# Absorption and Translocation of Root and Foliage Applied 2,4-Dichlorophenol, 2,7-Dichlorodibenzo-*p*-dioxin, and 2,3,7,8-Tetrachlorodibenzo-*p*-dioxin

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Uptake of $^{14}C$-labeled 2,4-dichlorophenol (DCP), 2,7-dichlorodibenzo-*p*-dioxin (DCDD), and 2,3,7,8-tetrachlorodibenzo-*p*-dioxin (TCDD) from nutrient solution, soil, and foliage by oats and soybeans was measured. Solutions and soils were treated with, respectively, 0.20 and 0.07 ppm of DCP, 0.26 and 0.10 ppm of DCDD, and 0.18 and 0.06 ppm of TCDD. After 14 days uptake from solution, seedling oats and soybeans contained (minus control) 1.84 and 0.13 ppm of DCP, 0.16 and 0.01 ppm of DCDD, and 0.11 and 0.01 ppm of TCDD, respectively. After growing to maturity in soil, oats and soybeans contained (minus control) 0.010 and 0.020 ppm of DCP, 0.020 and <0.001 ppm of DCDD, and <0.001 and <0.001 ppm of TCDD, respectively. Accumulation of TCDD by plants from soil was concluded to be highly unlikely. No translocation of foliar-applied DCP, DCDD, or TCDD was measured. More TCDD was removed by simulated rainfall 2 hr after application (50 to 60%) than after 7 days (26% oats and 2% soybeans).

A technical grade sample of the herbicide 2,4,5-trichlorophenoxyacetic acid (2,4,5-T) was shown to be teratogenic to mice and rats (Courtney *et al.*, 1970). Analysis showed later that the 2,4,5-T used contained approximately 30 ppm of 2,3,7,8-tetrachlorodibenzo-*p*-dioxin (TCDD) as a contaminant. TCDD has a mammalian toxicity ($LD_{50}$) of 10 μg/Kg in rabbits (Schultz, 1968) and is suspected of being teratogenic (Chem. Eng. News, 1970). Therefore, TCDD may have been responsible for teratogenicity rather than 2,4,5-T *per se*. Application of 2,4,5-T, which contains TCDD, would result in exposure of plants to TCDD and a possible accumulation of TCDD residues in soil. Accumulation of TCDD in plants from foliar application or uptake from soil could possibly create a health hazard.

This investigation was initiated to determine the quantity of TCDD taken up from soil by two agronomic crops and the fate of TCDD applied to foliage. For comparison, the same information was obtained on 2,4-dichlorophenol (DCP) and 2,7-dichlorodibenzo-*p*-dioxin (DCDD) since the metabolic fate of these and similar compounds in plants is unclear.

## METHODS AND MATERIALS

**Uptake from Solution.** The primary objective for conducting solution uptake experiments was to determine basic uptake patterns such as differences between plant species and maximum quantity absorbed.

Oats (*Avena sativa* L. cv. Markton) were germinated for 10 days in growth pouches (Scientific Products Cat. No. B1220) moistened with 15 ml of nutrient solution and placed in a growth chamber (800 ft-candle 14-hr day, 30° C day, 20° C night). Distilled water was added as needed to maintain an adequate moisture level. Soybeans (*Glycine max.* L. cv. Lee) were germinated in the greenhouse for 10 days in horticultural perlite moistened with nutrient solution. Seedlings of uniform size from both species were selected for the experiments.

The specific activities (ring-labeled $^{14}C$) of DCP, DCDD and TCDD used throughout this investigation were 5.84, 3.59, and 2.80 μc/mg, respectively.

A solubilizing surfactant, Tween 80, was used at 0.05% concentration to prepare solutions containing 0.20, 0.26, and 0.18 ppm, respectively, of DCP, DCDD, and TCDD. The phenol or dioxins, dissolved in benzene, were added to several milliliters of Tween 80. After blowing the benzene to dryness, the Tween 80 containing the phenol or dioxin was dissolved in nutrient solution and brought to final volume. Concentrations of DCP, DCDD, and TCDD were determined by counting the $^{14}C$, and the solutions were then pipetted into absorption flasks (50 ml each).

