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The effectiveness of low-cost soil treatments to reduce soil and dust lead hazards: The Boston lead safe yards low cost lead in soil treatment, demonstration and evaluation

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Abstract

The Boston lead safe yards low cost lead in soil treatment, demonstration, and evaluation was developed to explore the viability and effectiveness of low-cost soil interventions to reduce exposure to soil lead hazards. Buildings that had been abated for lead to Massachusetts's deleading standards in the previous 5 yrs and met other program requirements were recruited for the evaluation. Following individual property assessments, yards were treated with application of ground coverings and ground barriers in 2000–2001 and followed up at 1 yr. The treatment cost ranged from \$1095 to \$5643 with an average of \$2798. Soil lead levels at the building dripline, measured with a field-portable X-ray fluorescence analyzer (Niton Model 702 Spectrum Analyzer), dropped from 2021 PPM at baseline to 206 PPM at 1-yr follow-up. Most of the barrier treatments continued to block access to the lead-contaminated soil at 1 yr. At the follow-up, few properties with grass treatment had areas that were completely bare, but 28% had more than a small amount of treated areas bare. Treatments were effective in reducing entryway dust lead in the rear of the building if the residents reported they had maintained the yard treatments. Each additional yard work activity reported was predicted to lower 1-yr floor dust lead loading at the rear common/main and dwelling unit entries by about 20%. Each additional 100 ft² of yard treated was predicted to lower 1-yr floor dust loading at the rear dwelling unit entry by 19%. Treatments did not show a dust lead effect at 1 yr in the front entryway of the building, but the investigators believe that this may be due to the effect of resident cleaning overshadowing the treatment effect.

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1. Introduction

The contribution of lead-contaminated soil to children's blood lead levels has been clearly established (Lanphear et al., 1998; Clark et al., 1991; Mielke and Reagan, 1998). Children may be exposed to soil lead directly when playing outdoors or indirectly through track-in into the home. Stanek and Calabrese (1995) and Murgueytio et al. (1998)

estimated that the source of 30–40% of total indoor dust is outdoor soil. Reducing soil lead levels or improving the condition of the yard surface cover may lessen direct and indirect soil lead effects.

A number of studies have examined effectiveness of soil lead interventions on soil and dust lead hazards (Aschengrau et al., 1994; Binns et al., 2004; Farrell et al., 1998; Lanphear et al., 2003; Weitzman et al., 1993). The USEPA Three-City Soil Abatement Study found that in Boston, soil abatement resulted in significant declines in children's blood lead levels, while there was little effect of abatement

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in Baltimore or Cincinnati (Aschengrau et al., 1994). Aschengrau and colleagues further found that within the Boston study group some subpopulations gained little or no benefit from soil abatement, such as children living in apartments with interior floor dust lead levels consistently above the baseline median of 90 $\mu\text{g}/\text{ft}^2$ (as measured by vacuum sampling). This study and others suggested that when soil abatement was conducted in conjunction with interior lead treatments or in homes where the soil was the primary source of lead exposure the soil treatments were associated with declines in interior dust lead levels and the health benefits of soil treatments were greatest (Aschengrau et al., 1994, 1997; Lanphear et al., 1998).

Many of the early soil intervention studies abated soil by removing and replacing the top soil layers (Aschengrau et al., 1994; Farrell et al., 1998; US EPA, 1996; von Lindern et al., 2003; Weitzman et al., 1993). These interventions were relatively expensive (\$9600 per yard in 1990) (Weitzman et al., 1993), so lower cost options such as in-place management (grass, sod, mulch) have been explored subsequently. However, the efficacy of these treatments has been questioned because grass seed or sod may not hold up over time unless owners maintain their yards. Clark et al. found that properties that underwent interior lead treatments with generally lower-cost soil lead treatments had lower follow-up exterior entry, dwelling unit entry, and interior floor dust lead levels than comparable properties where soil was not treated (Clark et al., 2004). Binns et al. (2004) had mixed results with low-cost soil interventions in Chicago. In that study, geometric mean (GM) entry floor dust lead loading decreased from baseline to 1 yr for the 14 properties with raised garden boxes but increased for the 23 properties treated with ground covering/barriers but no raised garden boxes.

The Boston Lead Safe Yards Low Cost Lead in Soil Treatment, Demonstration and Evaluation (Lead-Safe Yards Evaluation) was developed to examine the viability and effectiveness of low-cost soil interventions to reduce residential exposure to soil lead hazards. Properties were followed from preintervention to 1 yr after the baseline visit. Effectiveness was assessed with entry dust lead loadings, field-portable XRF soil lead concentrations, and treatment integrity at 1-yr follow-up by visual inspection. Track-in potential was also examined with the dust lead loading accumulated per day on a dust mat placed at the front building entry (for approximately 2 wks).

2. Methods

2.1. Overall design

The Lead Safe Yards Evaluation was developed to examine the effectiveness of lead safe yard treatments in properties that had been deleaded or abated for lead to Massachusetts' standards in the previous 5 yrs. US Environmental Protection Agency (EPA) Region I, Lead-Safe Boston (LSB), and the US Department of Housing and Urban Development (HUD) funded the evaluation. The National Center for

Healthy Housing (NCHH) was the project coordinator and evaluator. Properties from three lead-safe yards projects with different funding sources were recruited for this evaluation:

1. An EPA Environmental Monitoring for Public Access and Community Tracking (EMPACT) funded project, conducted in the Roxbury and North Dorchester neighborhood, in partnership with the Dudley Street Neighborhood Initiative (DSNI).
2. A 1994 HUD Lead Hazard Control Grant funded project managed by the City of Boston's Department of Neighborhood Development's LSB Program in Dorchester and Roxbury.
3. A 1994 HUD Lead Hazard Control Grant funded project managed by the Boston Public Health Commission's Office of Environmental Health and LSB in the Humphrey's Place neighborhood of Dorchester (HP).

The soil sampling, treatment, and maintenance strategies used in these projects are documented in the US EPA Lead Safe Yards publication (US EPA, 2001a). The levels of lead in soil from the EMPACT funded project were documented in a previous publication (Litt et al., 2002).

The Lead Safe Yards team, consisting of representatives from Region I EPA, LSB, Office of Environmental Health, Boston University, DSNI, and NCHH met regularly to coordinate efforts during the development and execution of the evaluation.

Baseline sampling was conducted from April 2000 to October 2001. Interventions were conducted from May 2000 to November 2001. On average, treatments were started 13 wks from the baseline visit and were completed in 4 wks. One-year follow-up visits were conducted from July to November 2001, ranging from 12 to 15 months after the baseline visit.

