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Soil Adherence to Human Skin

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Dermal exposure to soils contaminated with toxic chemicals represents a potential public health hazard. These soils, contaminated with chemicals such as PCBs and dioxins, may be found at various locations throughout the U.S. (EPA 1987). Furthermore, dermal contact with pesticide-containing particles and contaminated soil particles is of importance for exposures to agricultural workers who reenter fields after pesticide application (Knaak et al. 1989). Dermal exposure estimates based on the dislodgeable residue procedures for measuring the transfer of pesticide residues to workers includes pesticide residues present on contaminated particulate material that adheres to foliage. Particles present on sprayed foliage surfaces can consist of dried pesticide deposits from liquid formulation, granular formulations, and dust or clay particles, especially when they are used as inert carriers in the applied formulation. It has been suggested that differences in soil type, particle size distribution, and crop foliage may affect exposures obtained during reentry (Nigg et al. 1984). Because of the wide geographical distribution of agricultural and hazardous waste sites, soil characteristics (e.g., particle size distribution, organic content, moisture content, pH) may vary significantly.

With respect to dermal exposure to pesticide-contaminated particulate matter, several occurrences of human toxicity to ethyl parathion in citrus groves have been reported. These exposures resulted from dermal contact with high concentrations of the toxic transformation product paraoxon in soil dust contaminated as a result of application of pesticide to the overhead foliage of trees (Gunther et al. 1976). Soil dust can serve as a vehicle for transfer of paraoxon to various parts of the body (e.g., hands, arms, legs, feet) of workers harvesting fruit (Iwata 1980). Such contact has resulted in human toxicity even in the presence of levels on treated foliage presumed to be safe based on an adequate time interval before reentry. Similarly, dermal exposure of strawberry harvesters and weeders to captan has been thought to be related to resuspended, contaminated dust (Zweig et al. 1985).

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To assess dermal exposure to chemically-contaminated soil at sites of concern, dermal adherence of soil must be determined prior to the assessment of dermal absorption. Several studies have been reported which measured either directly or indirectly, soil adherence to skin. Lepow et al. (1975) employed adhesive tape to sample 21.5 cm^2 of skin on an area of the hand. This method yielded approximately 11 mg of material on the skin surface. Assuming all the material recovered was soil and the method yielded a substantial portion of the soil adhering to the skin, approximately 0.5 mg of soil was determined to be adhering to 1.0 cm^2 of skin.

In another study, the amount of lead adhering to the hands of children (average age of 11 years) was determined during school yard activities (Roels et al. 1980). The amount of lead adhering to the hand was determined by pouring 500 ml of dilute nitric acid over the palm. The lead content of the hand rinse and of representative soil samples from the school yard was determined. An estimate of the amount of soil (g) on the hand was calculated by dividing the hand lead amount (μg) by the soil lead amount (μg/g). The mean soil amount adhering to the hand was 0.159 g. The California Department of Health Services, Toxic Substances Control Division (1986) used this estimate and the average surface area of the hand of an eleven year old - 307 cm^2 (Anderson et al. 1985, McDougal 1978, Lund and Browder 1944), to estimate the amount of soil adhering per unit area of skin - 0.9 mg/cm^2. This estimate assumed approximately 60 percent (185 cm^2) of the hand was sampled by the method employed by Roels et al. (1980).

Que Hee et al. (1985) used soil in particle sizes ranging from 44 to 833 μm diameters, fractionated into 6 size ranges to estimate the amount of soil adhering to skin. For each range of particle sizes, the amount of soil that adhered to the palm of the hand of a small adult was determined by applying approximately 5 g of soil for each size fraction and measuring the difference in weight before and after soil application. Several assumptions were made including: soil is composed of particles of the indicated diameters, all soil types and particle sizes adhere to the skin to the degree observed in this study, and an equivalent weight of particles of any diameter adhere to the same surface area of skin. On average, 31.2 mg of soil adhered to the small adult palm. Assuming the surface area of the palm of a small adult (approximately 14 years old with an average total body surface area of 16,000 cm^2 and a hand surface area of 400 cm^2) is approximately 160 cm^2 (Anderson et al. 1985), 0.2 mg of soil adhered to 1 cm^2 of skin.