Three oats or one soybean seedling were placed in each flask. Treatments were replicated three times. The plants were grown in the laboratory (maximum temperature fluctuation 25 to 33° C) under fluorescent light (800 ft-candle) and 12-hr day. After 1, 2, 4, 6, 8, 10, 12, or 14 days, the plants were removed from solution, their roots washed with distilled water, and blotted dry. Control plants, grown in untreated nutrient solution, were harvested at 14 days. Roots and tops were separated, placed in combustion boats, and oven dried at 60° C overnight. After dry weight was determined the tissue was completely covered with a mixture at CuO and anhydrous $Al_2O_3$ (1:5 weight). The tissue was combusted for 7 min in an $O_2$ stream. The evolved $^{14}CO_2$ was dried by passing through a column of anhydrous $CaSO_4$ and trapped in 10 ml of monoethanolamine/2-methoxyethanol (1:7 by volume). A 5-ml aliquot of the trapping solution was diluted to 15 ml with toluene counting solution in a liquid scintillation vial and counted. All $^{14}C$ activity in the tissue was expressed on the basis of the parent compound.

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Table I. Uptake of $^{14}C$-2,4-Dichlorophenol, $^{14}C$-2,7-Dichlorodibenzo-*p*-dioxin, and $^{14}C$-2,3,7,8-Tetrachlorodibenzo-*p*-dioxin from Nutrient Solution by Oats and Soybeans[a]

| | Soybeans[b] | | | | Oats[b] | | | |
|---|---|---|---|---|---|---|---|---|
| | Roots | | Tops | | Roots | | Tops | |
| Absorption time (days) | μg/g[c] | %[d] | μg/g | % | μg/g | % | μg/g | % |
| | | | | **2,4-Dichlorophenol** | | | | |
| 1 | 273a[e] | 83.6a | 0.33bc | 0.29c | 87a | 56.0a | 2.05a | 0.46a |
| 2 | 239ab | 83.4a | 0.40ab | 0.40bc | 100ab | 61.8bc | 2.40c | 0.69ab |
| 4 | 178bc | 83.3a | 0.49a | 0.64a | 99ab | 59.8ab | 2.74a | 0.86abc |
| 6 | 155bc | 75.0b | 0.36ab | 0.50ab | 106b | 66.5cde | 1.88c | 0.73ab |
| 8 | 132c | 79.3ab | 0.19cd | 0.33bc | 101ab | 72.5f | 1.89a | 1.07bc |
| 10 | 128c | 84.7a | 0.11d | 0.32c | 98ab | 71.2ef | 1.91a | 1.03bc |
| 12 | 107c | 83.8a | 0.10d | 0.30c | 87a | 65.4cd | 1.73a | 1.02bc |
| 14 | 87c | 75.0b | 0.13d | 0.32c | 90a | 68.5def | 1.85a | 1.37c |
| Control[f] | 0.060 | | 0.002 | | 0.070 | | 0.010 | |
| | | | | **2,7-Dichlorodibenzo-*p*-dioxin** | | | | |
| 1 | 50a[e] | 10.7a | 0.40b | 0.24a | 7a | 3.5a | 1.8cd | 0.27ab |
| 2 | 86b | 23.5a | 1.01a | 0.71bc | 11a | 6.5a | 0.5ab | 0.11a |
| 4 | 126c | 41.3b | 1.12a | 1.00c | 27b | 12.8b | 1.1bc | 0.27ab |
| 6 | 145c | 40.0b | 0.43b | 0.50b | 28b | 13.7bc | ... | ... |
| 8 | 88b | 36.8b | 0.08b | 0.10a | 37bc | 18.0cd | 2.2d | 0.76c |
| 10 | 137c | 48.7b | 0.04b | 0.06a | 41c | 22.1de | 0.9ab | 0.37b |
| 12 | 81b | 41.1b | 0.04b | 0.04a | 41c | 23.2e | 0.9ab | 0.43b |
| 14 | 62a | 41.6b | 0.01b | 0.02a | 54d | 32.2f | 0.2a | 0.11ab |
| Control[f] | 0.010 | | 0.004 | | 0.090 | | 0.040 | |
| | | | | **2,3,7,8-Tetrachlorodibenzo-*p*-dioxin** | | | | |
| 1 | 9.7a[e] | 3.6a | 0.77a | 0.35ab | 8.8a | 6.2a | 1.50a | 0.43ab |
| 2 | 13.9ab | 5.7b | 0.65a | 0.41a | 14.9abc | 10.5ab | 0.73b | 0.24bc |
| 4 | 19.0bc | 9.5cd | 0.34bc | 0.30ab | 18.6c | 12.6bc | 0.68b | 0.28bc |
| 6 | 17.5bc | 9.2cd | 0.38b | 0.36a | 20.6cd | 14.2bcd | 0.77b | 0.33ab |
| 8 | 16.4bc | 8.8cd | 0.11cd | 0.11cd | 27.1d | 19.2c | 0.21c | 0.09c |
| 10 | 13.9ab | 7.1bc | 0.18bcd | 0.23bc | 10.7ab | 9.5a | 0.80b | 0.52a |
| 12 | 20.2c | 11.2d | 0.07d | 0.11cd | 21.5cd | 17.2cd | 0.13c | 0.08c |
| 14 | 15.0abc | 10.0d | 0.03d | 0.09d | 17.0bc | 15.8bcd | 0.13c | 0.09c |
| Control[f] | 0.080 | | 0.020 | | 0.090 | | 0.020 | |

