Soil Moisture and Soil Type Influence Initial Penetration by Organochlorine Insecticides

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Because present recommendations for termite control by soil application of chlorinated hydrocarbons were developed on soils and for termites in southern Mississippi, field tests were established at seven locations to compare control of the various species of termites in different soils and climates (1). In the upper 4 inches of soil, the amount and distribution of insecticide residues and degradation products varied considerably for the different locations 3 years after application (2). Differences in initial penetration may have been a major cause for this variation. In 24 hours the insecticide emulsions penetrated least in arid soils in Arizona and Oregon and most in wet soil from Missouri (1). This paper reports the results of laboratory studies into the factors influencing soil penetration by insecticides. A mixture of aldrin, dieldrin, and heptachlor was applied as a water emulsion to columns of soil obtained from the field test locations.

METHODS AND MATERIALS

Soil.--Untreated soil from the field test area was sampled at the seven locations selected to represent major soil types and rainfall patterns in the United States. Locations and soil properties are summarized in Table 1. Soil, taken from the upper 6 inches, was air-dried and well mixed. The Missouri soil, which was wet when sampled, dried in large hard lumps and had to be ground before using. Particle size was estimated by the Bouyoucos hydrometer method (3). Correction was not made for the organic matter. Moisture content was determined as percent loss in weight from ovendrying an aliquot of the soil at 104°C for 24 hours. The relatively high value for the Hawaii soil (7.23%) was attributed to the high organic content of the soil. Values for other locations were low. Readily-oxidizable organic matter was estimated by the modified Walkley-Black method (4). The pH measurements were determined electrometrically with a glass electrode pH meter.

Column preparations.--Five or six layers of soil each equivalent to 4 g air-dried weight were packed in glass columns (24 cm long, 1.59 cm OD, and 1.32 cm ID). Good drainage was insured by supporting the soil column on either styrofoam sponge or pyrex wool held in place by nylon mesh. Moisture of the soil was adjusted to obtain three levels (5, 10, and 15%) above that of the air-dried level (arbitrarily assigned value of 0%). Each 4-g portion of soil

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TABLE 1

Location and Properties of Test Soils

Soil type and location	pH	% moisture	% sand	% silt	% clay	% organic matter
Continental gravelly sandy loam Tucson, Ariz.	6.2	0.80	67	24	9	0.65
Lakeland sand Marianna, Fla.	4.6	0.27	94	3	3	0.40
Makalapa clay Honolulu, Hawaii	6.3	7.23	54	27	19	10.53
Beltsville silt loam Beltsville, Md.	4.0	0.89	38	47	15	2.57
Lebanon silt loam Salem, Mo.	4.9	1.26	20	58	22	0.59
Quincy loamy fine sand Hermiston, Oreg.	7.1	0.61	96	4	0	0.13
Cataula loamy sand Union, S.C.	5.8	0.37	86	9	5	0.42

was mixed in a small beaker with the required amount of distilled water to give the desired moisture content before packing into the column. Soil layers were separated by circles cut from filter paper support cloth. This procedure was believed to be the most practicable for quantification of the analytical results on a parts per million basis.

Insecticides.--Insecticides were obtained as emulsifiable concentrates: aldrin and dieldrin from Shell Chemical Company and heptachlor from Velsicol Chemical Corporation.[1/] The three technical insecticides were applied as a mixture to simplify the experiment and equalize the effect of emulsifiers present in the concentrates. The concentrates were diluted with water to obtain appropriate concentrations of active ingredients for two series of experiments. For series A, the concentration was approximately 0.5% for each insecticide. Because quantities of 0.70 and 1.40 ml per column correspond respectively to the 1 and 2 pt/ft^2 applied in the field tests, 1 ml was applied to each column of the seven soils at the four moisture levels. For series B, 3 ml of a mixture containing 0.17% concentrations of each insecticide were added to the columns. The volume was increased to insure deeper penetration

[1/] Mention of companies and trade names is to identify chemicals and equipment used and does not imply endorsement by the U. S. Department of Agriculture.

of liquid into the column and to make any difference in penetration by the individual insecticides more readily apparent.