The purpose of the experiment reported herein was to determine the amount of soil (mg/cm^2) that adheres to adult hands under various soil conditions. These conditions include the type of soil, the organic content of the soil, and the particle size of the soil.

MATERIALS AND METHODS

The experiments involved the use of various soil types collected from sites in Virginia. A total of five soil types or "series" were collected: Hyde, Chesapeake, Panorama, Jackland, and Montalto. Both top soils and subsoils were collected for each soil type. The soils were also characterized by cation exchange capacity, organic content, clay mineralogy, and particle size distribution. The soils were dry sieved to obtain particle sizes of ≤ 250 μm and ≤ 150 μm. For each soil type the amount (mg) of soil adhering to adult male hands, using both sieved and unsieved soils, was determined using the following methods:

1) A known weight (mg) of soil was placed into a pre-cleaned, tared plastic container; adult hands were then placed in the soil for a 30 second contact period; during the 30 second period the hands were constantly agitated in the soil; the weight (mg) of adhered soil was then determined by subtracting the soil post-contact weight from the pre-contact weight.

2) Triplicate adherence weight (mg) measurement determinations were made for each soil type at the ≤ 150 μm size, the ≤ 250 μm size, and for unsieved samples.

3) The surface area of adult hands was estimated using the following equation (Anderson et al. 1985):

$$SA = (0.0257)(W^{0.573})(H^{0.218}) \text{ where,}$$

SA = surface area of adult male hands in m^2,
W = body weight in kg, and
H = height in cm.

4) Pre- and post-contact weights were determined with the same temperature and humidity conditions using an analytical balance.

5) The adult male hands were cleaned with soap and water followed by triplicate rinses with double-distilled, deionized water. The hands were allowed to "air dry." The same hands were used for all experiments.

6) To determine the recovery efficiency for net soil loss after skin contact the following procedure was employed: from a known amount (mg) of soil, a sample was removed and weighed. The original soil was then reweighed to compare the net loss by subtraction versus the net loss by direct weighing. Net loss by subtraction differed from net loss by direct weighing by less than 1%.

Two-factor analysis of variance experiments were performed on soil adherence data. The two experimental factors were soil type and soil particle size. The experiment involved a total of eleven soil samples (from five soil types) and three particle sizes (unsieved, $\leq$ 150 μm, and $\leq$ 250 μm).

RESULTS AND DISCUSSION

Mean soil adherence values (mg/cm^2) are presented in Table 1 for all soil types, including top soils and subsoils. Data are presented for both sieved and unsieved samples. The analysis of variance statistics are shown in Table 2. The most important factor affecting adherence variability was particle size with a variance (F) ratio far in excess of the 0.999 significance value ($p < 0.001$). The next most important factor was soil type and subtype with an F ratio also in excess of the 0.999 significance value ($p < 0.001$). The interaction factor of soil type and particle size was also significant, but at a lower 0.99 significance level ($p < 0.01$). The standard error for comparing the difference between soil type means was $4\sqrt{1(2 \times 0.0344/9)} = 0.087$. Twice this standard error was greater than the difference between some, but not all, row means.

This implies that some, but not all, soil type and subtype means were not significantly different at the 0.95 significance level. The standard error for comparing the difference between particle size means was $4\sqrt{1(2 \times 0.0344/33)} = 0.046$. Twice this standard error was far less than the difference between any two column means implying that all such means were clearly distinct. This confirms that particle size was the most important factor of variability in the experiment.

Another experiment was conducted using two soil types: a high organic content soil of the Hyde series and a low organic content soil of the Chesapeake series. Two particle sizes (unsieved and $\leq$ 150 μm) were used for each soil type. Mean soil adherence values from this experiment are shown in Table 3, and the analysis of variance statistics are shown in Table 4. Again, the most important factor affecting experimental variability was particle size with an F ratio in excess of the 0.999 significance level ($p < 0.001$). The soil type factor was also significant, but at a lower 0.99 significance level ($p < 0.01$), and the interaction factor was not significant at all.

