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Factors Affecting Soil Adherence to Skin in Hand-Press Trials

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Risk attributable to dermal contact with contaminated soil is often estimated to be significant in assessment of risks presented by Superfund sites. However parameters used to calculate dermal pathway risk (USEPA, 1992) are typically poorly quantified. Among the parameters required is soil loading on skin. Estimates of soil adherence have been obtained from 1) laboratory studies using artificial loading scenarios (Que Hee et al., 1985; Driver et al., 1989; Sheppard and Evenden, 1992), 2) studies of Pb exposure in which Pb concentrations in soil and dust have been reported (Roels et al., 1980; Charney et al., 1980; Gallacher et al., 1984; Duggan et al., 1985), and 3) direct field measurement using gravimetric methods (Lepow et al., 1975). Each approach offers information of value. Laboratory studies provide an opportunity for systematic examination of the possible effects of soil characteristics on adherence. Driver et al. (1989), for example, conducted laboratory adherence tests on 11 topsoil and subsoil samples from five soil types. Adherence was evaluated for each of three size classes (1150 µm, ≤250 µm, unsieved) and each soil was characterized with respect to organic carbon content. Particle size was found to be the most important variable and the sub-150 µm size class was found to adhere to the greatest extent.

Driver et al. (1989) did not, however, investigate the impact of soil moisture content on adherence. In addition, they used pre-fractionated soils. Post-adherence size classification, although experimentally more difficult, is conceptually more attractive. Duggan et al. (1985) and Sheppard and Evenden (1994) have reported preferential adherence of finer particles based on post-adherence analyses. Duggan et al. studied playground dust/soil recovered from hands by wet wiping. Sheppard and Evenden used an artificial loading scenario and three soil types, and recovered soil by adhesive tape stripping. They also reported greater adherence of wet soils. The only failure to find a particle size dependence to date was reported by Que Hee et al. (1985) who observed no relationship between particle size and adherence of pre-fractionated dry house dust in very limited measurements following artificial loading.

Results are reported here from a series of laboratory studies conducted to address particle size and moisture content issues. Objectives were 1) confirmation that an alternative soil contact protocol would produce results consistent with those of Driver et al. (1989), 2) investigation of the effects of soil moisture content on adherence, and 3) investigation of size characteristics of adhering soils post adherence.

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MATERIALS AND METHODS

Numbers of soil types, size ranges, and moisture contents for each experiment are presented in Table 1. Five soils were obtained locally and are described in Table 2. All soils were analyzed by hydrometer (settling velocity) to determine compostion. Clay contents ranged from 0.5 to 7 percent. Organic carbon contents were determined by combustion and ranged from 0.7 to 4.6 percent.

Table 1. Summary of soil adherence experiments.

Variable	Soil Types	Size Ranges	Moisture Ranges	Subjects	Replicates
Size/pre-sieved soils	5	3	2	1	≥ 3
Moisture/whole soils	5	1	3	1	≥ 3
Size/post-sieved soils	3	5	2	1	4

Table 2. Soils used.

Descriptor	Type	Hydrometer Test Results			% Organic Carbon	
		% sand	% silt	% clay	whole soil	< 150 µm
211	sand	88.0	11.5	0.5	1.5	1.9
CP	loamy sand	81.0	17.1	1.9	4.6	3.7
85	loamy sand	76.5	21.6	1.9	3.5	3.3
228	sandy loam	62.7	32.0	5.3	3.3	3.4
72	silt loam	25.8	67.2	7.0	0.7	0.7

The hand-press protocol involved placement of a hand palm down in a pan containing soil (sometimes with added moisture) followed by gentle agitation for 30 seconds. A single subject was used. Hands were washed using a 2 percent detergent solution (Liqui-Nox, Alconox) in a plastic squeeze bottle and a 4-liter garden-type sprayer (Burgess, D.B. Smith & Co.) to provide water pressure. Washing occurred over funnels placed in sample jars. Wash water was filtered through 47 mm glass fiber filters with a nominal pore size of 0.5 µm (Gelman Metrigard). Filter holders (MFS, Cole-Palmer) were mounted on stainless steel manifolds (Nalgene). Vacuum was applied by aspirator or pump (Gast 0523). Filters were placed in tared aluminum weigh boats, oven dried (Labline L-C) overnight at 100°C then cooled in a dessicator (Sanplatec Dry Keeper) before weighing on an analytical balance (Mettler College 150) readable to 0.1 mg.