The Boston Public Health Commission's Office of Environmental Health submitted the application for IRB review to the Boston University School of Medicine, where it was found to be exempt. Property owners and tenants gave written informed consent to participate. All property owners and tenants were informed in writing of the results of dust, mat, and soil testing for their property and referred to the Office of Environmental Health for assistance in lead dust control if interior dust lead levels in their properties were over federal standards.

2.2. Enrollment criteria

The following properties qualified for evaluation inclusion: (1) properties deleaded by the LSB 1994 HUD Grant Program; (2) properties located in the HP neighborhood of Dorchester and deleaded by Boston's Office of Environmental Health in 1999–2000; or (3) DSNI properties located in the Brownfield catchment area, and abated after 1994 with a Massachusetts Certificate of Full Compliance.

Three additional requirements had to be met: (1) the owner had current homeowner's insurance; (2) the owner signed a consent to participate, which included agreement to clear the yard of trash and debris prior to treatment; and (3) the owner had paid property taxes. LSB property owners were required to have a child living on the property and to have paid water and sewer bills or have made provisions to do so.

Sixty property owners applied for inclusion and signed the consent form, but only 47 were enrolled in the study and received soil treatments. One property was de-enrolled before the 1-yr visit following a change in ownership.

Properties included in this analysis were required to have a full set of data, including soil lead measurement of the dripline areas with AA analysis at baseline, details of treatment, a completed resident questionnaire at 1 yr, an exterior building assessment at baseline and 1 yr, and exterior and common/main dust lead results from the specific entry (i.e., front or rear) at baseline and 1 yr. Forty-one properties met the inclusion criteria for this paper. Twenty-one were LSB properties, five were HP, and 15 were DSNI properties.

2.3. Data collection

2.3.1. Dust sampling

Dust sampling was conducted at baseline and approximately 1 yr after the baseline visit according to the method described in the 1995 HUD Guidelines (US HUD, 1995). Mat placement, retrieval and sample extraction were performed according to the procedures established in the Farfel et al. (2001) dust mat study. The study used the Akro “Floor Sentry” Indoor floor mat, a short-pile, rubber-backed, 18" × 27" floor mat used in previous research (Farfel et al., 2001).

Six floor dust lead samples were collected at each visit in each building using a 12" by 12" template or a 6" by 12" template if the larger template did not fit. If a mat was in place at a sampling location, the mat was moved and the sample was collected on the surface underneath the mat. One sample was collected on the porch or step, just outside the most commonly used front entry door (the exterior entry). A second sample was collected just inside the front entry to the building in the vestibule or interior common area hallway (the common/main entry). If the building was single-family and there was no vestibule, no sample was collected. A third sample was collected just inside the most commonly used front doorway to the unit (the dwelling unit entry). Three samples were collected at the rear of the building in the analogous locations. For every dust-wiped location the surface condition was categorized as (1) smooth and cleanable; (2) mostly smooth and cleanable; minor deterioration; (3) not smooth but mostly cleanable; or (4) not smooth and not cleanable.

Farfel and Binns suggest that measuring the dust lead accumulated in a dust mat placed at a building entrance may be a useful measure of soil lead track-in potential (Binns et al., 2004; Farfel et al., 2001). The dust mat accumulation measure has the advantage of measuring dust accumulation over an exact time period, compared to other methods that measure dust lead levels at one point in time. After dust wipe sampling was completed on a visit, field staff placed a walk-off mat at the front entrance and then returned after 14–16 days to remove the mat. The exact mat placement depended on the configuration of the front entryway. If there was space for the mat in the common/main area, the mat was placed there as close to the exterior as possible. If there was no space for a mat in that area, the mat was placed within the dwelling unit entry just inside the doorway. If the resident already had a mat in the desired location, he or she was asked to remove it for the mat dust collection period. The importance of not moving or cleaning the mat for the data collection period was stressed to the residents. At the end of the collection period, field staff placed the mat into a cardboard box that was sealed with duct tape and labeled.

2.3.2. Soil sampling at baseline

Soil samples were analyzed in situ with a Niton Model 702 field-portable X-ray fluorescence (FPXRF) analyzer according to the procedures outlined in EPA method 6200 (US EPA, 2005). The depth of in situ measurements was approximately 2–3 mm and sample results were obtained within 30–60 s, which was shown to be an effective method of measuring lead in soil (Clark et al., 1999). In situ FPXRF readings were taken by direct measurement on surface soils that were not saturated with water. Prior to sampling, non representative debris (rocks, pebbles, leaves) was removed from the surface to allow smooth, uniform contact between the instrument and the surface. Four yard areas were evaluated: the house drip line (3-ft perimeter of house); areas of unique use, such as children's play areas and picnic and gardening areas; areas of bare soil and high foot traffic; and other areas noted by the sampling team that might present a possible source of lead contamination to the subject property. The number of measurements per property ranged from 8 to 50 with an average of 30 measurements. Each sampling location was categorized according to its distance from the house: up to 4 ft from the building is “dripline”; 4–10 ft from the house is “mid yard”; and samples more than 10 ft from the house are “perimeter.” The non-dripline region was split at 10 ft because the investigators wanted to ensure that fence lines and outbuildings were included in the perimeter region.

Three standard reference material (SRM) measures and a blank measure were used at the beginning of each sampling day to verify

linearity over the expected sampling range (400–5000 ppm) and to ensure the absence of instrument contamination. The three SRMs used were NIST 2710 (5532 ppm), NIST 2711 (1162 ppm), and NIST 2586 (432 ppm). The 3rd SRM, which was near the lowest action level, was also used as a continuing calibration check after every 10th reading. In this study, a slight variation of EPA 6200 Method (US EPA, 2005) was employed: if a measured value was not within 25% of the true value for initial and continuing calibration checks, the SRM was remeasured and usually found to be within standards. If the instrument was still out of range after the second try, it was recalibrated and all samples taken since the last continuing calibration were reanalyzed.

Composite soil samples were collected from selected locations after the in situ readings were taken. Composite samples consisted of small subsamples of superficial soil from the house dripline, play area, high-use areas, and/or garden areas. Dripline composites typically consisted of 12 subsamples with a minimum of 3 from each side of the house, while other composites typically consisted of 5 subsamples. Careful records were kept so that these composite samples could be directly linked to the XRF measurements collected at the same locations.

The surface cover was coded at the play area, each side of the building at the dripline, and other sampled areas as follows: 1 = no bare, 2 = small amount bare, 3 = half bare, 4 = mostly bare, or 5 = all bare.

