in the chromatogram of the extract was equal to or greater than the area of the same component in the chromatogram of the 0.2 ng/mL standard. The signal-to-noise ratio for the 0.2 ng/mL standards was 50:1.

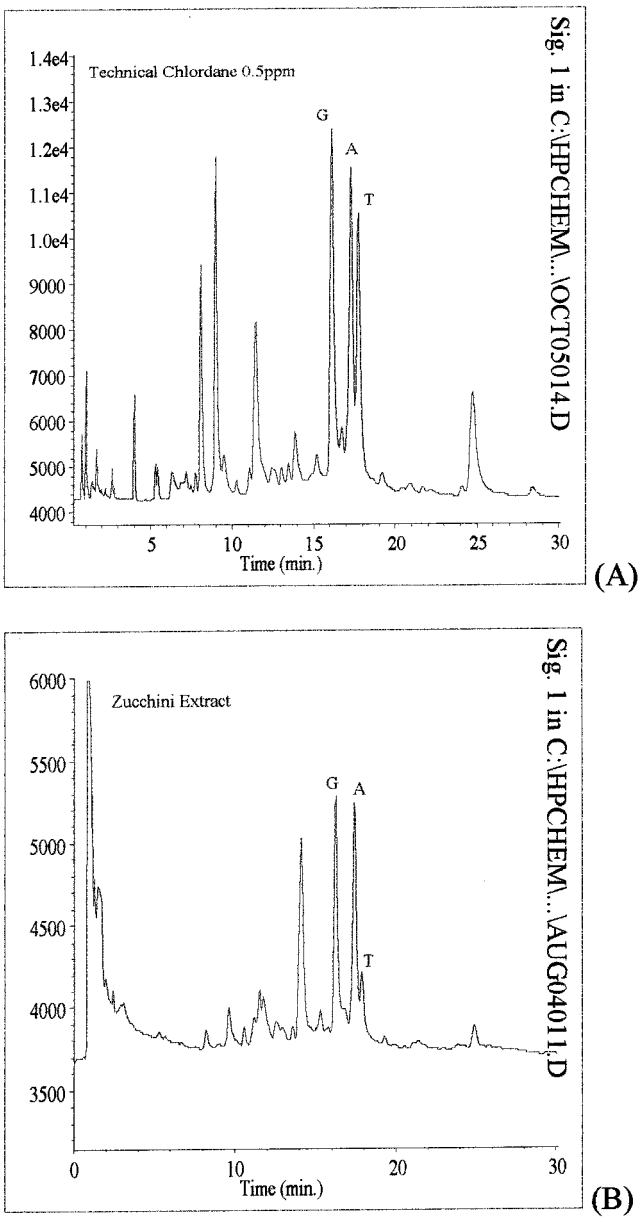

Figure 3. Chromatogram of (A) technical chlordane and (B) whole zucchini extract. G, *trans*-chlordane; A, *cis*-chlordane; T, *trans*-nonachlor.

In Figure 3A the GC-ECD chromatogram for technical chlordane is shown, and in Figure 3B the GC-ECD chromatogram for an extract from whole zucchini fruit is shown. Technical chlordane has been shown to be a mixture of >140 components (Dearth et al., 1991). It should be noted that of the major technical chlordane components visible in Figure 3A, γ-chlordane, α-chlordane, and *trans*-nonachlor may also be identified in substantial amounts in the zucchini fruit extract, the chromatogram of which is shown in Figure 3B. Therefore, each of these three components was quantitated individually, and the sum of the three is proposed as a reasonable approximation of the chlordane content of the vegetation. The same three technical chlordane components are also present in substantial amounts in the GC-ECD chromatogram of the extract of soil from the vicinity of the zucchini plants. All chlordane concentrations in vegetation and soil given in this paper are the sum of γ-chlordane, α-chlordane, and *trans*-nonachlor expressed as micrograms per gram on a dry weight basis of the particular matrix.