Sample preparation.--Layers were removed approximately 24 hours after application of the emulsion. A modified spatula with a bent and split tip was used to remove the soil. The lowest layer was removed first to minimize contamination. Soil was placed in sample bottles (capacity about 235 ml) and extracted on a shaker for 1 hour with 100 ml of a solvent mixture of 2:1 hexane and isopropyl alcohol. A 75-ml aliquot of the filtered extract was then washed three times with distilled water. The hexane layer was filtered and adjusted to either 60 or 90 ml with distilled-in-glass hexane. One g of soil was equivalent to 20 ml of the first extract and 30 ml of the second.

Gas chromatographic analysis.--Extracts were analyzed with a Micro-Tek 2000MF gas chromatograph equipped with a 130-mc tritium electron capture detector and operated with a pulse power supply. The columns were 6-foot by 1/4-inch glass tubings packed with 3% DC-200 on 100/120 mesh Gas Chrom Q. Operating temperatures and gas-flow rate varied somewhat, but appropriate standards were run daily with the samples. Typical operating parameters were: oven 195°, detector 205°, inlet 215°, and outlet 240°C. The flow rate of carrier gas, a mixture of 95% argon and 5% methane, was normally 120 ml/min.

A mixture of analytical grade heptachlor, aldrin, gamma-chlordane, and dieldrin was used as a standard. Gamma-chlordane was included because it is present in technical heptachlor. Small peaks from minor components of the technical insecticide were disregarded. Insecticide composition in the soil layers was calculated as parts per million (ppm) and as percent of total insecticide found per column.

RESULTS AND DISCUSSION

The four insecticides penetrated the soil layers of the individual columns essentially to the same extent. Since all are chlorinated hydrocarbons and were applied as a mixture with the same emulsifiers, this result was not considered to be surprising. The results for aldrin, which are representative, are given in ppm in Table 2 for series A and B. The mean values of aldrin recovered from the columns were 1070 ppm for series A and 1205 ppm for series B (values adjusted for Hawaii columns and omitted for 15% Arizona). A comparison of the results of the individual columns and the means indicates that the experimental error is reasonable for analyses of such small soil samples. For comparative purposes the concentration of each insecticide in each soil layer was calculated as a percent of its total amount recovered per column. The mean percent values of the four insecticides in the soil layers for series A and B are summarized in Table 3.

TABLE 2

Distribution of aldrin (ppm) in 4-g layers of columns prepared from seven soils at four moisture levels with 1.0 ml 0.5% insecticide mixture applied for series A and 3.0 ml 0.17% insecticide mixture applied for series B (5.0 ml to Hawaii column)

Soil and	Series A layer					Series B layer					
moisture	1	2	3	4	5	1	2	3	4	5	6
Ariz.											
0%	898	145	-	-	-	917	106	138	8	-	-
5%	990	34	-	-	-	919	94	111	51	-	-
10%	709	275	-	-	-	963	114	75	43	-	-
15%	935	-	-	-	-	336*	-	-	-	-	-
Fla.											
0%	815	187	-	-	-	645	376	103	71	2	-
5%	513	377	128	-	-	303	332	409	116	72	40
10%	595	397	89	-	-	224	257	276	297	122	74
15%	760	172	17	-	-	421	423	200	94	68	31
Hawaii											
0%	1050	-	-	-	-	1870	183	11	-	-	-
5%	988	-	-	-	-	1920	212	16	-	-	-
10%	1090	-	-	-	-	1780	319	63	-	-	-
15%	1090	-	-	-	-	1770	312	94	2	-	-
Md.											
0%	1080	-	-	-	-	1130	113	-	-	-	-
5%	1120	1	-	-	-	1010	52	7	-	-	-
10%	927	69	-	-	-	1040	63	17	2	-	-
15%	1020	1	-	-	-	995	39	11	1	-	-
Mo.											
0%	1010	-	-	-	-	1150	23	-	-	-	-
5%	1080	-	-	-	-	1160	60	-	-	-	-
10%	1150	-	-	-	-	997	142	26	-	-	-
15%	1190	-	-	-	-	923	110	89	93	14	-
Oreg.											
0%	642	473	39	-	-	690	225	81	78	91	32
5%	713	471	6	-	-	374	444	224	78	62	44
10%	509	311	215	1	-	437	423	98	59	84	73
15%	618	442	102	6	-	543	343	160	64	67	49
S.C.											
0%	611	481	-	-	-	477	425	195	100	46	-
5%	570	561	19	-	-	426	371	209	128	82	51
10%	483	253	314	46	-	241	181	185	210	183	148
15%	1020	122	2	-	-	921	117	58	42	13	2

* More than 2 ml insecticide mixture was left above soil surface.

