

THE POTENTIAL FOR HEAVY METAL EXPOSURE FROM URBAN GARDENS AND SOILS

Rufus L. Chaney, Susan B. Sterrett^{1/}, and Howard W. Mielke^{2/} 7213 0 004

USDA, Agricultural Research Service
Biological Waste Management and Organic Resources Laboratory
Beltsville, MD 20705

INTRODUCTION

In 1978, the Cornell University Extension Service Urban Garden Program held a conference in New York City to evaluate the potential problems for urban gardening if air or soils are enriched in heavy metals such as Pb. At that conference, work of Preer and Rosen (1977) and Spittler and Feder (1979) was presented, indicating that Pb paints can contaminate urban garden soils and vegetable crops. Before that conference, little consideration had been given by the agricultural community to potential health effects of contaminated urban soil. Many scientists had considered contamination of crops by automotive Pb emissions, by sewage sludge, by smelter emissions, by pesticides, and by metal-enriched manure. This new information changed the way we must view potential Pb problems in urban areas, including urban gardening.

Several related Pb poisoning issues were also undergoing increasingly intense research in the later 1970's which indicate greater risk to children from Pb in urban soils than previously recognized: 1) Pb exposure by inadvertent ingestion of house dust, and 2) neurobehavioral impairment in children at lower Pb exposures than previously believed needed to cause health effects. This review considers the relationships of Pb exposure from urban soils and dusts and from crops grown in urban gardens, and the potential consequences of that exposure. It considers the sources of metals in urban soil and dust, how these can be economically tested for, and the potential consequences on garden productivity and child safety regarding Pb poisoning. We also consider pathways from soil to humans, both via plant uptake of metals and soil ingestion by children.

But why have these questions become relevant? The connection results from modern interest in vegetable gardening. Gardening has become popular in nearly all socioeconomic groups in the U.S. For some, gardening is adopted because it can provide fresh, high quality vegetable crops; for others, it is the exercise, fresh air, and contact with nature; and for still others, it is the savings on food costs. The U.S. Department of Agriculture has always been involved in vegetable crop production, and home gardens, at both research and advisory levels. The Congressionally mandated Urban Gardening Program has been managed through the USDA Extension Service and the individual State Extension Services. This program focuses on Community Gardens in inner-city urban areas in specific states. Extension specialists cooperate with public and private groups, and help gather neighborhood groups to operate their own

^{1/} Presently at Virginia Truck and Ornamentals Research Station, Painter, VA 23420

^{2/} Presently at Department of Geography, Macalester College, St. Paul, MN 55105.

community garden. Extension provides knowledge, encouragement, and often helps arrange for tools, seeds, and other gardening resources. They also teach canning, freezing, and other preservation practices, and how to use locally produced vegetables in tasty, economic, and nutritious meals.

Thus, because people are increasing gardening in urban areas, the processes that cause heavy metal enrichment of soils, plants, and people in cities must be reconsidered. Although there is little evidence that most gardeners are at risk, it is clear that gardeners in some inner-city areas, and near some industries, and in some cities where highly polluted sewage sludges were given away, are at enough risk to need information to protect themselves or their children. Further, because nearly all soil pollution is anthropogenic (resulting from human activities), individuals would be wise to obtain garden and houseside soil tests before they begin gardening, and probably before they purchase or move children into a house or rental unit. The need for soil tests is slight for suburban areas, but much higher in the inner city or if Pb paint could have been used.

In the last 15 years, much research has been conducted on sources of heavy metal pollution, pathways for movement of soil or air-borne metals to humans, and potential health effects of these metals. Some important questions remain unanswered, but much is well characterized. The present review can not be comprehensive about these many areas of research, but pertinent reviews are cited to guide the reader to other detailed information.

FOOD-CHAIN PATHWAYS FOR URBAN HEAVY METALS

As reviewed below, many different sources can contribute heavy metals to urban air and soil. Most of these processes apply to suburban and rural areas as well, although automotive and smelter emissions are less intense at greater distances from the source.