Procedures were evaluated for mass recovery by conducting experiments using pre-weighed pans of dry soil. Following removal of the soil by hand press, the pan was reweighed to obtain mass lost. If moisture had been added, the pan was first dried in an oven before reweighing. Pans and soil were weighed on a 6 kg capacity electronic balance readable to 10 mg. Mass recovered following filtration and drying, with and without hand-press activity, was compared to pan weight loss. Recovered mass was assayed on an analytical balance readable to 0.1 mg.

Experiments were conducted at variable soil loading levels. A recovery (mean ± standard error of mean) of 99.3 ± 1.88 percent (n = 42) was observed in high load, dry soil, hand-press tests. In corresponding wet soil tests, mean recovery was 93.9 ± 1.23 percent (n = 47). Lower recovery in the wet soil tests reflects additional handling of the soil and a 24 hour delay in measurement of final pan weight. Filter only (no hand press), high load recovery tests produced a mean recovery of 99.2 ± 0.28 percent (n = 18). Low mass, hand-press recovery tests were only be run with dry soil due to greater adherence of some wet soils. Triplicates were run using each of two soil types (CP and 72) and three mass loading levels. Overall mass recovery was 110 ± 3.53 percent (n = 18) following hand washing without soap and 101 ± 1.41 percent (n = 18) in the case of direct filter loading. Low level trials with soap were also conducted yielding a mean recovery of 100 ± 2.69 percent (n=6).

In adherence tests of pre-fractionated soils, soils were separated into portions passing a No. 100 sieve (U.S.A. Standard Series, W.S. Tyler) (<150 µm), retained on a No. 60 sieve (>250 µm), and passing No. 60 but retained on No. 100. Soils were fractionated by dry sieving for 30 minutes. Post-adherence fractionation of soil required determination of how little soil mass could be sieved with reproducible results. A (50 mm diameter, Bel-Art) mini-sieve series (425, 250, 135, and 65 µm) was used for all post-adherence sieving activities. Sieving duration of 30 minutes was maintained. Three soils, 211, CP and 72, were employed. Repetitive contact events were required to obtain sufficient soil for sieving, using both wet and dry soils. Data presented below represent sieve analyses of approximately 2 to 5 g (dry weight) aliquots of soil. Mass recoveries obtained during sieving of these samples ranged from 98.9 to 100.1 percent for dry soil post-adherence tests and from 99.5 to 100.2 percent in wet soil post-adherence tests.

A washed soil control was used in post-adherence trials because of the potential for particle disaggregation during recovery. All post-adherence experiments were conducted in quadruplicate. Moisture contents varied from 1 to 6 percent and from 14 to 19 percent for soils described as dry and wet, respectively.

Hand area was computed using a correlation with height and weight presented by Anderson et al. (1985). The (single) subject in all experiments was an adult female. Total hand surface area (both hands) was estimated as:

$$SA_{female,hands} = 0.0131 \cdot W^{0.412} \cdot H^{0.0274}$$

where SA = surface area [m^2], W = weight [kg] and H = height [cm]. The area of a single hand was assumed to be one half the total. The standard error about this regression was reported to be less than 2 percent. Loadings presented below are recovered mass divided by the area of one hand, although loading occurred primarily on only one side of the hand, and are not adjusted for recovery.

Statistical analyses were conducted using SPSS® (Norusis, 1993). Datasets were evaluated for normality using the Lilliefors modification of the Kolmogorov-Smirnov test (Norusis, 1993). Normality generally could not be rejected ($p > 0.05$) for data aggregated by soil type and moisture content. However, variances of size-specific data subsets were often unequal. Consequently comparisons were made using the nonparametric Mann-Whitney U test and t-tests with correction, if necessary, for unequal variance. Homogeneity of variance was assessed by Levene's test (Norusis, 1993).