[a] Average of three replications. Solution contained 0.20, 0.26, and 0.18 ppm of $^{14}C$-2,4-dichlorophenol, $^{14}C$-2,7-dichlorodibenzo-*p*-dioxin, and $^{14}C$-2,3,7,8-tetrachlorodibenzo-*p*-dioxin, respectively. [b] Soybeans and oats germinated for 10 days before placing in treatment flasks. One soybean and three oat seedlings per flask. [c] μg/g dry tissue. [d] Tissue content expressed as % of total activity available in treatment flask. [e] Numbers followed by the same letter are not significantly different at the 5% level of probability. [f] Plants grown in untreated nutrient solution and harvested at 14 days.

**Uptake from Soil.** Lakeland sandy loam soil (air dried and sieved at <2 mm) was treated with $^{14}C$-labeled DCP, DCDD, and TCDD dissolved in benzene. After the benzene evaporated, the soil was thoroughly mixed, placed in pots (200 g/pot), and seven oat or three soybean seeds were planted in each. Soil concentrations of DCP, DCDD, and TCDD were 0.07, 0.10, and 0.06 ppm, respectively. Pots were initially watered to field capacity with nutrient solution, placed in the greenhouse, and subsequently watered as needed with tap water. Soybeans were thinned to one seedling per pot and oats to five seedlings per pot after 5 days germination. Tops of soybeans and oats were harvested 6, 10, 20, 25, 30, and 40 days after planting. A final harvest of soybeans and oats was made at 50 and 85 days, respectively. Soybeans were not fully ripe at 50 days but were harvested due to mite damage. Oats were completely ripe at 85 days. Untreated control plants for each species were harvested at 10, 20, 30, 50, and 85 days. Control values for all three compounds were based on total tissue activity (above background) from a single set of plants at each harvest. After harvest the tissue was oven dried overnight at 60° C, ground, mixed, and a portion combusted and analyzed as described above.