For this paper, we present dripline soil results because only dripline soil-lead measurements were consistently reported for all properties.

2.3.3. Soil assessment at 1-yr follow-up

One year after the preintervention visit, EPA field investigators returned to approximately 50% of the properties to collect a limited set of FPXRF in situ samples from treated and untreated areas sampled at baseline (25% of originally sampled locations). One-year FPXRF sampling was conducted 1 day a week when the weather was good. Properties that were closest to the target 1-yr date and where the owner granted access were selected for sampling. A minimum of three FPXRF readings were collected from each of four regions: (1) treated areas with high (i.e., ≥ 2000 ppm) baseline soil lead levels; (2) treated areas with baseline mid (i.e., ≥ 400 and < 2000 ppm) soil lead levels; (3) treated areas with low (i.e., < 400 ppm) lead levels; and (4) untreated areas. Samples were collected in bare areas if present in the targeted area. Areas treated with gravel or stones were not tested because FPXRF testing is not possible on these substrates. The FPXRF measured the lead content at the surface of the soil. Thus, if a new substrate was in place, that is what was tested.

2.3.4. Exterior visual conditions

The condition of key exterior building components was assessed at baseline and 12-month follow-up. The following components were assessed at both the front and back of the building: door, door jamb, porch floor, porch rails and trim, porch ceiling, and other porch components. Each component was rated as intact paint, fair paint, poor paint condition, or unpainted. Although window, siding, and trim components were also assessed, they were not included in this analysis because their proximity to the front and rear entry was unknown.

2.4. Laboratory analysis of samples

2.4.1. Dust wipes

The dust wipes were analyzed by flame atomic absorption spectroscopy following the EPA SW-846 (US EPA, 1986) method protocols by the University of Cincinnati's (UC) Hematology and Environmental Laboratory, which is recognized by the EPA National Lead Laboratory Accreditation Program (NLLAP) as proficient in dust lead analysis under the Environmental Lead Proficiency Analytical Testing Program. The method limit of detection was 2 μg of lead. Spikes and blanks, which were regularly inserted into the normal stream of samples submitted to the laboratory so they could not distinguish them from ordinary samples, were found to be acceptable over the course of the study.

2.4.2. Floor mats

At the EPA Region 1 Laboratory, an EPA chemist collected a representative sample of the accumulated dust and dirt for the floor mat using a high volume furniture and surface sampler (HVFS manufactured by CS3, Inc., Sandpoint, ID). The HVFS is a specially modified Dirt Devil vacuum cleaner equipped with a cyclone capturing particles greater than 5 μm and is found to be highly efficient in removing deeply embedded dust particles from door mats (Lewis et al., 1998). The dust sampling methods are outlined in the *Protocol for Sampling Entryway Mats Using R&M Cyclone Vacuum Device* (Kennedy Krieger Institute Laboratory Guidance Document Version No. 8, March 31, 2000).

Mat dust samples were submitted to the EPA Region 1 Laboratory for lead analysis according to EPA Method 6010B. QC samples include blanks, mats spike with purified sand (J.T. Baker Product 3382-05), and matrix spike samples (mats spiked with certified reference materials). Samples were analyzed through inductive coupled plasma mass spectrometry (ICP). EPA 6010B reports the estimated detection level of 10 ppm of lead (1996 revision 2, 6019B-19). Sample results were converted to lead loading per day ($\mu\text{g}/\text{ft}^2/\text{day}$) based on the area sampled, the quantity of lead collected, and the number of days the mat was in place.

Fifteen blanks and 12 spike samples with true lead concentrations between 432 and 3395 ppm were analyzed. All spike samples fell within the required range with recoveries ranging from 84% to 107%. All 12 blanks were below the detection level.

2.4.3. Composite soil samples

Composite soil samples were analyzed at the Hematology and Environmental Laboratory for the University of Cincinnati (UC). The <250 μm fraction sample aliquots were digested following a modification of NIOSH 7082 and analyzed by flame atomic absorption spectroscopy (FAAS) (NIOSH 7082, Lead by Flame AAS). The laboratory's MDL was 0.6 μg or 3.5 ppm. Spikes and blanks, which were regularly inserted into the normal stream of samples submitted to the laboratory so they could not distinguish them from ordinary samples, were found to be acceptable over the course of the study.

2.5. Soil treatments

Each XRF measurement collected during on-site sampling was averaged with others in that area (e.g., house dripline area) to determine the mean level for the area. The XRF soil lead concentration averages were transcribed onto a color-coded map of the property for use in the remedial landscape strategy. Color codes were used on the property map to indicate the nature and extent of lead contamination in each area sampled and particular yard uses of concern, such as play and gardening areas. A member of the professional landscaper crew then met with homeowners to design landscape treatments consistent with owners' use of the yard and preferences and established a preliminary plan. The primary target areas for treatment were areas with average soil lead levels above 400 ppm of lead.

Based on the EPA recommendations (US EPA, 1995) for residential lead-contaminated soil, the evaluators developed treatment options that were affordable and replicable. Table 1 describes the treatments employed. The types of treatments implemented and the areas treated were recorded by the landscaper and checked immediately postintervention by NCHH field staff.

At 1-yr follow-up, the integrity of each treatment was assessed.

2.6. Resident questionnaire

The 1-yr follow-up resident questionnaire included questions about residents' satisfaction with the soil treatments, yard work, work on the outside of the house, yard use patterns, and pets. The questionnaire was completed by the owner occupant, by the property owner, or by a tenant.

2.7. Statistical methods

Dust and soil lead levels were log-transformed for all analysis. Dust lead levels below the limit of detection were replaced by the limit of detection divided by $\sqrt{2}$. Paired *t*-tests were used to test for a change in mean or GM values from one sampling time to another. Two-sample *t*-tests were used to test for equality of mean or GM values for two groups. McNemar's test was used to test for a difference in a dichotomous variable (e.g., yes/no) between baseline and 1 yr or the front and rear of a building. Pearson's product-moment correlation coefficient was used to examine associations. Regression modeling (described below) was used to examine predictors of an outcome of interest. Nested models were used to examine predictors of an outcome of interest when multiple observations from the same property were included.

2.7.1. Regression modeling

Regression models were created to predict five 1-yr dust lead loadings: the front common/main entry, rear common/main entry, front dwelling unit entry, rear dwelling unit entry, and front dust mat loading (per day).

Four treatment variables were considered: the square footage of the property treated, the percentage of the property treated, the square footage of the property treated with nongrass treatments, and the percentage of the property treated with nongrass treatments.

