Influence of the Type of Mineral Soil on the Uptake of Dieldrin by Wheat Seedlings

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The effect of soil type on the uptake of dieldrin by wheat seedlings was studied using seven mineral soils containing 9 to 23 ppm of dieldrin. Although wheat seedlings grown in the sandy soils contained more dieldrin than those grown in the clay soils, there was no close relationship between sand, clay, or organic matter contents of the soils and the dieldrin contents of the plants. However, there was significant correlation between dieldrin uptake by wheat seedlings, the silt content of the soils, and the concentration of dieldrin in the soil water.

Numerous reports in the literature have shown that crops can absorb organochlorine pesticide residues from soil. The degree of absorption depends on the crop, the specific insecticide involved, its concentration in the soil, soil type, and climate (Lichtenstein, 1965). It has been shown that pesticide residues are absorbed more readily from sandy soils and less readily from organic soils (Harris and Sans, 1967; Lichtenstein, 1959). However, most agricultural soils, at least those used for growing cereal and forage crops, are mineral soils. The organic matter content of such soils is usually 1 to 6% and rarely exceeds 10%, as compared to 20 to 90% for muck or organic soils.

Mineral soils vary widely in their sand, silt, and clay content and it is reasonable to expect that these components might influence the uptake of insecticide residues by crops. Beall and Nash (1969) found that organic matter in mineral soils reduced the uptake of heptachlor, dieldrin, and DDT by soybeans, corn, and alfalfa. However, the uptake of endrin by these crops was significantly affected by silt and not by organic matter. There was no significant correlation between the uptake of these insecticides by these crops and pH, cation exchange capacity, or clay content of the soils. Nor was there any correlation between the uptake of these insecticides by bromegrass and cucumber plants and any of the soil factors mentioned above. This study indicated that the occurrence of a correlation depended on the specific crop and insecticide involved. In another study Beestman *et al.* (1969) observed that soil organic matter negatively affected the uptake of dieldrin by corn plants but no relationship existed between dieldrin uptake and cation exchange capacity, free iron oxide content, or types and amounts of clay minerals in the soil.

Wheat is the most important crop grown in the Canadian prairie provinces. The effect of the type of mineral soil on the uptake of any organochlorine pesticide by wheat has not yet been reported and was, therefore, examined in the present study.

EXPERIMENTAL

The seven mineral soils used in this study were part of a large number of soil samples collected from various farms in Saskatchewan for the determination of organochlorine pesticide residues. These seven soils, when analyzed for lindane, aldrin, dieldrin, heptachlor, heptachlor epoxide, endrin, DDT, DDE, and DDD by the methods described by Saha *et al.* (1968), contained less than 0.01 ppm of these insecticides. All the soils were air-dried at room temperature (3 to 6% moisture) and screened through a 20-mesh screen. Six soils (nos. 1–6, Table I) were treated with dieldrin at 12 to 16 ppm (oven dry basis) by adding an aqueous suspension of 18 mg of dieldrin in 150 ml of water containing 1% Triton-X-100 (Rohm and Haas) to 1200–1600 g of air-dried soil. Sixteen-hundred grams of soil no. 7 (oven dry basis) were treated with an aqueous suspension of 40 mg (25 ppm) of dieldrin in 200 ml of 1% Triton-X-100 solution. Each treated soil was then tumbled for 6 hr to ensure thorough mixing and packed into four 4-in. plastic pots. Two more plastic pots were packed with each of the soils without the addition of any dieldrin and about 15 Canthatch wheat seeds were planted in each pot. The pots were placed in the greenhouse and watered daily from below to maintain healthy growth. Wheat seedlings were harvested by cutting 1 in. above the soil surface 30 days after planting. Fresh weights were taken, the plants diced, and moisture content determined by heating an aliquot in an oven at 110° C for 4 hr.

Analytical Methods. All the samples, including those grown in untreated soil, were analyzed in duplicate by gas–liquid chromatography using a Model 600D Aerograph Hi-Fi gas chromatograph with electron capture detector and a 5-ft × $^1/_8$-in. i.d. aluminum column packed with 4% SE30 on 80- to 100-mesh Chromosorb W. The carrier gas was oxygen-free nitrogen with a flow rate of 120 ml/min. The injector, column oven, and detector temperatures were 180°, 176°, and 190° C, respectively. Under these conditions the retention times of heptachlor epoxide and dieldrin were 4.2 and 8.0 min, respectively. The amount of diedrin present in a particular sample was determined by the internal standard method (Saha, 1966) using heptachlor epoxide as the standard. The volumes of the soil and plant extracts were so adjusted that injection of 1 to 3 μl of the solutions gave 30 to 60% full-scale recorder response.