**Foliage Application.** Soybeans were grown in Lakeland sandy loam soil (400 g/pot) until they reached the second trifoliate leaf stage. The center leaflet (upper surface) of the first trifoliate leaf was treated with aqueous Tween 80 (0.05%) solutions (25 2-μl drops/leaflet) of DCP (5.2 ppm), DCDD (5.5 ppm,) and TCDD (5.4 ppm). Tween 80 was added to enhance leaf absorption and keep the highly water-insoluble dioxins in solution. After treatment, the plants were returned to the greenhouse and watered as needed. Harvests were made at 2, 7, 14, and 21 days after treatment. Each plant was dissected into the following six parts: treated leaflet, remainder of first trifoliate leaf plus petiole, second trifoliate, all remaining trifoliate leaves, first two leaves, and stem. All samples were dried and analyzed as described above.

Oats were grown in Lakeland sandy loam soil for 12 days, thinned to three plants per pot, and treated (upper surface, first leaf blade) with ten 2-μl drops of TCDD (same solution as above). Harvests were made 2, 7, 14, and 21 days after treatment. Tissue was separated into first leaf blade and remaining blades, dried, and analyzed as described above.

The effect of simulated rainfall on removal of foliage applied TCDD was assessed in another experiment. TCDD was applied to leaves in 2-μl droplets. Soybeans were treated with 25 droplets/leaf and oats with 10 droplets. TCDD was applied at two rates to each plant: 61 and 14 ng/oat leaf and 143 and 30 ng/soybean leaf. The treated leaves were washed with 10-ml portions of water 2 hr, 2, and 7 days after treatment. The TCDD content of each wash and the washed leaves was determined with combustion and

Table II. Uptake of $^{14}C$-2,4-Dichlorophenol (DCP), $^{14}C$-2,7-Dichlorodibenzo-*p*-dioxin (DCDD), and $^{14}C$-2,3,7,8-Tetrachlorodibenzo-*p*-dioxin (TCDD) from Soil by Oats and Soybeans[a]

| Absorption time (days)[c] | DCP | | | | DCDD | | | | TCDD | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Oats[b] | | Soybeans[b] | | Oats | | Soybeans | | Oats | | Soybeans | |
| | μg/g[d] | %[e] | μg/g | % | μg/g | % | μg/g | % | μg/g | % | μg/g | % |
| 6 | 0.195a[f] | 0.049c | 1.480a | 0.889a | 0.135a | 0.030b | 0.160a | 0.099a | 0.066b | 0.025d | 0.032c | 0.028c |
| 10 | 0.173a | 0.130b | 0.085b | 0.055d | 0.145a | 0.095a | 0.069b | 0.041cd | 0.132a | 0.151a | 0.057a | 0.058bc |
| C10[g] | 0.032 | | 0.028 | | 0.052 | | 0.040 | | 0.067 | | 0.059 | |
| 15 | 0.115b | 0.149b | 0.093b | 0.127c | 0.065a | 0.070ab | 0.036c | 0.055bcd | 0.057b | 0.108b | 0.042b | 0.100ab |
| 20 | 0.093bc | 0.197a | 0.083b | 0.187bc | 0.053b | 0.089a | 0.028cd | 0.073abcd | 0.041b | 0.114b | 0.015d | 0.055c |
| C20[g] | 0.010 | | 0.006 | | 0.018 | | 0.008 | | 0.022 | | 0.010 | |
| 25 | 0.073cd | 0.164ab | 0.048b | 0.192b | 0.045bc | 0.092a | 0.018de | 0.074abcd | 0.030cd | 0.089bc | 0.010de | 0.049c |
| 30 | 0.055de | 0.154b | 0.040b | 0.215b | 0.028cd | 0.090a | 0.011de | 0.067abcd | 0.020de | 0.059c | 0.006e | 0.059bc |
| C30[g] | 0.005 | | 0.002 | | 0.008 | | 0.004 | | 0.012 | | 0.005 | |
| 40 | 0.038e | 0.160ab | 0.028b | 0.170bc | 0.025cd | 0.104a | 0.008e | 0.088ab | 0.013e | 0.075c | 0.005e | 0.054c |
| 50 or 85[h] | | | | | | | | | | | | |
| Tissue | 0.010f | 0.062c | 0.023b | 0.174bc | 0.020d | 0.063ab | 0.004e | 0.036d | <0.001f | <0.001f | 0.005e | 0.062abc |
| seeds | <0.001 | | 0.011 | 0.003 | <0.001 | | 0.018 | 0.002 | <0.001 | | 0.004 | 0.001 |
| C50 or 85[g] | | | | | | | | | | | | |
| Tissue | <0.001 | | 0.003 | | <0.001 | | 0.004 | | <0.001 | | 0.006 | |
| seeds | <0.001 | | ... | | <0.001 | | ... | | <0.001 | | ... | |