Each model included variables for baseline dust lead loading at that location, whether the wiped surface was smooth and cleanable or not (not applicable for dust mat), seasonality, FAAS dripline soil lead concentration and yard cover, percentage of components with nonintact paint at the exterior building entry, resident use patterns, resident work to the yard and outside of the house during 1 yr, after the intervention, season of dust sample collection, and soil treatment variables. The models allowed treatment effects to vary by baseline soil lead concentration, baseline yard cover, and resident work to the yard or outside of the home. The effects of yard work and work of the outside of the home were also allowed to vary by baseline soil lead concentration and yard cover. For the dwelling unit entry models, variables were also included for the floor number of the dwelling and whether the entry was the most commonly used dwelling entry.

Backward elimination of insignificant independent variables ($P > 0.05$) was performed, followed by additional steps to allow addition and/or removal of variables with the SAS procedure PROC GLM. After the stepwise procedure was finished, we attempted to add the front mat lead loading per day to the front models for the dwelling unit entry and common/main entry.

3. Results

3.1. Enrolled properties

Thirty-seven front entries and 39 rear entries in 41 buildings met the inclusion requirements for this paper.

All the buildings were constructed between 1870 and 1929, when year of construction was ascertained. The most common building type was triplex (44%), followed by duplex (29%), single detached (20%), and buildings with more than four units (7%). Owner occupants completed 80% (33) of the 1-yr follow-up questionnaires; nonresident property owners completed 7 of the questionnaires; and at one property a tenant completed the questionnaire. Most buildings had 1–3 children in residence at 1 yr (59%). Thirty-two percent had four or more children and only 10% had no children. Forty-four percent of respondents reported that no children play in the yard. Thirty-two percent reported that 1–3 children and the remaining 24%

Table 1
Specifications for soil/yard treatments

Treatment	Description
Dripline boxes	Install 2" × 6" ACQ pressure-treated wood box 3' from foundation wall. All joints and corners mechanically fastened with 3" galvanized wood screws to a 1½" square stake driven into the ground to a minimum depth of 12". All corners braced with triangular exterior plywood keystones mechanically fastened directly to the wood box with 3" galvanized wood screws. Raised perimeter box filled with gravel (no plantings). Install 3" of loam and 2" of ¾" crushed stone over filter fabric weed barrier. Raised perimeter box filled with mulch and plantings. Install 4" of loam and 3" of pine bark mulch over filter fabric weed barrier. Install a minimum of 10 perennials per the list of plantings or approved equal.
Stepping stone paths	Stone path. Install round or square red patio stepping stones at all egresses from front to rear yard. All stones protrude no more than ½" above the existing grade.
Wood chips or mulch	Wood chip and mulched areas. Installation of filter fabric, adding 2" of topsoil spread by hand, covered with 6" of wood chips or mulch. Miscellaneous treatments. Additional mulch or wood chips beneath existing plantings, no fabric cloth required.
Grass sod/seedling	Existing lawn improvement. Rake bare areas to loosen soil. Apply rye, fescue, and bluegrass seed mix at the rate specified by the manufacturer. Apply ¼" of top soil over new seed and water thoroughly. New lawn installation (at existing grade). Rototill existing lawn bed 6" deep. Apply water to contain dust during rototilling. Apply rye, fescue, and bluegrass seed mix at the rate specified by the manufacturer. Spread ¼" loam on top of seed. Water thoroughly.
Wood-raised garden plot	Raised vegetable garden bed. Install 2" × 8" ACQ pressure-treated wood box at owner-approved location. All joints and corners mechanically fastened with 3" galvanized wood screws to a 1½" square stake driven into the ground to a maximum of 12". All corners braced with triangular exterior grade plywood keystones mechanically fastened directly to the wood box with 3" galvanized wood screws. Install 6" of loam over filter fabric weed barrier.
Wood-raised play/picnic area	Raised play area. Install 2" × 6" ACQ pressure-treated wood box. All joints and corners mechanically fastened with 3" galvanized wood screws to a 1½" square stake driven into the ground a minimum of 12". All corners braced with triangular exterior grade plywood keystones mechanically fastened directly to the wood box with 3" galvanized wood screws. Install 4" of loam and 2" of pine bark mulch or woodchips over filter fabric weed barrier. Wood platform. Install a 10' × 12' ACQ wood platform built from 2" × 6" stock, 16" on center with 5 3/4" × 6" radius edge decking. All decking and joints to be mechanically fastened with 3" galvanized screws. Platform installed with a ¼" pitch to drain rainwater off of surface.
Gravel drive/path	Gravel parking areas. Install 6" of compacted gravel/crushed stone base to all areas designated as parking areas. Top of base 2"–3" below finish grade of surrounding area. Install a top layer of 1½" – 2" of processed gravel or crushed stone (¾" or ¾" size) over gravel/crushed stone base. Final grade is to have a minimum of 2% pitch across the surface to ensure that water will not puddle. Asphalt parking areas. Level surface by preparing a 6" gravel base over a uniformly graded and compacted subgrade. Form, spread, and roll 2" of bituminous base coat and 1" topcoat to create a driveway 10' wide. Final grade is to have a minimum of 2% pitch across the surface to ensure that water will not puddle.

reported that at least four children play in the yard. The majority of questionnaire respondents were very satisfied (57%) or satisfied (33%) with the soil treatments at their properties. Five percent of respondents were neutral. The remaining two respondents were dissatisfied or very dissatisfied.

Table 1 describes the specifications for the yard treatments implemented. The average total treatment cost was \$2798 with a range of \$1095–\$5643. The average yard was 3880 ft² with a range of 450–11,072 ft².

Table 2 presents the frequency and extent of treatments conducted on study properties. Overall, treatments averaged 1278 ft² with 37% of the yard treated. Dripline boxes were installed at 90% of the properties covering an average of 267 ft² (10% of the yard). Fifty-eight percent of the properties had stepping stone paths installed covering an area of 52 ft² (1.8% of the yard). Mulch was used in 56% of the properties covering an average of 371 ft² (12% of the yard). Grass was the treatment that covered the greatest average area (1001 ft²) and was used in 51% of the

properties. Thirty-seven percent of properties received wood-raised garden plots with an average size of 138 ft² (4% of the yard). Wood-raised picnic/play areas were installed in 37% of the properties averaging 177 ft² (7% of the yard). Gravel drive/paths treatments were used in 20% of the properties averaging 385 ft² (7% of the yard). Wood chips were only used in 10% of the properties, where the average areas treated was 310 ft² (8% of the yard). Treatments that did not fit into the categories described in Table 1 were classified as "other." Other treatments included installation of lattices under porches and placing gravel, stone, or sand around trees, in garbage can areas, at the dripline, under the porch, around the swing set area, or in other places around the building.