RESULTS AND DISCUSSION

Results of tests of adherence of pre-fractionated soils are presented in Table 3. Under dry soil conditions (less than 2 percent moisture in this experiment), adherence varied inversely with grain size. Soil-specific pairwise differences between adherences of sub-150 µm, 150-250 µm, and super-250 µm fractions are significant (two-tailed p-values < 0.05) in all cases by Mann-Whitney criteria and in all cases but one (sub-150 µm vs. 150-250 µm for dry soil 72) by t-test. This outcome is qualitatively consistent with Driver et al.'s (1989) results (which suggests the effect is robust since loading techniques differed).

Table 3. Mean adherence (± standard error of mean) [mg/cm^2] vs. size range and moisture content in pre-fractionated soils

Soil	Moisture					
	dry (< 2%)			wet (12-18%)		
	Size range [µm]					
	≤ 150	150-250	≥ 250	≤ 150	150-250	≥ 250
211	0.67 ± 0.059	0.24 ± 0.017	0.06 ± 0.007	0.75 ± 0.009	8.31 ± 0.17	10.1 ± 0.58
CP	0.42 ± 0.034	0.27 ± 0.023	0.10 ± 0.020	1.30 ± 0.039	3.66 ± 0.53	10.2 ± 1.96
85	0.76 ± 0.021	0.31 ± 0.014	0.08 ± 0.007	0.34 ± 0.025	2.10 ± 0.53	6.25 ± 0.46
228	0.63 ± 0.019	0.39 ± 0.015	0.12 ± 0.018	0.37 ± 0.034	0.32 ± 0.073	2.98 ± 0.82
72	0.62 ± 0.054	0.49 ± 0.010	0.34 ± 0.025	0.57 ± 0.048	0.41 ± 0.068	0.39 ± 0.090

In wet soils (12-18 percent moisture in this experiment), however, adherence generally varied directly with particle size. Three of five soils (211, CP, and 85) displayed consistently increasing adherence with increasing grain size. Pairwise differences between size fractions within those soils are significant in all cases by Mann-Whitney U test and in all but possibly one case (sub-150 µm vs. 150-250 µm for wet soil 85), in which the two tailed p-value is 0.08, by t-test. In contrast, for wet soil 72, all differences between adherences of various size fractions are non-significant by both Mann-Whitney and t-test criteria. For wet soil 228, differences in adherence of the two smaller size classes are nonsignificant by both criteria. Differences between those classes and the largest size class are significant by Mann-Whitney U test and marginally significant (two tailed p-value < 0.10) by t-test. Soils 72 and 228 contain the highest proportions of silt and clay. However, since particle size was controlled in this experiment, reduced tendency for larger size classes to display greater adherence must reflect some property of soils 72 and 228 other than a predominance of fine particles in unfractionated soil.

Comparison of wet/dry differences within size fractions in Table 3 reveals that the effect of moisture on adherence of fine particles is inconsistent across soils. Soil CP displays a significant increase in the adherence of the sub- 150 µm fraction with the addition of moisture by both Mann-Whitney U test and t-test, but the other soils show either no effect (211 and 72) or a significant decline (85 and 228). These results probably reflect differences in the surface characteristics of the various soils. Effects on larger particles are less variable. Three of five soils show a significant increase in adherence of the 150-250 µm fraction under wet conditions and four of five show this effect for the super-250 µm fraction.

The effect of soil moisture on adherence of whole (unfractionated) soils is displayed in Table 4. Adherence at moisture contents above 20 percent differed significantly (two tailed p-values < 0.05) from adherence at less than 10 percent moisture and adherence at 10-20 percent moisture for all five soils by both t-test and Mann-Whitney nonparametric criteria. The magnitude of the effect is greatest in soils 211, CP and 85, which have the highest fraction of sand (largest grain sizes), and least in soils 72 and 228, which have the greatest fractions of silt and clay (smallest grain sizes). Comparison of adherence at 10-20 percent moisture with adherence at less than 10 percent moisture produces less consistent results. Soils 211, CP and 85 show significant increases, but results for soil 228 are not significant and soil 72 displays a significant decrease in adherence (all by both parametric and nonparametric tests).