[a] Average of three replications. Soil contained 0.07, 0.10, and 0.06 ppm DCP, DCDD, and TCDD, respectively. [b] One soybean and five oat plants per pot. [c] Days after planting. [d] μg/g dry tissue. [e] Tissue content expressed as % of total activity in soils. [f] Numbers followed by the same letters are not significantly different at the 5% level of probability. [g] Plants grown in untreated soil and harvested at indicated times. Control values for each compound based on total tissue activity from one set of plants. [h] Soybeans harvested at 50 days and oats at 85 days.

liquid scintillation techniques. An identically treated but unwashed leaflet was also analyzed.

## RESULTS AND DISCUSSION

**Uptake from Solution.** The uptake of DCP, DCDD, and TCDD by soybeans and oats is shown in Table I. The root uptake data are somewhat difficult to interpret since the degree to which absorption or adsorption contributes to the total root content is unknown. However, several trends are clear. First, soybean and oat roots took up two to ten times more DCP than DCDD or TCDD. Second, DCP reached a stable concentration within 24 hr and remained constant or declined over the duration of the experiment. The dioxins, on the other hand, generally increased for several days before reaching stable concentrations. Differences in water solubility or adsorption could account for both of these trends. In addition, both dioxins adsorbed to the flask walls, reducing solution concentration.

Far smaller quantities of DCP, DCDD, and TCDD were translocated to soybean and oat tops than were found in the roots. However, maximum quantities of the three compounds taken up differed from each other by a factor of only 2. Again several different uptake patterns appeared. DCP accumulated for several days before reaching a stable concentration. DCDD also accumulated for several days, but then continuously decreased over the rest of the experiment. TCDD reached a maximum concentration in 24 hr, after which it too continuously decreased in concentration with time. Both tissue concentration (μg/g) and total (%) values for the dioxins decreased with time, which indicated that the dioxins dissipated from the plant tops rather than diluted by tissue growth. Metabolism, volatilization from the tissue, and translocation back to the roots could all contribute to this removal.

**Uptake from Soil.** Tissue content (μg/g) of DCP, DCDD, and TCDD decreased as age of soybeans and oats increased (Table II). Total content (% values) generally increased for 15 to 20 days and then remained relatively constant over the duration of the experiment. Tissue dilution (due to growth) could account for a relationship of this type and indicate that no further uptake occurred after 15 to 20 days. However, several other processes such as metabolism, volatilization from the tissue, and translocation back to the roots could also be functioning. It is impossible to determine from this experiment which, if any, of these processes may be operating.

No detectable quantities of DCP, DCDD, or TCDD were found in oat grain at maturity. Small quantities of DCP, DCDD, and TCDD were found in soybean seeds, but the amount consisted of only $^1/_{20}$ to $^1/_{60}$ of the total tissue content. Therefore, oats and soybeans do not concentrate these compounds in their seeds. In addition, oat and soybean tissue content of TCDD was very small at all sampling times. Control values were only slightly smaller than treatment values and at maturity became about equal.

Initial control values were rather high and then decreased with time. This decrease was apparently due to tissue dilution since total counts per minute (data not shown) remained constant. Both DCP and DCDD are volatile (as indicated in Table III). Since the control plants were randomly placed with treated plants, adsorption of volatilized DCP and DCDD by control plants could have occurred.