The standard error for comparing the difference between both row and column means was 0.054. Since the difference between the column means ($\approx$ 0.4) was about twice the difference between the row means, this confirms that, again, particle size (columns) was the most important element of variability in the experiment.

The importance of dermal exposure assessment for chemically-contaminated soils has been recognized by the U.S. Environmental Protection Agency (USEPA). For example, although inhalation exposure

Table 1. Soil adherence means (mg soil/cm^2 skin)

		Soil Adherence by Particle size			
Soil type[1]	% organic matter	Unsieved	≤ 250 μm	≤ 150 μm	Row Means
1A	3.04	0.5957	1.2268	1.6423	1.1549
1E	0.92	0.7166	1.2041	1.8515	1.2574
1Bt	0.22	0.3701	0.8041	1.1883	0.7877
2A	1.83	0.7390	1.1630	1.6914	1.1978
2B	0.31	0.2347	1.0669	1.4625	0.9213
3A	1.46	0.5431	0.9106	1.1155	0.8564
3B	0.61	0.1738	0.5140	0.7552	0.4810
4A	17.19	0.5826	0.8730	0.9762	0.8106
4Bt	N.D.	0.8965	0.9868	1.6808	1.1880
5A	10.03	0.7737	0.9012	1.6262	1.1003
5Bt	1.31	0.7901	0.7594	1.3940	0.9811
Column means:		0.5821	0.9463	1.3986	

[1] 1 Montalto Series 4 Hyde Series
2 Panorama Series 5 Chesapeake Series
3 Jackland Series

Letters following soil type designate soil horizons.
N.D. = Not Determined.

Table 2. ANOVA statistics for skin adherence factors of soil type and particle size

Source of Variance	Degrees of freedom	Sum of squares	Mean square	F ratio	Significance (p)
Soil type	10	4.914	0.491	14.299	< 0.001
Particle size	2	11.012	5.506	160.229	< 0.001
Interaction	20	1.737	0.087	2.527	< 0.01
Error	66	2.268	0.034		

Table 3. Soil adherence means (mg soil/cm^2 skin) for high and low organic content soils

		Soil Adherence by Particle Size		
Soil type	% organic	Unsieved	≤ 150 μm	Row means
Hyde	19.35	0.3627	0.7925	0.5776
Chesapeake	0.77	0.5955	0.9728	0.7841
Column means:		0.4791	0.8826	

Table 4. ANOVA statistics for skin adherence factors of soil type and particle size using high and low organic content soils

Source of Variance	Degrees of freedom	Sum of square	Mean square	F ratio	Significance (p)
Soil type	1	0.1280	0.1280	14.447	< 0.01
Particle size	8	0.4886	0.4886	55.142	< 0.001
Interaction	1	0.0021	0.0021	0.234	
Error	8	0.0709	0.0089		

to vapor phase and particulate residues occurs during pesticide worker reentry activities, it has been reported to represent less than one percent of dermal exposure in field situations (USEPA 1984). To prevent adverse health effects for workers by residues of some of the most toxic pesticides, EPA has established waiting times for reentry known as reentry intervals. The basis for determining a reentry interval is a dissipation study that examines the decrease in residue levels in the field after application due to environmental transformation processes (e.g., photolysis, hydrolysis). Subdivision K of the EPA's pesticide assessment guidelines directs that when contaminated soil residues are expected to be a major source of exposure for workers during reentry activities, a dissipation study must be performed for soil residues using soil samples of particle sizes $\leq$ 147 μm.

The implications of the soil adherence values for unsieved and sieved soils in exposure assessment are important to consider. Dermal exposure scenarios should be related to soil-specific characteristics (e.g., particle size distributions, soil type) to accurately determine exposure levels for a given toxicant. It is also important to consider soil characteristics (e.g., organic content) because of their influence on dermal absorption (Umbreit et al. 1986, Shu et al. 1988). Site-specific soil adherence values should be determined, if possible, based upon soil characteristics at the site. Further, soil adherence data should be developed for additional particle size intervals. This will allow the estimation of total soil adherence based on weighted adherence values (i.e., weighted according to the predominance of each particle size interval at a specific site). Once developed, soil adherence values will allow more accurate estimation of dermal exposure to chemically-contaminated soil.

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