Table 3 displays the types of yard work activities reported by the residents at 1-yr post intervention. The majority of residents weeded (76%), watered grass or plants (73%), mowed grass regularly (63%), and planted in project boxes (51%). Fertilizing (34%), planting grass or reseeded (34%), and adding mulch/gravel to boxes or

Table 2
Lead-safe yard treatments on 41 properties: square feet and percentage of property treated

Treatment	Number of properties with treatment area reported (%)	Average square feet treated (range)	Average percentage of yard with treatment (range)
Dripline boxes	37 (90%)	267 (13,1045)	10 (0.3,37)
Stepping stone paths	24 (58%)	52 (5,121)	1.8 (0.1,5.8)
Mulch	23 (56%)	371 (25,1043)	12 (1.4,50)
Other treatment	22 (54%)	179 (6,900)	4 (0.2,21)
Grass sod/seeding	21 (51%)	1001 (60,3500)	24 (1.3,84)
Wood-raised garden plot	15 (37%)	138 (47,333)	4 (1,8)
Wood-raised play/picnic area	15 (37%)	177 (49,600)	7 (2.6,28)
Gravel drive/path	8 (20%)	385 (20,1740)	7 (0.5,27)
Wood chips	4 (10%)	310 (100,600)	8 (0.9,14)
All nongrass treatments	41 (100%)	766 (133,2618)	25 (2.5,70)
All treatments	41 (100%)	1278 (133,4352)	37 (2.5,98)

Table 3
Types of yard work activities reported at 1-yr follow-up

Activity	Number of properties reporting activity (%)
Mowed grass regularly	26 (63%)
Weeded	31 (76%)
Fertilized	14 (34%)
Repaired the boxes	0 (0%)
Added mulch/gravel to boxes or work areas	12 (29%)
Added mulch/gravel to nonwork areas	4 (10%)
Watered grass or plants	30 (73%)
Planted grass or reseeded	14 (34%)
Removed any plants or treatments	5 (12%)
Planted in project boxes	21 (51%)
Moved/added vegetable garden	7 (17%)
Other (trimmed hedges, turned mulch, installed new fence)	3 (7%)

work areas (29%) were also common activities. Moving or adding a vegetable garden (17%), removing plants or treatments (12%), and adding mulch/gravel to nonwork areas (10%) were reported at some properties. Trimming hedges, turning mulch, and installing a new fence were each reported at one property.

Table 4 gives the frequency distribution of the number of yard work activities. Only one resident reported doing no yard work. The median number of yard work activities reported was 3 or 4. Twenty percent of properties reported seven or eight yard work activities.

3.2. Changes in soil lead concentration

Table 5 presents GM dripline FAAS and FPXRF soil lead concentrations. One-year FPXRF sampling was conducted in a subset of locations sampled at baseline. If a location was sampled at both times we refer to it as “matched”; otherwise it is “unmatched.” For each

Table 4
Number of yard work activities reported at one-year follow-up

Number of yard work activities reported	Number of properties (%)
Zero	1 (2%)
One	3 (5%)
Two	12 (29%)
Three or four	10 (24%)
Five or six	8 (20%)
Seven or eight	8 (20%)

property, the average of matched samples was calculated for baseline and 1 yr. The average of unmatched samples was calculated for baseline.

One-year dripline FPXRF testing was only conducted at 21 (51%) of the 41 properties included in the study. At the 21 properties, 217 locations were FPXRF tested at baseline and 30% (65) of the locations were retested at 1 yr.

Locations that were tested with FPXRF at baseline and 1 yr had a higher GM FPXRF soil lead concentration at baseline than locations tested only at baseline (2021 and 1749 ppm, respectively; $P = 0.040$). There was a significant reduction in FPXRF lead concentration readings from baseline to 1-yr follow-up (2021–206 ppm, $P < 0.0001$).

3.3. Treatment integrity at 1-year follow-up

Table 6 presents information on the integrity of soil treatments at the 1-yr follow-up visit. The most common treatment, dripline boxes, held up very well, with the boxes continuing to block access in 97% of the properties with this treatment. At many properties, plants had been planted in the boxes, but weeds were growing in most of the boxes. In a few cases, boxes had missing parts, were warping, or had corners pulling away, but the boxes still blocked access.

The grass sod/seeding treatment affected the greatest areas in the yards. At 1 yr, a small amount of bare soil was reported in 43% of properties with this treatment and 29%

Table 5
Geometric mean AA and building dripline FPXRF soil lead concentrations and 95% CI at baseline and 1-yr follow-up

Analysis method	Data set	Baseline (ppm)	One-year (ppm)
AA	All ($n = 41$)	3090 (2466,3873)	—
	Set with FPXRF sampling ($n = 39$)	3268 (2695,3963)	—
FPXRF	Matched ($n = 21$)	2021 (1437,2843)	206 (128,329)
	Unmatched ($n = 37$)	1749 (1372,2230)	—
	All ($n = 39$)	1888 (1503,2371)	—

Note: yard surface cover for AA sampling locations at baseline was coded as 1 = no bare, 2 = small amount bare, 3 = half bare, 4 = mostly bare, or 5 = all bare. The average cover was 3.4, which is half to mostly bare.

Table 6
Treatment integrity at 1-yr follow-up

Treatment	Number of properties with treatment reported	Question	Response
Dripline boxes	37	Does the box fully block access to exposed soil at the dripline?	Yes 97% No 3%
Stepping stone paths	24	Is the walkway path functional? (i.e., does it keep dirt off shoes, etc.?)	Yes 88% No 12%
Mulch	23	Are there visible areas of bare soil?	No 83% Yes 17%
Other treatment	22	Is the condition of the treated area satisfactory?	Yes 77% No 14% Did not answer 9%
Grass sod/seeding	21	Assessment of soil coverage?	No bare 29% Small amount bare 43% Half bare 14% Mostly bare 14%
Wood-raised garden plot	15	Is the frame filled still filled with loam and compost?	Yes 100%
Wood-raised play/picnic area	15	Does the system still block access to soil in the area as designated?	Yes 100%
Gravel drive/path	8	Are there visible areas of bare soil?	No 88% Yes 12%
Wood chips	4	Are there visible areas of bare soil?	No 75% Yes 25%

Note: one property reported the frame being broken but the loam and compost were still in place.

of properties were reported to have no bare soil. The surface cover in the treated area was found to be mostly bare in 14% of properties and another 14% of properties reported half bare surface cover.