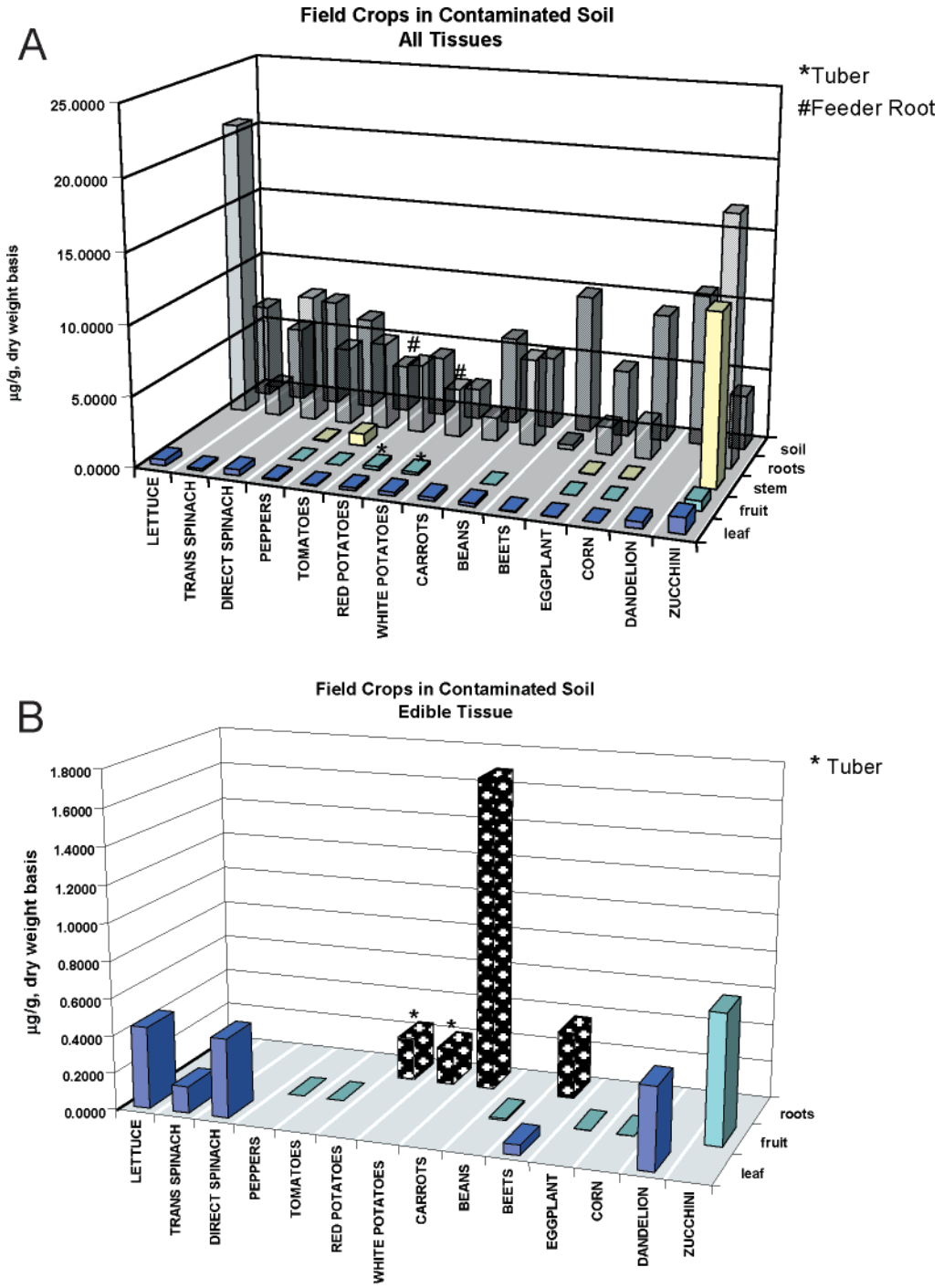

Figure 4. Chlordane concentration in (A) plant tissues for crops grown in soil containing weathered chlordane residues and (B) edible plant tissues for crops grown in soil containing weathered chlordane residues.

RESULTS AND DISCUSSION

Crop Selectivity. Field Trial. The data for crops grown directly in contaminated soil are presented in Figure 4. The chlordane concentration in the soil collected around the plant roots for each crop is also shown in Figure 4A. For the root tissue from the destructive harvest of each crop the data represent one extraction and quantitation of composite roots from several plants. For most of the other plant tissues several extractions and quantitations were performed; for example, there were 14 analyses of tomato fruit and 12 analyses of whole zucchini fruit. For each of 11 crops grown in chlordane-contaminated soil in the field trial it is noted in Figure 4A that the chlordane concentration in the root tissue exceeds that in the other tissues. Plant roots have typically been found to contain larger amounts of soil-derived pesticides relative to other plant tissues (Lichtenstein et al., 1965b; Andreux et al., 1993). That the root concentration represents actual *absorption* into the root tissue rather than *adsorption* of the chemical in the soil to the outer root layer is supported by additional data. We have noted that there is no difference in chlordane concentration between spinach roots which have been sonicated in distilled water for 5 min (8.228 μg/g, $n = 2$) and those which have not been sonicated (8.158 μg/g, $n = 2$) after the regular tap water rinse. Furthermore, as shown by the data summarized in Table 1 the root crops potatoes, carrots, and beets