Dieldrin concentrations in the soils prior to planting were calculated from the amount of a particular soil added to 18 mg of dieldrin. However, soil residues were determined experimentally at the time wheat seedlings were harvested. All soils from the four pots of one soil type were pooled, air-dried at room temperature, and screened through a 20-mesh screen. The moisture content of the air-dried soils was determined by heating a 5-g sample in an air oven at 110° C until there was no further loss in weight. Ten grams of air-dried soil were mixed with 2 ml of distilled water. The mixture was then shaken for 1 hr with 50 ml of a mixture of hexane/acetone (1:1, v/v) and allowed to stand for 10 min. The supernatant liquid was filtered and the solid residue reextracted twice, in the same way, with 10 ml of the same solvent mixture each time but with only 10 min of shaking. The combined extract was partitioned between petroleum ether and water. The petroleum ether extract was washed

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Table I. Effect of Organic Matter, Sand, Silt, and Clay Content of Soil on Dieldrin Uptake by Wheat Plants[a]

No.	Type	pH	Organic matter, % C × 1.724	% Oven-dried weight after removal of organic matter: Sand	Silt	Clay	Dieldrin, ppm (oven-dry basis): Soil at Seeding[b]	Soil at Harvest[c]	Wheat plants[c]	ppm dieldrin in wheat plants per ppm in soil
1	Dark brown Elstow Chermozem clay	6.8	4.1	14.4	38.5	47.1	15.9	14.05	6.17	0.44
2	Dark brown orthic Elstow Chermozem clay loam	6.0	5.1	27.7	44.9	27.4	11.9	9.33	5.80	0.62
3	Dark brown Elstow Chermozem clay loam	6.8	2.7	28.7	42.1	29.2	15.6	13.10	4.05	0.31
4	Black Oxbow Chermozem silty loam	7.3	1.4	33.0	53.2	13.8	15.9	14.35	3.67	0.25
5	Dark brown Asquith Chermozem sandy loam	7.0	1.6	74.6	14.8	10.6	13.5	9.78	7.83	0.80
6	Dark brown Asquith Chermozem loamy sand	6.9	1.0	86.1	7.1	6.8	15.1	10.75	8.70	0.81
7	Peaty Gley clay loam	7.2	9.3	25.7	47.0	27.3	25.0	23.00	0.58	0.03

[a] All soils had less than 0.01 ppm of any organochlorine insecticide prior to the addition of dieldrin; wheat plants grown in untreated soil had less than 0.03 ppm dieldrin (oven-dry basis). [b] Calculated from the amount of dieldrin and soil used. [c] Standard errors of means for the dieldrin contents of soil and wheat plants were ±0.06 and ±0.12, respectively.

with water, dried with anhydrous sodium sulfate, and concentrated to 10 to 15 ml. The concentrated extract was chromatographed on a magnesia-Celite column (1:1, w/w) and eluted with 250 ml of benzene–hexane mixture (15:85, v/v). The dieldrin content of the eluate was determined by gas–liquid chromatography after the addition of a known amount of the internal standard to the eluate, and the results were expressed on the oven-dry weight of the soil. The true recovery of dieldrin from soil, as determined by using dieldrin-^{14}C treated soil, was 92 to 98% (Saha *et al.*, 1969), irrespective of the soil type.

A 10-g sample of diced fresh wheat plants was macerated for 10 min at high speed with 100 ml of acetonitrile in a VirTis blender and filtered under suction. The residue was washed three times with 5 ml of acetonitrile each time. The combined filtrate was diluted with 500 ml of 1% NaCl solution and extracted three times with petroleum ether. The petroleum ether extract was washed with water and dried over anhydrous Na_2SO_4. The extract was concentrated to 10 to 15 ml, chromatographed on a magnesia-Celite column (4:1, w/w), and eluted with 250 ml of benzene–hexane mixture (15:85, v/v). The eluate was concentrated to a suitable volume and analyzed by gas–liquid chromatography after adding a known amount of heptachlor epoxide, the internal standard. The true recovery of dieldrin from fresh wheat plants as determined by the extraction of root-absorbed dieldrin-^{14}C by this method was 68% (Saha, 1971). The dieldrin content of wheat plants was corrected for recovery efficiency and expressed on oven-dry weight of plant tissues (Table I).

To study the desorption of dieldrin from soil by water, 50 g of air-dried soil was shaken for 5 hr with 250 ml of distilled water and filtered under suction. The filtrate (200 ml) was extracted three times with petroleum ether. The total amount of dieldrin present in the petroleum extract was determined by the procedure described for soil residues and the results were expressed as ng of dieldrin/ml of water extract, ppb (Table II).

To study the effect of the ratio of water to soil on the desorption of dieldrin, 50-g samples of soil nos. 3 and 6 were extracted with 250, 200, 150, and 100 ml of water and the dieldrin content of an aliquot of the water extract was determined by the method described above (Table II).