One hundred percent of areas treated with wood-raised garden plots or wood-raised play/picnic areas blocked access to the soil. The problems seen with the dripline boxes, such as warping, were also apparent in the garden boxes.

Mulch and wood chip treatments completely covered bare soil in 83% and 75% of the properties, respectively. Stepping stone and gravel driveway/path treatments were each intact in 88% of the properties treated. “Other” treatments were satisfactory in 77% of the properties.

3.4. Pathways of lead at baseline

3.4.1. Soil lead

Simple models were run to determine if dust lead is related to the FAAS dripline soil lead concentration and/or the dripline area cover at baseline. The dripline area cover variable is the average of the cover scores from the four sides of the building where dripline soil was present (1 = no bare, 2 = small amount bare, 3 = half bare, 4 = mostly bare, or 5 = all bare). The simple models included three possible predictors: FAAS dripline soil lead concentration, dripline area cover, and the interaction of FAAS soil lead concentration and dripline area cover. Neither soil lead concentration nor yard cover was predictive of dust lead levels at the exterior entry, common/main entry, or

dwelling unit entry at the front and rear or for front dust mats.

Results were similar when the soil models were run with the yard average FPXRF replacing FAAS dripline and overall yard cover replacing dripline area cover.

3.4.2. Dust lead at baseline

Exterior entry dust was significantly correlated with common/main entry dust at the front and rear ($r = 0.33$, $P = 0.038$; $r = 0.47$, $P = 0.002$). Exterior entry dust was significantly correlated with dwelling unit entry dust at the rear but not the front ($r = 0.38$, $P = 0.023$; $r = 0.24$, $P = 0.148$).

Baseline common/main entry dust was correlated with dwelling unit entry dust at the front and rear ($r = 0.42$, $P = 0.007$; $r = 0.56$, $P < 0.001$).

Front mat dust was significantly correlated with front common/main entry dust ($r = 0.40$, $P = 0.014$) but not with exterior entry or dwelling unit entry dust ($r = 0.22$, $P = 0.17$; $r = 0.28$, $P = 0.103$).

3.5. Dust lead loading at baseline and 1-yr follow-up

Table 7 presents GM dust lead loadings at baseline and 1-yr follow-up. Table 8 presents the percentage of buildings failing the federal dust hazard standard of $40 \mu\text{g}/\text{ft}^2$ at baseline and 1 yr in the front and rear of the building (US EPA, 2001b).

3.5.1. Common/main entry

There was a marginally significant reduction in GM common/main dust lead loading at the front of the building ($49\text{--}38 \mu\text{g}/\text{ft}^2$; $P = 0.089$). At the rear, the GM common/

main dust lead loading dropped from 116 to $104 \mu\text{g}/\text{ft}^2$ but the reduction was not significant ($P = 0.293$). GM dust lead loadings were significantly higher at the rear of the building than the front at baseline and 1 yr ($P = 0.015$ and 0.001 , respectively).

Fifty-one percent of the front main/common entries failed the floor dust hazard standard at baseline and 1 yr. At the rear main/common entry, 77% fail at baseline and 72% fail at 1 yr.

Common/main entry dust at baseline was correlated with 1-yr dust at the front and rear of the building ($r = 0.56$, $P < 0.001$; $r = 0.65$, $P < 0.001$). Common/main entry dust at the front was not correlated with the rear at baseline or 1 yr ($r = 0.24$, $P = 0.200$; $r = 0.30$, $P = 0.104$).

3.5.2. Dwelling unit entry

There was not a significant reduction in GM dwelling unit dust lead loading from baseline to 1-yr follow-up at the front ($11\text{--}13 \mu\text{g}/\text{ft}^2$, $P = 0.805$) or rear of the building ($17\text{--}13 \mu\text{g}/\text{ft}^2$, $P = 0.198$). GM dust lead loadings at the front and rear are not significantly different for baseline and 1 yr ($P = 0.267$ and 0.845 , respectively).

Five percent of the front dwelling unit entries failed the floor dust hazard standard at baseline, while 14% failed at 1 yr. At the rear dwelling unit entry, 28% failed at baseline and 8% failed at 1 yr.

3.5.3. Dust mat

Ninety-five percent of the mats were placed in the common/main entry. The remaining 5% were placed at the dwelling unit entry.

GM front dust mat dust lead loading per day decreased from $28 \mu\text{g}/\text{ft}^2$ at baseline to $23 \mu\text{g}/\text{ft}^2$ at 1 yr but this

Table 7
Geometric mean and 95% confidence intervals for dust lead loadings ($\mu\text{g}/\text{ft}^2$) at the front and rear entries at baseline and 1-yr follow-up

Sampling location	Front				Rear			
	N	GM baseline ($\mu\text{g}/\text{ft}^2$)	GM 1 yr ($\mu\text{g}/\text{ft}^2$)	Percent reduction in GM ^a	N	GM baseline ($\mu\text{g}/\text{ft}^2$)	GM 1 yr ($\mu\text{g}/\text{ft}^2$)	Percent reduction in GM ^a
Exterior entry	37	107 (70,164)	93 (61,143)	13% ($P = 0.266$)	39	192 (119,309)	206 (134,316)	-7% ($P = 0.618$)
Common/main entry	37	49 (33,73)	38 (25,58)	23% ($P = 0.089$)	39	116 (96,196)	104 (67,160)	10% ($P = 0.293$)
Dwelling unit entry	36	11 (7,16)	13 (9,18)	-18% ($P = 0.805$)	36	17 (9,33)	13 (9,18)	24% ($P = 0.198$)
Dust mat (per day)	36	28 (21,38)	23 (17,32)	17% ($P = 0.174$)	36	—	—	—

^aP-value from a paired sample *t*-test based on log-transformed dust lead loadings.

Table 8
Percentage of buildings exceeding the floor hazard standard of $40 \mu\text{g}/\text{ft}^2$ at baseline and 1-yr follow-up in the front and rear entries of the building

Location	Front		Rear	
	Baseline	1 yr	Baseline	1 yr
Common/main	51% ($n = 37$)	51% ($n = 37$)	77% ($n = 39$)	72% ($n = 39$)
Dwelling unit	5% ($n = 36$)	14% ($n = 36$)	28% ($n = 36$)	8% ($n = 36$)

reduction was not significant ($P = 0.174$). Baseline and 1-yr front mat loading per day are not significantly correlated ($r = 0.21$, $P = 0.216$).