Table 1. Chlordane Concentration in Edible Layers of Crops Grown in Contaminated Soil

tissue		μg/g	tissue		μg/g
red tuber	whole	0.2322	beets	whole root	0.3606
	peel	0.5494		peel	0.9875
	flesh	0.0418		flesh	0.0498
white tuber	whole	0.1986	eggplant	whole fruit	0.0034
	peel	0.6383		peel	0.0097
	flesh	0.0079		flesh	0.0035
carrot	whole root	1.6841	zucchini	whole fruit	0.6939
	peel	5.1796		peel	1.1223
	flesh	0.1253		flesh	0.7762

are seen to contain chlordane not only in their outer peel but also in the inner flesh tissues, which is clearly indicative of absorption rather than adsorption.

Not only is the chlordane concentration in the root tissue higher for all 11 of the crops for which this tissue type was analyzed, but it is also obvious from Figure 4A that the concentrations in the roots of 2 crops, lettuce and zucchini, are the highest determined in these trials. What unique properties of the physiology of Asteraceae (lettuce) and Cucurbitaceae (zucchini) might account for this observation remain to be determined.

Chlordane concentrations for edible plant tissue for all 12 crops grown in the field trial are shown in the graph in Figure 4B. The data show that zucchini contains sizable residues in its edible fruit, whereas tomato and pepper fruits and corn grain contain no detectable residues. Eggplant and beans contain trace amounts of chlordane in the edible fruit. What is notable in the comparison of Figure 4A with Figure 4B is that despite these differences in their edible fruits, chlordane is found in the stems and leaves of zucchini, beans, eggplant, tomatoes, peppers, and corn. These data indicate that the amount of chlordane in edible plant tissue is more complex than the single issue of "selective uptake" implies. Plants vary not only in their ability to uptake weathered chlordane from soil but also in their ability to translocate it throughout plant tissue and to bioaccumulate it in different tissues. Solely on the basis of the chlordane concentration in their *edible* tissue, the crops grown in this field trial may be rated as *uptakers* (beets, carrots, dandelion, lettuce, potatoes, spinach, and zucchini), *nonuptakers* (corn, pepper, and tomatoes), and *intermediates* (beans and eggplant). These classifications are obvious from the data in Figure 4B. It should be remarked that soil chlordane concentration in the CAES field trial exceeds typical concentrations in garden soils by an order of magnitude (Mattina et al., 1999). Nevertheless, although challenged by the high chlordane concentration in the CAES field trial soil, pepper *fruit*, tomato *fruit*, and corn grain contain no detectable chlordane residues.

Comparison of the current data with previously published studies is warranted. For the *uptakers* Stewart found chlordane residues in whole potatoes and potato peel and in whole rutabagas and rutabaga peel but none in the corresponding flesh of either crop (Stewart, 1975). In contrast as shown in Table 1, the flesh from beets, carrots, and potatoes grown in the CAES field soil contain chlordane, although the concentration is at least an order of magnitude less than in the outer root cover. Zucchini fruit flesh, on the other hand, contains almost as much chlordane as the fruit peel. Zucchini not only uptakes chlordane efficiently but translocates it efficiently throughout the plant.

In previous papers in the literature no residues were observed in the edible pods of beans when grown in soil to which aldrin and dieldrin were freshly applied (Lichtenstein, 1960). Previous work indicated that freshly applied chlordane was detected in corn stalk and silage but not in the grain or cob (Dorough et al., 1972). Very recently it was reported that PCDD/F were found in corn leaves but not in the kernels (Wagrowski et al., 1998). In this present study trace amounts of chlordane were found in bean pods and none in corn grain. It must be noted, however, that because animal silage is frequently produced from whole corn plants rather than from the cob, silage may be a source of human exposure to chlordane via an indirect dietary route. In these trials pepper fruit contained no detectable chlordane in its tissues even when the plant was grown in relatively high chlordane concentration soil. This contradicts a previous report by Kannan et al. (1997) which states that sweet peppers contain high chlordane concentrations.