The two key processes which allow human exposure to metal pollution through gardening are plant uptake where the plant is human food, and soil ingestion. Plant uptake includes both adsorption of air pollutants on plant surfaces, and uptake by the roots with translocation to edible plant tissues. Soil ingestion includes either pica, the intentional ingestion of non-food objects, or inadvertent soil ingestion during hand-to-mouth play.

Plant Contamination by Automotive Emissions.

The initial focus on Pb was contamination of crops grown near highways. Cannon and Bowles (1962) reported Pb in garden soil and vegetables in one of the very first papers on automotive Pb pollution. Because tetraethyl Pb is added to gasoline to reduce automotive engine knock, Pb is emitted from exhaust pipes (EPA, 1977; Ewing and Pearson, 1974; Smith, 1976; Zimdahl, 1976). Ethylene dibromide is added to gasoline so that volatile $PbBr_2$ can be formed in the engine and leave the car. Actually, only about 75% of the Pb is emitted, the rest remaining in the engine (10%) and engine oil (15%) (which is often dumped on soil). Although $PbBr_2$ is released to the air, $PbSO_4$ is quickly formed and precipitated (Olsen and Skogerboe, 1975; Biggins and Harrison, 1979). Aerosol Pb is apparently adsorbed from the air by surface tension of leaf surfaces, and is not readily remobilized from the leaf by wind (Wedding et al., 1975, 1977; Carlson et al., 1976). Although $PbCl_2$ is

soluble, and therefore, can be largely rinsed from leaf surfaces (Carlson et al., 1975), automotive Pb on leaves near roadways is mostly $PbSO_4$. Washing these leaves with water removes only about 50% of the Pb present (Preer et al., 1984).

Several research groups have studied the potential of roadside trees to reduce Pb pollution of crops. Heichel and Hankin (1976) noted that white pines removed much Pb; the trapped Pb increased soil Pb under the trees over time. Collett (1978) found reduction in Pb levels in vegetable crops if a row of trees grew between the highway and crops.

Many researchers have measured Pb concentration of crops grown at different distances from highways with different traffic density. The higher the traffic, the higher the crop Pb. Crops with hairy leaf surfaces retain more aerosol Pb than crops with smooth leaf surfaces. Many fruits have smooth surfaces and low Pb levels. Pb deposition falls logarithmically with distance from the highway (nicely shown in Page et al., 1971; Shuck and Locke, 1970; Ward et al., 1975; David and Williams, 1975; Motto et al., 1970). Therefore, more Pb is deposited close to the road, at least partly because larger particles settle out sooner and nearer to their source. This is difficult to interpret in urban areas where streets surround all 4 sides of a community garden or housing.

Roadside crop contamination has been extensively evaluated (USEPA, 1977). The amount of Pb on a leaf surface depends on distance from road, crop species, time exposed before harvest, and recent rainfall (Crump et al., 1980; Crump and Barlow, 1982). Rapid growing leafy crops, if properly washed before consumption, are not an important source of Pb for children. These crops are significantly higher in Pb than crops sampled in rural fields (Wolnick et al., 1983), but often not different in Pb than crops marketed in urban areas. Marketing in urban areas exposes fresh vegetables to contamination by urban dust rich in Pb. Based on analysis of ^{210}Pb in foods and feces, Chamberlain (1983) has estimated fallout Pb contributed less than 15% of adult dietary Pb.

Plant Uptake of Heavy Metals

Soil-Plant-Barrier Model. Plants absorb different elements from different soils to levels related to element properties, soil properties (pH, element level in soil, organic matter, cation exchange capacity, and level of other elements in the soil) and plant properties (plant age, species, type of crop edible portion [leafy or root vegetable, or garden fruit]). The accumulation of different elements has been reviewed extensively in review of potential effects of sewage sludge application on cropland (Logan and Chaney, 1984).