TABLE 3

Average % distribution of insecticide mixture (heptachlor, aldrin, gamma-chlordane, and dieldrin) in 4-g layers of columns prepared from seven soils at four moisture levels with 1.0 ml 0.5% insecticide mixture applied for series A and 3.0 ml 0.17% insecticide mixture applied for series B (5.0 ml to Hawaii column)

Soil & % moist.	Series A layer*				Series B layer					
	1	2	3	4	1	2	3	4	5	6
Ariz.										
0	86.5	13.5	-	-	76.6	10.0	12.6	0.8	-	-
5	96.8	3.2	-	-	75.9	9.0	10.4	4.7	-	-
10	72.6	27.4	-	-	79.2	10.4	6.7	3.7	-	-
15	100.	-	-	-	100.	-	-	-	-	-
Fla.										
0	82.7	17.3	-	-	49.2	34.5	9.6	6.5	0.2	-
5	50.2	37.2	12.6	-	22.0	25.3	33.2	10.2	6.0	3.3
10	55.3	36.5	8.2	-	17.0	19.9	22.3	24.4	10.1	6.3
15	80.1	18.2	1.7	-	31.7	34.2	16.9	8.5	6.1	2.6
Hawaii										
0	100.	-	-	-	90.2	9.2	0.6	-	-	-
5	100.	-	-	-	88.7	10.6	0.7	-	-	-
10	100.	-	-	-	80.8	16.1	3.1	-	-	-
15	100.	-	-	-	79.9	15.5	4.5	0.1	-	-
Md.										
0	100.	-	-	-	90.3	9.7	-	-	-	-
5	99.9	0.1	-	-	94.6	4.8	0.6	-	-	-
10	93.3	6.7	-	-	92.6	5.7	1.5	0.2	-	-
15	99.9	0.1	-	-	95.3	3.6	1.0	0.1	-	-
Mo.										
0	100.	-	-	-	97.9	2.1	-	-	-	-
5	100.	-	-	-	94.9	5.1	-	-	-	-
10	100.	-	-	-	84.4	13.1	2.5	-	-	-
15	100.	-	-	-	72.5	9.7	8.1	8.5	1.2	-
Ore.										
0	55.6	40.6	3.8	-	52.4	21.6	7.6	7.1	8.4	2.9
5	62.1	37.4	0.5	-	28.2	35.8	19.3	7.0	5.7	4.0
10	48.2	30.8	20.9	0.1	35.1	35.5	8.9	5.7	8.0	6.8
15	50.7	40.0	8.8	0.5	41.2	28.9	13.3	5.9	6.2	4.5
S.C.										
0	58.2	41.8	-	-	35.2	34.5	17.3	9.0	4.0	-
5	51.8	46.7	1.5	-	29.6	29.1	18.4	11.6	7.2	4.1
10	44.2	23.8	27.7	4.3	20.5	16.1	16.1	18.5	15.7	13.1
15	89.3	10.6	0.1	-	77.9	11.2	5.7	4.0	1.1	0.1

* No insecticide was found in the fifth layer.

For series A the least penetration was obtained in Hawaii and Missouri soil columns, where insecticides were found only in the top layer. Insecticides also did not enter into the second layer of 0% Maryland and 15% Arizona soils and penetrated only insignificantly in 5% and 15% Maryland columns. Penetration into the lower layers was obtained with the Florida, Oregon, and South Carolina sandy soils. Greatest penetration was obtained with the 10% South Carolina column, in which 4.3% of the insecticide was found in the fourth layer. Although the patterns of penetrated layers differed with changes in moisture level, they were not consistent over all the soils. The trend to greater penetration with greater moisture in the Florida and South Carolina soils was reversed at their 15% moisture level.