The field trial data permit several conclusions to be drawn: (1) weathered chlordane residues in soil are mobilized via a soil-to-plant uptake pathway; (2) chlordane is readily translocated throughout plant tissues despite the minimal water solubility of chlordane components [0.1 mg/L at 25 °C; see Kidd et al. (1991)]; (3) certain crops bioaccumulate chlordane more efficiently than other crops.

Uptake Pathways. *Greenhouse Experiments.* The greenhouse trials sought to distinguish uptake of chlordane in the air by foliar plant tissues from uptake of chlordane in the soil by plant roots. Detailed discussions of the modeling of plant uptake of organic chemicals in the environment are available in the literature (Paterson et al., 1994; Trapp et al., 1993) and are beyond the scope of the present discussion.

Trial 1. Table 2 summarizes the data from the greenhouse trials. Although every attempt was made to use noncontaminated soil in bays 2 and 4, a very small amount of chlordane contamination occurred in the process of trucking the soil from its original site 6 mi from the greenhouse and in filling the greenhouse bays.

Traces of chlordane in the greenhouse air were detected (range = 1300 to 350 pg/m^3 with a detection limit of 300 pg/m^3), although we were unequipped to quantitate the values accurately to monitor changes in air concentrations. A composite soil from the greenhouse floor was determined to contain 0.0585 μg/g chlordane and was a possible source, together with the contaminated soil in the bays and intake of outside air, of the chlordane in the greenhouse air.

Several comments are in order regarding the data from trial 1. Plants growing in soil containing substantial amounts of weathered chlordane residues, that is, in bays 1 and 3, contain substantial amounts of chlordane in root as well as aerial tissues. Single-factor ANOVA of the chlordane concentration in individual fruits from bays 1 and 3 indicated no significant difference in the concentrations at the 95% confidence level. The concentration of the chlordane residues in the plant tissues from bays 1 and 3 is in the order root ≅ woody stem > leaf ≅ fruit.

There is a low but detectable amount of chlordane in the soil in bays 2 and 4, and the tissues from zucchini plants growing in bays 2 and 4 contain trace chlordane residues. However, the plants growing in bays 2 and 4 contain more chlordane in their leaf tissue than in their

Table 2. Data from Greenhouse Trials 1 and 2[a]

source	tissue	tissue μg/g, trial 1	soil μg/g	tissue μg/g, trial 2	soil μg/g
bay 1	leaf	0.576 ± 0.112, $n = 5$	0.525	1.025 ± 0.280, $n = 7$	0.320
	fruit	*0.723 ± 0.507*, $n = 5$		*0.425 ± 0.124*, $n = 7$	
	stem	2.452 ± 0.776, $n = 3$		3.383 ± 0.877, $n = 4$	
	root	3.264, $n = 1$		2.241, $n = 1$	
bay 3	leaf	0.432 ± 0.091, $n = 6$	0.525	0.806 ± 0.258, $n = 5$	0.330
	fruit	*0.402 ± 0.070*, $n = 3$		*0.355 ± 0.050*, $n = 5$	
	stem	1.891 ± 0.432, $n = 3$		3.668 ± 0.569, $n = 3$	
	root	1.393, $n = 1$		1.742, $n = 1$	
bay 5	zucchini leaf			0.612, $n = 1$	0.327
	zucchini fruit			*0.275*, $n = 1$	
	zucchini stem			2.047, $n = 1$	
	zucchini root			3.674, $n = 1$	
	tomato leaf			0.0043 ± 0.0039, $n = 3$	
	tomato fruit			*0*, $n = 3$	
	tomato stem			0.0045, $n = 1$	
	tomato root			0.0770, $n = 1$	
bay 2	leaf	0.0062 ± 0.0078, $n = 4$	0.008	0.0157 ± 0.011, $n = 10$	0.001
	fruit	*0*, $n = 2$		*0*, $n = 13$	
	stem	0.0023 ± 0, $n = 2$		0.002 ± 0.0039, $n = 4$	
	root	0.0023, $n = 1$		0, $n = 1$	
bay 4	leaf	0.0011 ± 0, $n = 2$	0.008	0.0079 ± 0.0075, $n = 8$	0.003
	fruit	*0*, $n = 1$		*0*, $n = 6$	
	stem	0.0013 ± 0.0003, $n = 2$		0, $n = 4$	
	root	0, $n = 1$		0, $n = 1$	

[a] Italicized entries denote data from edible plant tissue. *n* represents the number of separate analyses of the specified plant tissue in the designated bay.

root tissue. Because all aerial tissue is exposed to the same chlordane concentration in the greenhouse air, the differences observed in the plant tissue across all bays from trial 1 must be attributed to differences in the soil chlordane concentration.