In short, some elements are easily absorbed and translocated to food chain plant tissues (e.g. Zn, Cd, Mn, Mo, Se) while others are not. Some elements are strongly bound or precipitated in the soil, or in the fibrous plant roots, and are not translocated to plant foliage in injurious amounts even when soils are greatly enriched (Pb, Fe, Hg, Al, Ti, Cr, etc.). Other elements are easily or relatively easily absorbed and translocated to plant foliage, but phytotoxicity to the crop may limit plant levels of the element to levels safe for chronic ingestion by animals (Zn, Cu, Ni, Mn, As, B). These processes have been collectively labeled the "Soil-Plant Barrier" (Chaney, 1980). The exceptions to the protection of the food-chain by the Soil-Plant Barrier are

1) soil ingestion, and 2) the elements Cd, Se, and Mo. For urban gardens, this means soil ingestion which can allow excessive acute or chronic Pb ingestion in some cases, and crop uptake of Cd which can allow excessive chronic Cd ingestion.

Plant Uptake of Pb-General. During the last 15 years researchers have improved the techniques needed to conduct more valid research on plant uptake of elements (Logan and Chaney, 1984). Examples can easily be found in the Pb, Cd, or phytotoxicity literature. When soluble Pb salts [$PbCl_2$; $Pb(NO_3)_2$] are added to soils, the anion temporarily increases Pb solubility. The high ionic strength reduces metal sorption by the soil. Pb-complexes may form and keep Pb soluble. The metal addition can substantially lower soil pH as the metal reacts with the soil. More Pb is taken up in pot studies than field studies. Zimdahl et al. (1978) studied the effect of adding different Pb compounds and found much more Pb was absorbed by 5 crops from $Pb(NO_3)_2$ than $PbSO_4$ amended soils.

Numerous researchers have evaluated the effect of soil properties. When soluble Pb salts are added to soils in pot studies, higher soil pH or higher soil cation exchange capacity (CEC) reduce Pb uptake (MacLean et al., 1969; Cox and Rains, 1972; Miller et al., 1975a, 1975b). The effects of lime or CEC are usually attributed to greater adsorption of the Pb by the soil under the conditions which reduce plant Pb. Added phosphate, manure, limestone, or sewage sludge compost can reduce plant uptake of Pb (Zimdahl and Foster, 1976; Cox and Rains, 1972; MacLean et al., 1969; Scialdone et al., 1980; Judel and Stelte, 1977; Chaney et al., Table 3). Soils deficient in phosphate or sulfur show strong reduction in plant Pb when these elements are added (Jones et al., 1973). However, few urban soils are low in phosphate, and none low in sulfur.

When Pb salts have a longer period to react with the soil, or when Pb salts are applied in the field (Baumhardt and Welch, 1972) rather than to pots of soils, much lower Pb uptake occurs. Hassett and Miller (1977) grew corn on roadside soils in pots, and found much lower Pb uptake than from the $PbCl_2$ -amended soils studied by Miller et al. (1975b). These studies demonstrate the need for care in selecting research methods which represent long term availability of environmental Pb to plants.

Pb uptake in the field shows a seasonal variation. Mitchell and Reith (1966) found Pb in orchardgrass and clover rose in the Fall and Winter, by as much as 10-fold. It was not due to soil contamination, and their evidence did not support an aerosol source. Haye et al. (1976) evaluated this seasonal response further, and found it even in a growth chamber with filtered air. Research has been conducted to settle whether slow growth during cold weather simply increases the total exposure time of leaves to aerosol Pb, or whether simple plant uptake explains these seasonality findings.

Ratcliffe and Beeby (1980) found decaying grass leaves adsorbed more soluble Pb than young growing leaf blades. Crump et al. (1980) found the seasonal increase in Pb concentration in perennial ryegrass, but found that young leaf blades harvested at any time of year had similar Pb levels at a specific location, but old leaf blades were up to 10-fold higher in Pb. Crump and Barlow (1982) then used bags of sphagnum peat moss and bags of cut grass leaves to assess seasonal patterns of deposition of aerosol Pb. Moss accumulated more Pb in winter than summer, apparently due to seasonal

windspeed differences. However, Pb levels in grass growing during 30 days and Pb caught in moss bags during the same 30 days were very comparable. Thus, the continuing accumulation of Pb in old leaf blades appears to explain the seasonal pattern of Pb in pastures and roadside crops. These results have little implications for garden crops except supporting the need for careful washing of leafy vegetables.