Table 4. Mean adherence (± standard error of mean) [mg/cm^2] vs. moisture content in whole soils

Soil	Moisture		
	< 0.1-9 %	10-19 %	21-27 %
211	0.33 ± 0.021	3.09 ± 0.33	5.88 ± 1.10
CP	0.22 ± 0.015	2.98 ± 0.14	14.8 ± 2.82
85	0.25 ± 0.027	1.26 ± 0.27	5.99 ± 0.44
228	0.22 ± 0.034	0.45 ± 0.12	1.64 ± 0.13
72	0.54 ± 0.048	0.39 ± 0.028	2.10 ± 0.24

Results from post-adherence sieving are presented in Figure 1 with corresponding distributions of the same soils obtained by washing (filtering) the soil without prior hand-press activity. Soils 211 and CP display similar patterns. Each soil is primarily composed (weight basis) of relatively coarse material (sand). Under dry conditions, preferential selection of smaller sized particles is apparent (i.e., the distributions are shifted leftward in Figure 1). For each soil, the relative proportion of sub-65 µm particles increases by about fourfold while very little of the largest class adheres to skin. For soil 211, dry adherence means are significantly different (two-tailed p-values < 0.05) than wash only means for five of five size fractions by Mann-Whitney criteria and four of five size fractions by t-test. For soil CP, the corresponding figures are three of five and four of five, respectively. Under wet conditions, selection for mid-ranged soil grains is most apparent and 135-250 µm particles represent the largest mass fraction of soils 211 and CP that adhere. In contrast, soil 72 is primarily composed of smaller particles (silt). Sub-65 µm grains represent the largest single fraction of the sieved washed soil. Adhering soil is characterized primarily by increased representation of the 65-135 µm fraction and loss of super-425 µm material under both wet and dry conditions. A significant decline in the relative adherence of the sub-65 µm fraction is also apparent under wet conditions.