The initial content of DCP and DCDD was much higher for the first soybean harvest than for any other harvest, and may have resulted from adsorption to the cotyledons as they

Table III. Soybean Leaf Content of 2,4-Dichlorophenol (DCP), 2,7-Dichlorodibenzo-*p*-dioxin (DCDD), and 2,3,7,8-Tetrachlorodibenzo-*p*-dioxin (TCDD) and Oat Leaf Content of TCDD Several Days after Application[a]

| Days after application | Soybeans | | | Oats |
|---|---|---|---|---|
| | DCP %[b] | DCDD % | TCDD % | TCDD % |
| 2 | 2.2 | 16.3 | 91.8 | 83.3 |
| 7 | 1.9 | 15.0 | 94.4 | 78.8 |
| 14 | 2.1 | 11.3 | 96.9 | 75.4 |
| 21 | 2.6 | 16.7 | 93.8 | 63.0 |

[a] Average of three replications. [b] Tissue content expressed as % of total activity placed on leaflet.

Table IV. Effect of Simulated Rainfall on Foliage (Oats and Soybeans) Applied TCDD as Influenced by Application Rate and Time[a]

| Time after application | % of total applied: Unwashed leaf[b] | Washed leaf[c] | 1st wash | 2nd wash | Sum of 1 and 2 washes | Sum of washes and washed leaf |
|---|---|---|---|---|---|---|
| | | | **61 ng/oat leaf** | | | |
| 2 hr | 80.7 | 8.4 | 55.6 | 2.0 | 57.6 | 66.0 |
| 2 days | 86.0 | 14.8 | 46.3 | 4.7 | 51.0 | 65.8 |
| 7 days | 82.6 | 30.3 | 24.6 | 4.1 | 28.7 | 59 |
| | | | **14 ng/oat leaf** | | | |
| 2 hr | 90.0 | 7.9 | 52.0 | 9.8 | 61.8 | 69.7 |
| 2 days | 85.8 | 31.5 | 40.2 | 3.1 | 43.3 | 74.8 |
| 7 days | 67.4 | 47.7 | 19.7 | 3.1 | 22.8 | 70.5 |
| | | | **143 ng/soybean leaf** | | | |
| 2 hr | 99.5 | 11.8 | 53.6 | 1.0 | 54.6 | 66.5 |
| 2 days | 91.7 | 33.2 | 35.1 | 6.2 | 41.5 | 74.6 |
| 7 days | 90.5 | 88.0 | 0.1 | 2.1 | 2.2 | 90.2 |
| | | | **30 ng/soybean leaf** | | | |
| 2 hr | 98.3 | 9.3 | 61.0 | 2.2 | 63.3 | 72.5 |
| 2 days | 76.4 | 47.8 | 14.3 | 6.6 | 20.9 | 68.7 |
| 7 days | 72.5 | 68.7 | 0.0 | 0.8 | 0.8 | 69.5 |

[a] Average of three replications. [b] Percent of total activity originally applied. [c] Percent of total activity remaining after two washes.

emerged from the soil. The cotyledons were included in the first harvest only.

Smaller quantities of DCP, DCDD, and TCDD were taken up from soil than from solution. Plants harvested at 10, 15, 20, and 25 days roughly correspond in age to solution absorption times of 1, 4, 10, and 14 days. When compared on an equal age basis, oats took up 8 to 25 and 4 to 10 times more DCP and DCDD, respectively, from solution than from soil. The different quantities taken up by soybeans from the two media were far smaller (1 to 5 times). Oats and soybeans took up 2 to 10 times more TCDD from solution than from soil. Differences in uptake from soil and solution decreased as plant age increased. Solution concentration of DCP, DCDD, and TCDD was about 3 times soil concentration, which may partly explain uptake differences. However, the 200 g of soil contained 1.4 times as much DCP, DCDD, and TCDD than did 50 ml of solution.