Plant Levels of Pb in Urban Gardens. Although all evidence indicates that inadvertent soil ingestion allows much greater Pb exposure than eating garden vegetables grown on the soil, plants grown in urban gardens which are highly contaminated with heavy metals may contain elevated metal levels in their edible portions. To examine the influence of urban gardening on plant uptake of metals, two approaches have been used: 1) bring garden soils to clean air environment for pot study of metal uptake; and 2) grow crops in gardens and analyze. Davies (1978), for example, chose to grow radish in many gardens. Since the influence of aerosol Pb on Pb levels in this root crop is minimal, soil Pb availability could be evaluated.

Preer and Rosen (1978) reported significantly higher crop Pb and Cd when crops were grown in a community garden over an old landfill where soil Pb was the predominant Pb source. Spittler and Feder (1979) grew several vegetables in unreplicated beds of urban garden soils, and found very high Pb in lettuce and root crops. Preer et al. (1980a) sampled leafy vegetables and soil (10-1400 ppm Pb; mean 200) in Washington, D.C. gardens. Although crop Pb was correlated with soil Pb, it was more highly correlated with (average daily traffic/distance from road). In this study plant Pb averaged only 4.5 ppm (range 1-12 ppm)(dry weight basis). In a subsequent study of downtown Washington, D.C. gardens, Preer et al. (1984) found appreciably higher soil Pb (44-5300; mean 680), and slightly but significantly higher leafy vegetable Pb (6.4 ppm). However plant Pb was not linearly correlated with soil total Pb. Preer et al. (1980b, 1980c) have reported analyses of many crops and effects of soil pH and traffic on plant Pb and Cd in urban gardens. As expected, fruits are always much lower in Pb than leafy or root vegetables; leafy crops are usually higher than root crops, but this comparison is affected by soil Pb level. Collards and kale are lower in Pb than lettuce, chard, and beet greens.

Hibben et al. (1984) attempted to separate air and soil factors by creating soil beds from urban and suburban soil at urban and suburban locations. The soils used were only 66 and 273 ppm Pb, and a substantial difference in fertility confounds the study. In one year, the urban location caused significantly higher Pb in leafy crops but not root crops, even though they were grown relatively distant from traffic. The higher Pb soil caused a small, but significant increase in Pb in leafy crops. Kneip (1979) analyzed several crops grown in demonstration gardens in New York City. Soil Pb was below 500 ppm, and some of these demonstration gardens had fresh soil when they were begun. Crop Pb was compared to crops from markets and the FDA analysis of Pb in foods. He concluded that, for these gardens, the crops would add little dietary Pb compared to market crops.

A few studies have been conducted with garden soils very rich in Pb. We sampled collard (washed with care of home cook) and soils from 50 inner-city gardens in Baltimore, MD. Table 1 shows these results. Plant Pb concentration and was significantly related to log transformed soil total Pb concentration. Collard Pb was only 6.6 ppm (range = 2.6 - 13.4 ppm). In

Table 1. Heavy Metals in Soils and Collards from 50 Baltimore Urban Gardens.

FACTOR	MEAN	S.D.	Geo. MEAN	MIN.	MED.	80th	MAX.
-----mg/kg dry-----							
Soil Pb	1171.	1889.	586.	46.	573.	1450.	10900.
Soil Cd	2.50	2.55		0.28	1.72	3.06	13.6
Soil Zn	588.	815.		20.6	352.	751.	4880
Soil Cu	78.	67.		5.8	54.	120.	293.
Soil Ni	6.3	4.6		1.6	4.9	7.8	25.2
Soil Mn	167.	90.		28.	140.	238.	386.
Soil pH	6.19	0.60		4.51	6.28	6.66	7.17
Plant Pb	6.63	2.34	6.26	2.60	5.9	8.4	13.4
Plant Cd	0.80	0.66		0.10	0.54	1.10	2.91
Plant Zn	192.	150.		31.9	165.	256.	621.
Plant Cu	7.2	7.0		2.5	5.1	8.5	48.5
Plant Ni	1.7	1.8		0.10	1.4	2.0	11.6
Plant Fe	104.	70.		44.	79.	130.	463.