Table II. Relationship between Desorption of Dieldrin from Soil by Water and Uptake by Wheat Plants

Soil No.	Soil Type	Dieldrin in Soil ppm	Dieldrin in Water extract of soil ppb (ng/ml)	ppb dieldrin in water extract per ppm in soil	ppm dieldrin in wheat plants per ppm in soil
1	Elstow clay	14.05	30.9	2.20	0.44
2	Elstow clay loam	9.33	34.0	3.64	0.62
3	Elstow clay loam	13.10	26.7	2.04	0.31
4	Oxbow silty loam	14.35	24.2	1.68	0.25
5	Asquith sandy loam	9.78	37.5	3.83	0.80
6	Asquith loamy sand	10.75	42.5	3.95	0.81
7	Peaty Gley clay loam	23.0	7.2	0.31	0.03

RESULTS AND DISCUSSION

Since the wheat plants were grown in the greenhouse they were all in a similar environment and the observed differences in uptake can be attributed to the differences in the characteristics of the soils. This was a distinct advantage over previous studies (Harris and Sans, 1967; Lichtenstein, 1959) on the absorption of organochlorine insecticides from agricultural soils by root crops grown in different locations where plant growth and hence uptake of residues could be influenced by differences in the climatic conditions. Studies with wheat plants grown in soil treated with radioactive dieldrin have shown that these plants can absorb dieldrin through the roots and translocate it into the aerial parts (Nash, 1968; Wheeler *et al.*, 1967). It has also been shown (Nash, 1968; Wheeler *et al.*, 1967) that the dieldrin content of wheat plants grown in soil treated with 0 to 25 ppm dieldrin bears a linear relationship to the dieldrin content of the soil. In the present study dieldrin content of the soils ranged from 12 to 25 ppm at the time they were treated with dieldrin and 9 to 23 ppm at the time the plants were harvested. It is reasonable to assume that the dieldrin content of the wheat plants grown in these soils would also be directly proportional to the dieldrin content of the soil. Therefore dieldrin uptake by wheat plants grown in different soils can be compared by relating the ppm of dieldrin in wheat plants to ppm of dieldrin in soil (Table I).

There were considerable differences in the degree of dieldrin uptake by wheat seedlings grown in the seven soils treated with dieldrin (Table I). To determine the influence of soil characteristics on the uptake of dieldrin, correlation coefficients (r values) were calculated between ppm of dieldrin in wheat plants/ppm of dieldrin in soil and percentage of organic matter, sand, silt, and clay in the soils and soil pH. Correlation coefficients necessary to show significance at the 5% and 1% levels are ±0.754 and 0.874, respectively. The r values obtained from the correlation of dieldrin content of wheat plants with pH, percentage organic matter, sand, silt, and clay of the soils were −0.408, −0.624, +0.742, −0.822, and −0.430, respectively. The organic matter contents of the soils exerted a negative but nonsignificant effect on the uptake of dieldrin by wheat plants. Wheat plants grown in the two sandy soils containing less than 2% organic matter contained 27 times more dieldrin than those grown in the clay loam soil containing 9% organic matter (soil nos. 5 and 6 *vs.* 7, Table I). The two clay loam soils (nos. 2 and 3) had similar amounts of sand, silt, and clay contents but one had twice the amount of organic matter as the other. Wheat plants grown in the soil no. 2 had proportionately twice as much dieldrin as those grown in the soil no. 3, which had half the amount of organic matter. Thus the correlation between the organic matter contents of the soils and dieldrin uptake by wheat plants was rather poor in the present study.

Beall and Nash (1969) stated that organic matter content of mineral soils negatively affected the uptake of dieldrin, heptachlor, and DDT by soybeans, corn, and alfalfa, although only a few of the r values were significant at the 5% (four out of 18) and 1% (three out of 18) level. On the other hand, none of the six r values for endrin uptake by these crops were significant even at the 5% level. In the study carried out by Beestman *et al.* (1969) the organic matter contents of the A- and B-horizon soils were 3.8 to 7.7 and 0.4 to 0.7%, respectively. There was less uptake of dieldrin by corn plants grown in the A-horizon soil than those grown in the B-horizon soil, containing only about one-tenth organic matter. But there was no statistical analysis of the data to show any significant correlation between dieldrin contents of the wheat plants grown in the same horizon soil where there was about a twofold difference in the organic matter content.

The degree of uptake of dieldrin by wheat plants grown in the soils was not related to the sand (r = +0.742) and clay (r = −0.430) contents of the soils and their pH (r = −0.408). These observations are in agreement with those of Beall and Nash (1969) and Beestman *et al.* (1969). Beestman *et al.* (1969) also observed no correlation between dieldrin uptake by corn plants and free iron oxide content or types and amounts of clay size minerals in the soils. However, the data presented in Table I show that the uptake of dieldrin by wheat plants was negatively affected by the silt content of the soils (r = 0.822). Beall and Nash (1969) also observed a similar significant negative effect exerted by silt on endrin uptake by soybean, corn, and alfalfa plants, although no such correlation was observed with DDT, dieldrin, and heptachlor.