Trial 2. The experiment described in trial 1 was repeated, keeping the clean soil in bays 2 and 4 covered but removing the plastic from bays 1, 3, and 5. Despite our attempts to keep temperature and light conditions equivalent during the two trials, plants from trial 2 were generally healthier than those from trial 1. Data from this second greenhouse trial are summarized in Table 2. Again, single-factor ANOVA of the chlordane concentration in individual fruits from bays 1 and 3 indicated no significant difference in concentrations at the 95% confidence level. For zucchini grown in bays 1, 3, and 5 chlordane is distributed throughout the four different tissue types examined, and the observed concentrations are in the order root ≅ woody stem > leaf ≅ fruit. The leaves from zucchini plants growing in bays 2 and 4 contain more chlordane than other tissues from plants growing in these bays. It should also be remarked that although the zucchini growing in bay 5 contained chlordane in all tissue types, the tomato growing in the same bay did not contain chlordane in its fruit. This observation implies that crop selectivity of chlordane uptake, observed anecdotally in the marketbasket samples and noted in the data from the field trial, is more accurately described as selective accumulation in plant tissues by different crops.

Field Experiments. The distinction between uptake by foliar plant tissues of chlordane in the air from uptake by roots of chlordane in the soil, followed in both cases by translocation throughout the plant, was examined for several crops in the field. The crops indicated in Table 3 were grown in "clean" soil in bins in the field. Covering the soil in the bins with plastic does not eliminate atmospheric deposition to leaves of crops grown in bins in the field. The data from the field trials as summarized in Table 3 confirm the observations

Table 3. Field Trial, Crops Grown in Clean Soil in Bins

crop	tissue	tissue μg/g	soil μg/g
beet	leaf	*0.009 ± 0.007*, $n = 2$	0.008
	whole root	*0.018 ± 0.021*, $n = 2$	
carrot	leaf	0.158 ± 0.111, $n = 2$	0.008
	whole root	*0.371 ± 0.497*, $n = 2$	
eggplant	leaf	0.032 ± 0.016, $n = 3$	0
	whole fruit	*0*, $n = 4$	
	stem	0.006, $n = 1$	
	root	0.002, $n = 1$	
pepper	leaf	no data	0.001
	fruit	*0*, $n = 2$	
	stem	0.002, $n = 1$	
	root	0, $n = 1$	
tomato	leaf	0.046, $n = 1$	0.001
	fruit	*0*, $n = 2$	
	stem	0, $n = 2$	
	root	0.0124, $n = 1$	
zucchini	leaf	0.018 ± 0.0.012, $n = 21$	0.003
	whole fruit	*0.054 ± 0.016*, $n = 19$	
	stem	0.025 ± 0.021, $n = 9$	
	root	0.079 ± 0.026, $n = 1$	

made in the greenhouse experiments. A few conclusions can be drawn from these data: (1) under the experimental conditions the soil-to-plant route is the predominant pathway for chlordane uptake; (2) the air-to-plant uptake pathway does make a contribution to plant chlordane content.

Experiments are underway to establish quantitatively the relative importance of the soil-to-plant route versus the air-to-plant route. Dose/response curves will be measured in growth chamber experiments in which variables can be rigorously controlled. Comparison of the enantiomeric ratios of γ-chlordane and α-chlordane in the soil, in the atmosphere, and in plant tissues will also be pursued to provide data to distinguish between the soil-to-plant uptake route and the air-to-plant uptake route.

We note with interest that it was recently reported that chlordane was found in six samples of compost

produced in New Jersey from leaves and grass clippings. Chlordane was in the range 0.29−3.23 μg/g and was the only one of the 27 targeted pesticides found in all six samples (Strom, 1998). The author of the New Jersey study proposes that the source of the chlordane is the residential soil taken up with the leaves and grass clippings, because in his opinion "*Chlordane is not expected to be taken up by plant roots nor translocated into the tree or grass leaves*" (italics added). In light of the data from the present study, this comment clearly merits reexamination.

Supporting Information Available: Scientific nomenclature and varieties of crops included in field trial, chlordane residues in crops grown in contaminated soil, and chromatogram of soil extract from zucchini root. This material is available free of charge via the Internet at http://pubs.acs.org.

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