Soil Method: 1 N HNO₃, 5g/50mL, 2 hr. extraction.

Plant Method: Dry Ash, HNO₃, HCl

later studies, lettuce Pb was appreciably higher, and unrelated to soil Pb. We believe this indicates aerosol deposition usually exceeds soil as the Pb source for lettuce, collards, and other leafy vegetables growing in urban gardens.

One pot study of Pb uptake was conducted using Baltimore urban garden soils. 'Tania' lettuce was used in this research because Feder et al. (1980) found this cultivar to accumulate more Pb than others grown on an incinerator ash rich in Pb (Table 2). The ability of NPK fertilizer, limestone, high phosphate fertilizer, or sewage sludge compost to reduce crop Pb uptake was evaluated (Table 3). In general, lettuce Pb remained at acceptable levels if NPK fertilizer was applied. Elevated Pb levels were found in lettuce grown on a garden soil with 5210 ppm Pb. For the high Pb soil (5210 ppm), P or sludge compost in addition to NPK fertilizers, were more effective in reducing lettuce Pb than NPK fertilizer alone. Healthy lettuce was grown on all soils and treatments.

Nicklow et al. (1983) evaluated Pb uptake by 6 crops grown on a control soil, a high Pb urban garden soil, or a 1:1 mixture of these soils. Plant Pb was linearly related to soil Pb, probably because only one soil Pb source was studied. Lettuce and turnip greens were highest in Pb. Collard and kale were relatively low in Pb even with the very high soil Pb. Beet, turnip, and carrot also accumulated Pb, with very high levels in the peel. Soil fine particles adhering to root crop peels can contribute substantial Pb. Root crops must be washed and peeled to reduce crop Pb to acceptable levels for about 10% of urban gardens, those rich in Pb.

Table 2. Difference Among Lettuce Cultivars in Lead Accumulation from Control and Incinerator Ash-Amended Soil^{1/}

Cultivar	Pb in Lettuce Shoots, ppm dry wt.		
	Incinerator Ash	Control	Difference
Tania	27.4	8.6	18.8
Butterhead 1044	22.6	5.6	17.0
Butterhead 1034	21.9	10.6	11.3
Summer Bibb	21.5	9.3	12.2
Butterhead 1033	20.2	5.7	14.5
Buttercrunch	15.0	6.4	8.6
Belmay	12.6	11.0	1.6
Dark Green Boston	10.7	8.6	2.1
Valmaine	10.6	4.0	6.6
Soil Pb (1 N HNO ₃)	5585.	46.	-
Soil pH	7.8	5.8	-

^{1/} In cooperation with Dr. W. Feder, University of Massachusetts.

Table 3. Effect of Amendments on Pb Concentration in 'Tania' Lettuce Grown in Six Soils in a Growth Chamber.

Treatment	Soil Pb Concentration, ppm					
	12	392 ^Z	413 ^Z	655 ^Z	1334 ^Z	5210 ^Z
-----Pb in lettuce shoots, ppm dry-----						
Control	2.8a ^Y	4.6a	15.7a	4.7a	17.7a	37.8ab
NPK	2.0a	4.1a	3.8ab	7.6a	8.4a	26.6bc
NPK + CaCO ₃	1.8a	5.0a	9.3ab	6.4a	6.0a	43.7a
NPK + P	2.9a	9.3a	4.4ab	9.4a	10.5a	17.ac
NPK + 5% compost	2.2a	5.1a	2.4b	4.8a	6.5a	16.1c
NPK + 10% compost	2.6a	3.5a	2.8b	5.5a	5.3a	19.7c

^Z Urban garden soils from Baltimore, MD.