Studies with wheat plants grown in soil treated with radioactive dieldrin have shown that dieldrin is present only in the xylem vessels, tracheids, and the adjacent mechanical tissues of the aerial parts of the plants (Cotner *et al.*, 1968). This suggests upward transportation of dieldrin with water through the xylem vessels. The dieldrin content of the plant should then depend on the concentration of dieldrin in soil water. Insecticides applied to soil are adsorbed by soil particles

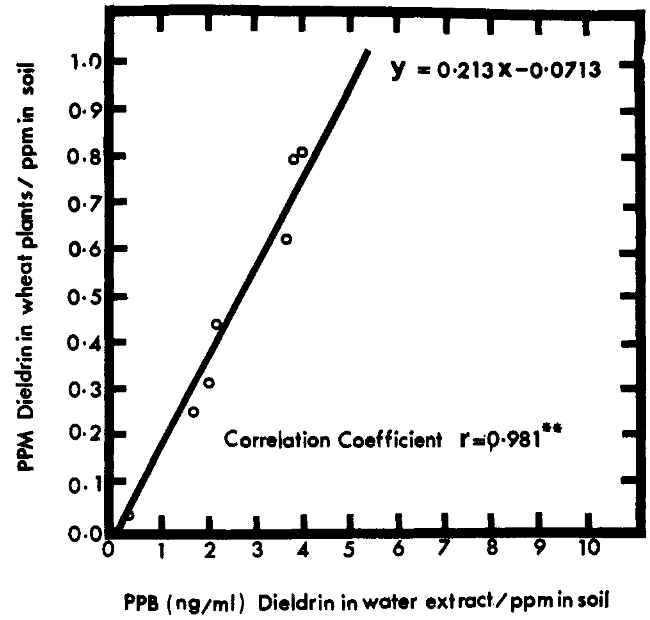

Figure 1. Relationship between desorption of dieldrin from soil by water and uptake by wheat plants

Table III. Effect of Water/Soil Ratio on the Desorption of Dieldrin from Soil

Soil No.	Soil Type	Ml water/g soil	Dieldrin in soil extract ppb (ng/ml)
3	Elstow clay loam	5	26.7
		4	26.0
		3	25.2
		2	26.4
6	Asquith loamy sand	5	42.5
		4	42.9
		3	43.0
		2	42.1

(Downs *et al.*, 1951; Hadaway and Barlow, 1951). Bioactivity of soil insecticides increases with increasing moisture content of the soil (Harris, 1964, 1966, 1967), suggesting that in dry soils insecticides are inactivated by strong adsorption on soil particles, and the presence of water in soil reactivates these compounds by desorption. A similar conclusion was reached from studies on the effect of moisture on the extraction of dieldrin from soil (Saha *et al.*, 1969). It was observed that the addition of water to dry soil desorbs dieldrin from soil particles, which can then be easily extracted by solvents. The desorbed insecticide would be present in soil water and would be taken up by the roots and transported to the aerial parts of the plants along with water and nutrients. The ability of water to desorb dieldrin from soil may depend on the nature of the soil. A measure of the degree of desorption of dieldrin from the seven soils in this study was obtained by extraction of the dieldrin-treated soils with water and determination of the dieldrin concentration of the water extracts (Table II). The concentration of dieldrin in the water extract was highest from the loamy sand soil and was lowest from the soil with the highest organic matter content. The r value obtained from the correlation of dieldrin content of wheat plants and dieldrin concentration of the water extracts of soils was +0.981 and it was significant at the 0.1% level (Figure 1). These soils were extracted with 5 ml of water/g of soil and the normal field moisture level would be considerably lower than this. The concentration of dieldrin actually present in soil water could be different from the dieldrin concentration in these water extracts. The data presented in Table III show that the amount of water per gram of soil had no effect on the concentration of dieldrin in the water extract, strongly suggesting that the results in Table II represent the concentration of dieldrin in soil water. The amount of dieldrin present in soil water depends on the nature of the soil. The soil components responsible for absorption of insecticides are not clearly identified and the mechanism of adsorption of insecticides by soil components is also poorly understood. In the absence of this information it would be hazardous to guess which component of the soil determines uptake of pesticide residues by plants, although silt and organic matter can be implicated. (Triton-X-100 used for the application of dieldrin to the soil may affect the uptake of dieldrin but the mechanism and the extent of this effect is not known.) However, the linear relationship shown between the concentration of dieldrin in the wheat plants and that in water extracts of the soil in which they were grown offers an explanation for the observed difference in uptake of dieldrin grown in different types of soil.

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