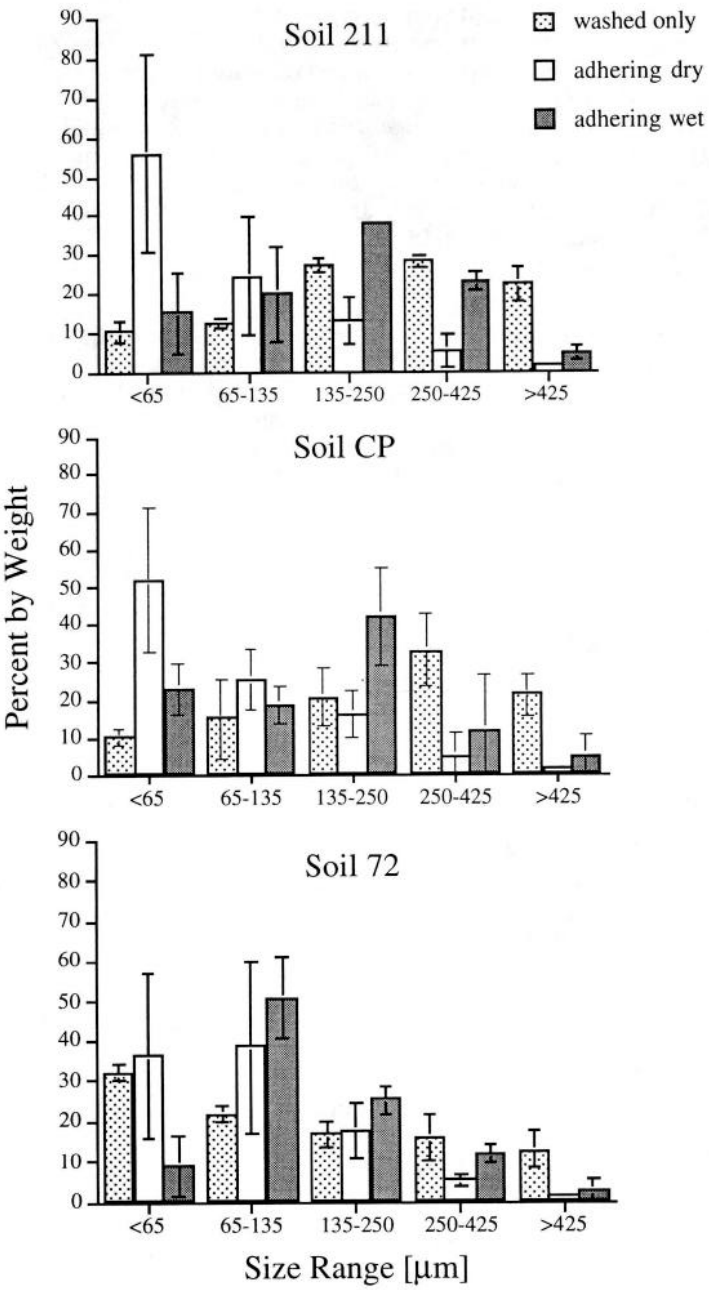

Figure 1. Comparison of size distributions recovered from skin after adherence under dry (1-6% moisture) and wet (14-19% moisture) conditions with distributions obtained following washing only for three soils. Error bars display 95 percent confidence intervals on arithmetic means (n = 4).

Increasing adherence of unsieved soils, on a mass basis, with increasing soil moisture appears to occur primarily as a result of the effect of moisture on adherence of larger size fractions. The effect of moisture is more apparent in coarse than fine-grained soils. As a consequence of Driver et al.'s (1989) work, 150 µm is sometimes taken as a practical upper limit on the size of soil and dust particles to be investigated as potential sources of human exposure to environmental agents. Results presented here suggest that somewhat larger grain sizes are also relevant if moisture content exceeds 10 percent. In dry (less than 10 percent moisture) soils, mass adherence appears predominately attributable to sub-150 µm, and perhaps even sub-65 µm particles.

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REFERENCES

Anderson E, Browne N, Duletsky S, Ramig J, Warn T (1985) Development of statistical distributions or ranges of standard factors used in exposure assessments. PB85-242667, NTIS, Springfield VA

Charney E, Sayre J, Coulter M (1980) Increased lead absorption in inner city children: where does the lead come from? Pediatr 65(2):226-231

Driver J, Konz J, Whitmyre G (1989) Soil adherence to human skin. Bull Environ Contam Toxicol 43:814-820

Duggan MJ, Inskip MJ, Rundle SA, Moorcraft JS (1985) Lead in playground dust and on the hands of children. Sci Tot Environ 44:65-79

Gallacher J, Elwood P, Phillips K, Davies B, Jones D (1984) Relation between pica and blood lead in areas of differing lead exposure. Arch Dis Child 59:40-

Lepow: M Bruckman L Gillette M Markowitz S Robino R Kapish J (1975) Investigations into ‘sources of lead in the environment of urban children. Environ Res 10:415-426

Norusis, M (1993) SPSS® for Windows? base system user’s guide, release 6.0. SPSS Inc, Chicago IL

Que Hee S, Peace B, Clark C, Boyle J, Bornschein R, Hammond P (1985) Evolution of efficient methods to sample lead sources, such as house dust and hand dust, in the homes of children. Environ Res 38:77-95

Roels H, Buchet J, Lauwerys R, Bruaux P, Claeys-Thoreau F, Lafontaine A, Verduyn G (1980) Exposure to lead by the oral and the pulmonary routes of children living in the vicinity of a primary lead smelter. Environ Res 22:81-94

Sheppard SC, Evenden WG (1992) Concentration enrichment of sparingly soluble contaminants (U, Th and Pb) by erosion and by soil adhesion to plants and skin. Environ Geochem Health 14(4):121-131

Sheppard SC, Evenden WG (1994) Contaminant enrichment and properties of soil adhering to skin. J Environ Qual 23:604-613

USEPA (1992) Dermal exposure assesement: principles and applications: interim report. Office of Health and Environmental Assessment, EPA/600/8-91/011B Washington DC