3.5.4. Exterior entry

At 1 yr, the reduction in GM exterior entry dust lead loading at the front ($107\text{--}93\ \mu\text{g}/\text{ft}^2$, $P = 0.266$) and rear of the building ($192\text{--}206\ \mu\text{g}/\text{ft}^2$, $P = 0.618$) were not significant. GM dust lead loadings at the front and rear were not significantly different at baseline ($P = 0.267$) but they were at 1 yr ($P = 0.003$).

3.6. One-year follow-up dust regression models

Table 9 presents the regression coefficients from the regression models.

3.6.1. The front of the building

The only significant predictors of 1-yr dust lead loading at the front main/common entry were the baseline loading from that location and multifamily building (versus single family) ($R^2 = 41\%$). One-year mat lead loading per day was significant when added to this model ($P = 0.004$), increasing the R^2 to 54%.

For the front dwelling unit entry, the only significant predictor of 1-yr dust lead loading was the baseline loading from that location $R^2 = 23\%$. Front dust mat loading was not significant when added to the model.

Dripline soil lead concentration at baseline was the only significant predictor of 1-yr front dust mat lead loading per day ($R^2 = 17\%$).

3.6.2. The rear of the building

For the rear main/common entry, five variables were associated with higher 1-yr dust: (1) smaller square footage of the property treated; (2) fewer yard work activities

reported; (3) wiped surface not being smooth and cleanable; (4) higher baseline dust lead loading at that location; and (5) a higher percentage of components with nonintact paint at the exterior building entry ($R^2 = 78\%$). Each additional yard work activity is predicted to reduce 1-yr dust lead by 19%. Each additional 100 ft² treated is predicted to reduce 1-yr dust lead by 19%.

For the dwelling unit entry, four variables were associated with higher 1-yr dust: (1) lower extent of yard work activities reported; (2) wiped surface not being smooth and cleanable; (3) single family building (versus multifamily); and (4) a resident reported change in the way they use the yard. $R^2 = 61\%$. Each additional yard work activity is predicted to reduce 1-yr dust lead by 22%.

3.7. Building conditions at baseline and 1-yr at the building front and rear

3.7.1. Comparison of front and rear

There was no difference between the front and rear in the percentage of wiped floor surfaces that were smooth and cleanable for the exterior entry, common/main, and dwelling unit entry at baseline or 1 yr (P -values range from 0.157 to 1.0). There was more nonintact paint at the front exterior building entry of the buildings compared to the rear, with marginally significant differences at baseline (40% versus 29%, $P = 0.050$) and at 1 yr (42% versus 31%, $P = 0.057$).

3.7.2. Changes from baseline to 1 yr

There were no difference between baseline and 1 yr rear in the percentage of wiped floor surfaces that were smooth and cleanable for the exterior entry, common/main, and dwelling unit entry at the front or rear (P -values range from 0.157 to 0.564). There was no difference between baseline and 1 yr in the average percentage nonintact paint

Table 9
Regression coefficients (and standard errors) for dust regression models

Variable	Front of the building model			Rear of the building model	
	Common/main	Dwelling unit	Dust mat (per day)	Common/main	Dwelling unit
R^2	41%	23%	17%	78%	61%
Intercept	-0.0058 (0.8100)	1.5813 (0.3402)	-1.1941 (1.6261)	3.8747 (0.5160)	5.3966 (0.5386)
Log baseline common/main dust lead loading ^a	0.6868 (0.1462)			0.4446 (0.0745)	
Log baseline dwelling unit dust lead loading ^a		0.4054 (0.1280)			
Log baseline dripline soil lead concentration (FPXRF)			0.5389 (0.2008)		
Multifamily dwelling (1 = yes, 0 = no)	1.1195 (0.4962)				-0.7647 (0.3516)
Square feet of yard treated				-0.0005 (0.0001)	
Percent of components with nonintact paint at the exterior building entry at baseline				1.4008 (0.4334)	
Number of yard work activities reported at 1 yr				-0.2060 (0.0494)	-0.2534 (0.0515)
Wiped surface is smooth and cleanable at 1 yr				-0.7757 (0.2498)	-1.6684 (0.3152)
Resident reported change in yard use at 1 yr					0.5031 (0.2408)

^aFor the front model, the front level is used. For the rear model, the rear level is used.

at the front or rear exterior building entry ($P = 0.702$ and 0.224 , respectively).

4. Discussion

Residents may be exposed to soil lead directly when outdoors and indirectly through track-in into the home. This study was conducted at properties where the buildings had been previously abated or deleaded to Massachusetts's standards in the 5 yr before enrollment. The expectation was that by conducting the soil treatments at previously abated properties, the primary remaining source of interior dust lead would be controlled. Reducing soil lead levels and/or improving the condition of the yard surface cover may lessen direct and indirect exposure to soil lead. Soil treatments, especially grass seed or sod, may not hold up over time unless residents maintain their yards. The number of yard work activities was found to be a predictor of 1-yr dust lead levels in the rear main/common entry and the dwelling unit entry.

4.1. Direct effects of soil lead treatments

Properties in this study were treated with application of ground coverings and ground barriers. The treatments resulted in a reduction in soil lead levels from baseline to 1 yr. Most of the barrier treatments continued to block access to the lead-contaminated soil at 1-yr follow-up. Although few properties had grass treatment areas that were completely bare at 1-yr follow-up, 28% had more than a small amount of treated areas bare at 1-yr follow-up.

Dripline soil lead levels as measured by FPXRF dropped drastically from 2021 ppm at baseline to 206 ppm at 1 yr. If a new substrate was in place at the surface at 1 yr, that substrate was tested with the FPXRF. The overall yard average FPXRF were similar, dropping from 1740 ppm at baseline to 320 ppm at 1 yr.

These results were somewhat surprising because many of the treatments were only ground covers that would not have had much effect on soil lead concentrations. Yet the reductions were similar to those observed in the earlier Boston Lead-in-Soil study, which used full soil abatement. The use of dripline boxes at 90% of the properties may explain the significant declines at the dripline, but the rest of the yard was more likely to be treated with grass and other coverings that did not include the introduction of substantial amounts of top soil. It is possible that the preparation of the soil for grass may have had a large effect because the FPXRF only reads the top 2–3 mm of soil lead.