Since 1 ml of the mixture used for series A did not penetrate into the second layers for 10 of the 28 columns (Table 3), series B was set up using 3 ml of a more dilute mixture and adding a sixth layer to each column. An additional 2 ml were added to the Hawaii columns to insure penetration into the lower layers. Little penetration occurred for the 15% Arizona column; approximately 2 ml were left above the column surface after 24 hours.

A comparison of the insecticide distribution patterns in the soil layers (Table 3) separates the soils into two general groups related primarily to soil type (Table 1). Penetration to both the fifth and sixth layers occurred only in the sandy soils of Florida, Oregon, and South Carolina. The soils of Hawaii, Maryland, Missouri, and Arizona had a higher content of silt and clay, and over 70% of the insecticide recovered was found in the upper layer regardless of moisture content. In the other sandy soils, this pattern was shown by only the 15% South Carolina loamy sand, into which the insecticide entered slowly; 77.9% of the insecticide was found in the upper layer. The remaining sandy soils, from Florida, Oregon, and South Carolina, generally retained less than 50% of the insecticide in their upper layer. For a number of columns, such as 5% and 10% Florida and Oregon, the values for layer 2 are higher than those for layer 1. Also noteworthy are the small differences in the values for the 10% South Carolina layers (20.5, 16.1, 16.1, 18.5, 15.7, and 13.1%) and the upper four layers of 10% Florida (17.0, 19.9, 22.3, and 24.4%). Apparently, fixation of the insecticides by soil particles was practically nil in these sandy soils.

A comparison of the average percent distribution values (Table 3) for layer 1 of the South Carolina columns of series A and B indicates that soil moisture affects insecticide penetration similarly for both series. Less insecticide was retained by the upper layer of soil with an increase in moisture content to 10%. At the 15% level the reverse effect occurred, with 89.3% and 77.9% insecticide being retained in layer 1 of series A and B, respectively. As expected, penetration was increased by the additional volume applied in series B. In both series, greatest penetration occurred in the 10% South Carolina column.

The results obtained with the Hawaii soil are of interest. In series A, insecticide was found entirely in the upper layer. In series B, 5 ml were added, and the insecticide penetrated to the third layer, where less than 5% was found. In an extra series the 0.5% mixture was diluted 20 fold, and 20 ml of the diluted mixture were applied to the columns. No aldrin was found in the fifth layer of the 0% column, whereas 8 ppm were found in the 5% column, 22 ppm in the 10% column, and 63 ppm in the 15% column. In contrast, in layer 1, 694 ppm were found in 0% column, 539 ppm in 5%, 421 ppm in 10%, and 184 ppm in 15%. Thus, increase in penetration was directly correlated with increase in moisture.

The columns made from Hawaii soil were considerably longer than those of the other soils. A rough estimation of the density of the seven soils was made by weighing the soil packed into a 50-ml container. The soils in order of increasing weights were: Hawaii, 46.8 g; Maryland, 56.6 g; Missouri, 65.6 g; South Carolina, 65.7 g; Florida, 75.8 g; Arizona, 77.5 g; and Oregon, 87.1 g. Differences in soil density and soil capacity to absorb and retain water probably account for some of the differences observed in the effects of moisture levels and volume applied on penetration and distribution of insecticide in the soils.

In contrast to the results obtained in the column tests, insecticide was absorbed in a thin layer in the Oregon soil in the field where the emulsion was applied to very dry undisturbed loamy sand. Greatest penetration was obtained in the Missouri field test, which was installed at a time of unusually high precipitation. For Missouri columns of series B, the percent distribution of insecticide in the lower layers increased with increases in moisture content. Although a wide range of moisture was tested, in some soils saturation was surpassed at the 15% level while others could have held considerably more water. Thus, with the same percent of moisture, we were testing a moist soil for one location and a very wet soil for another.

Analysis of variance for the combined soils shows significant differences for the soils in layers penetrated, regardless of moisture level. For each soil the pattern of layers penetrated depended upon moisture. Thus, the moisture level as well as the soil type is important.

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