Application of DCP, DCDD, and TCDD to soil would occur only if these chemicals were combined with or were a contaminant in some other material. TCDD reaches soil by the latter method, *i.e.*, it is a contaminant in 2,4,5-T. For example, a 2.24 kg/ha application of 2,4,5-T containing 1 ppm of TCDD would yield 0.9 mg of TCDD. By comparison, the soil used in this experiment was treated with 0.06 ppm of TCDD, which is equivalent to 63 g/ha. Application of the above 2.24 kg/ha of 2,4,5-T into the surface 1 cm of soil would result in a soil TCDD concentration $^1/_{4000}$ as great as the soil concentration of TCDD used in this experiment. However, incorporation of the 2,4,5-T supplied TCDD by normal tillage practices would dilute the TCDD to about $^1/_{70,000}$ of the 0.06-ppm concentration. By comparison this experiment presented optimum uptake conditions; but at maturity little or no TCDD was found in oats or soybeans. Therefore, accumulation of TCDD in plants from soil uptake is highly unlikely.

**Foliage Application.** Results indicated that DCP, DCDD, and TCDD were not translocated beyond the treated leaflet. The $^{14}C$ activity of all nontreated parts was equal to or less than the background activity for the control plants. No visual phytotoxicity (discoloration or necrosis) was apparent from application of DCP, DCDD, or TCDD to leaf surfaces at any sampling time. On the basis of these observations, it was assumed that the translocative capacity of the tissue was not impaired. Only data for the treated leaflet were included in Table III.

After 48 hr, 2, 16, and 92% of DCP, DCDD, and TCDD, respectively, remained on the treated soybean leaf (Table III). Volatilization from the leaf surface probably accounted for DCP and DCDD loss. Loss by volatilization was further assessed by applying these materials to glass surfaces. After 48 hr in the greenhouse, 4, 10, and 98% of DCP, DCDD, and TCDD remained, respectively. The similar quantities of DCP and DCDD lost from glass and leaf surfaces strongly indicate loss by volatilization. An average of 94% of the TCDD remained on soybean leaves for 21 days, but the amount continuously decreased on oat leaves. The 2-$\mu$l drops of TCDD solution adhered much better to soybeans than to oats. This suggests that TCDD adsorbed less tenaciously to oats than soybeans, and if so could result in more volatilization from oats than soybeans.

The results shown in Table III suggest that much of the foliage applied TCDD will remain in place until the plant matures and/or is harvested. However, the treated plants were not subject to rainfall, which could conceivably remove some foliage applied material. Therefore, the effect of simulated rainfall on foliage applied TCDD was assessed. Soybean and oat leaves treated with TCDD were washed, dropwise, with two 10-ml quantities of water and the tissue and washes were analyzed. A large portion (52 to 61%, 2-hr adsorption time) of the applied TCDD was removed by the first wash (Table IV). Far smaller amounts were removed by the second wash and the total amount washed off decreased as time after application increased. After 7 days an average of 25.5 and 1.5% of the applied TCDD was removed from oat and soybean leaves, respectively. The difference between oats and soybeans in the amount removed again indicates that TCDD and/or Tween 80 was adsorbed less tenaciously to oats than soybeans. This would sup-

port the above suggestion that TCDD volatilized more from oats than soybeans. Much more TCDD was lost than expected, based on water solubility (0.2 ppb). The surfactant may have been responsible for the large loss. Tween 80 is highly water-soluble and may be absorbed by the leaf for several days after application. Undoubtedly, some TCDD was adsorbed to the surfactant. Therefore, the amount of TCDD washed off the leaf was probably a direct function of surfactant removal.

The surfactant was removed from the system in another experiment by applying $^{14}C$-TCDD (dissolved in acetone) to a glass surface. Detectable quantities of TCDD were not removed from glass by two 10-ml water washes. This indicated that loss of TCDD from leaves by simulated rainfall may have been caused by the surfactant.

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