4.2. Effects of soil treatments on entry dust lead at 1-year follow-up

Overall the treatments were not effective in reducing GM dust lead loadings except marginally for the front main/common entry. However, the greater extent of treatment

(ft²) and yard work activity were associated with lower dust lead levels in the rear of the building. Each additional yard work activity is predicted to reduce 1-yr dust lead at the rear common/main and dwelling unit entries by about 20%. Each additional 100 ft² treated is predicted to reduce 1-yr dust lead at the rear of the dwelling by 19%. Findings support earlier work in Clark et al. (2004), which found that front exterior entry dust lead loadings were lower in buildings with soil treatments. In that analysis, soil treatments ranging from temporary treatments like mulching to full abatement were all combined.

The contractor developed an individualized yard treatment maintenance plan for each property treated and reviewed it with the residents upon completion of soil work. The researchers were encouraged to find that residents often implemented part or all of these plans within the year following the work. At over half the properties, the residents watered the lawn and garden, mowed the grass, added plantings to the project boxes and weeded the plantings. Residents reported 3 or 4 yard work activities on average at 1 yr. At a third of the properties, the residents also seeded and fertilized the lawn.

Soil treatments were more effective at reducing dust lead levels at buildings in better condition. At the rear common/main entry and rear dwelling unit entry, smooth and cleanable surfaces had lower 1-yr dust lead loadings. For the rear main/common entry, the percentage of building components with nonintact paint at the rear exterior building entry was associated with higher dust lead levels.

This may be because the nonintact paint contains lead or this variable may simply be an indicator for buildings in poor condition.

Higher baseline dust leads were associated with greater percent reductions in dust lead in the front and rear common/main models and the front dwelling unit entry model. However, the effects of baseline dust lead loading on 1-yr loadings were not overcome by the interventions. This may in part be because cleaning of the entry way was not a component of the interventions. Higher baseline dust leads were associated with higher 1-yr dust lead in the front and rear common/main models and the front dwelling unit entry model.

For both the common/main entry and the exterior entry, GM dust lead loadings were at least 100% higher in the rear than the front at both baseline and 1 yr. However, GM dwelling unit entry dust lead loadings at the front and rear were not statistically significantly different at baseline or 1 yr. Building conditions at front and rear entry of the building were similar. Equality of dwelling unit entry dusts at the front and rear despite the great differences in exterior and common/entry dust suggest that resident cleaning within the dwelling unit is fairly uniform. This brings into doubt the hypothesis that dust is tracked in from the exterior entry to the main/common entry to the dwelling unit entry. The inspectors anecdotally reported that they saw little evidence that the floors or resident's dust mats in the rear common area entries were ever cleaned, whereas

the floors in the front common areas appear to have been cleaned. The percent variation explained in the models (R^2) for the rear dust models were about double the R^2 for the front model. The investigators believe that because the building rear is cleaned so rarely, it is possible to see treatment effects. Cleaning effects may have such a large influence on dust lead at the front that it is not possible to see treatment effects or resident activity effects.

Field staff reported that rear doors were often the entrance to the yard and garden, where greater soil lead exposure would be expected. Although the rear dwelling entry was only reported to be the most commonly used entry in 10% of the dwellings at both baseline and 1 yr, the investigators believe that there may have been more foot traffic in the rear following the intervention. Extensive bare soil in the rear yard or pets on chains could contribute to higher dust lead loadings. Baseline surface conditions were no worse in the rear than the front at the dripline ($P = 0.405$) but surface cover information was not collected uniformly at other yard locations or collected at 1 yr. About half of the residents reported a change in yard usage from before the intervention to 1-yr follow-up, but the details of the changes were not specified. Our modeling found that a change in resident yard usage was associated with higher dwelling unit rear dust lead loading at 1 yr. Possible effects of pets in the soil treatment area or dogs or cats at the residence were explored but found to be nonsignificant.

Binns et al. in Chicago used treatments similar to those used in this evaluation and had similar results (Binns et al., 2004). In that study, GM entry floor dust lead loading decreased from baseline to 1 yr for the 14 properties with raised garden boxes but increased for the 23 properties treated with ground covering/barriers but no raised garden boxes. The results presented in this paper are consistent with the Binns paper in suggesting that using entryway dust lead loading as a measure of soil treatment effectiveness may be problematic.

5. Limitations

Children's blood lead levels were not measured in this study. Hence, it is not possible to evaluate the effects of the treatments on children's blood lead levels.

One-year FPXRF testing was conducted in 21 of the 41 enrolled properties. In those 21 properties, 30% of the baseline sampling locations were tested at 1 yr.

Binns and colleagues found a reduction in an "acute hazard soil lead" measurement that weighted soil lead concentrations by surface area and surface cover (Binns et al., 2004). The investigators believe that this type of measure would have shown significant improvement in this study but surface cover detail required to compute this measure was not collected.

Inspectors anecdotally reported extensive debris in the backyard before treatments. Although participation in the project required its removal before the treatment, the

debris may have blocked track-in of soil lead into the building by blocking access to the rear entry at baseline. The possible effect of debris in the yard at baseline is unknown.

If a resident's mat was in place at a sampling location, the mat was moved and the floor dust lead sample was collected on the surface underneath the mat. Although this could influence dust lead results, information on whether a resident mat was moved or not was not collected. If old dirty rugs or floor mats were put back down in the rear after the wipe samples were collected at baseline, the debris from the old mats could have redeposited over 1 yr, resulting in no reduction from baseline to 1 yr. Although other studies have suggested that placement of dust mats at building entries could be useful dust collection devices, analysis in this paper did not identify treatment effects on mat loading (Farfel et al., 2001; Binns et al., 2004).

6. Conclusions

In this study, soil lead levels and exterior and main/common entry dust lead levels at 1 yr served as measures for treatment effectiveness. In the absence of children's blood lead data, these environmental measures were used to project whether these nonabatement soil treatments would be expected to have a protective effect on children. The results are mixed. On one hand, soil lead concentrations declined in the same range (approximately 2000–200 ppm) as in the 1990 Boston Lead-in-Soil Demonstration Project where soil lead was abated (Aschengrau et al., 1994). That study documented significant declines in children's blood lead levels. Furthermore, surface cover in this study tended to be maintained for the 1-yr evaluation period. However, earlier studies have also suggested that an important component of the effectiveness of soil treatments is their effect on interior dust lead loadings. Significant dust lead changes were not observed at the more frequently used front entrance of the building, and rear common area and unit entry dust lead loadings significantly declined only when residents maintained their yards. It is possible that the windborne transport of lead in dust and soil from the neighborhood overshadows the effects of soil treatments on entry dust lead loadings. Like the findings of Binns and colleagues (Binns et al., 2004), this study suggests that in-place management of soil lead holds promise, but additional studies in which health data are collected are needed to demonstrate that the treatments reduce childhood lead exposure.

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