^Y Means within columns followed by the same letter are not significantly different (P<0.05) according to Duncan's New Multiple Range Test.

Davies has summarized his own work in his paper in this proceedings. He has found radish and lettuce can be significantly and unacceptably high in Pb when grown on high Pb urban gardens, or high in Pb or Cd in gardens influenced by mining and smelting wastes (Davies, 1978; Davies et al., 1979; Davies and Ginnever, 1979; Davies and Roberts, 1975; Davies and White, 1981; Davies et al., 1981).

Looking at the whole data base, it would appear that crop Pb is not yet a significant limitation for growing vegetables in a garden with 500-1000 ppm soil total Pb (crops washed; root crops peeled). However this much soil Pb when present in areas frequented by children can significantly contribute to blood Pb in children. Gardens very high in Pb (say over 3000 ppm) could be used to safely grow fruits and grain crops, but not leafy or root vegetables. For these very high Pb gardens, extreme care would be needed to reduce soil transfer to housedust and minimize exposure of children, too much care for practical gardening.

Ingestion of Metals in Soil and Dust.

When soils are contaminated with metals, soil ingestion can become an important exposure pathway to heavy metals. Soil ingestion by farm livestock was initially identified as the source of excessive tooth wear. Plants became contaminated by soil by 1) rainfall splash, and 2) trampling by the livestock. Cattle and sheep could eat as high as 24% soil in their dry diet under worst case, very poor management. Soil is normally only about 1-2% of the diet (Fries et al., 1982).

Cattle have been Pb-poisoned when grazing soils naturally high in Pb (Egan and O'Cuill, 1970; Harbourne et al., 1968; Thornton and Abrahams, 1981). When a Pb smelter contaminated a pasture, Pb-enriched crop residues remained on the soil surface even after the smelter closed. Cattle blood Pb fell to normal levels only when the sward surface thatch was incorporated into the soil to prevent direct ingestion by the cattle (Edwards and Clay, 1977). Inadvertent soil ingestion is an important source of exposure when plant uptake of an element is small compared to soil concentrations (e.g. Pb, As, Cu, F, Hg, toxic organic compounds, etc.).

Children of Pb-Industry Workers. In the late 1970's, the Pb-poisoning of children of Pb-industry workers became an important example of inadvertent soil and dust ingestion. Baker et al. (1977) studied workers' children and their neighbors at a secondary Pb smelter where the workers had not changed or showered at work. The housing was relatively new, and without Pb-rich paints. House dust was 404 ppm Pb in the neighbor's homes, but 2690 ppm in the workers' homes. Blood lead correlated well with Pb level in house dust, with 10 children needing chelation therapy to remove Pb. Similar results were reported by Dolcourt et al. (1978). Giguere et al. (1977) studied a smelter where workers changed clothes at work and showered, but brought their clothes home to wash. Blood Pb was not as high, but Pb in house dust was an important source. Rice et al. (1978) looked at smelters where workers showered at work and work clothes were washed at work. Housedust Pb was still significantly higher in workers' homes. They believed that workers' street clothing, shoes, and cars became Pb contaminated, and the Pb-rich dust was transferred to their homes. Millar (1978) also found higher blood Pb in children of Pb workers in the U.K.

Archer and Barratt (1976) measured Pb in "white cotton socks" given to employees at a secondary Pb smelter to study contamination of clothing. Although factory workers' socks had the highest Pb levels, supervisors' and administrative workers' socks were also Pb exposed. Simply walking through the factory contaminated shoes, socks, and pants legs. Fergusson et al. (1981) confirmed these contamination pathways.

We believe these observations are of great importance. They allow separation of the Pb in housedust relationship to children's blood Pb, from the other socioeconomic factors which ordinarily confound studies of urban children. In this research model, children lived in homes with or without high levels of Pb in the housedust. Simply living in these homes caused the children to ingest Pb-laden dust which led to higher blood Pb.

Research on multi-media Pb exposure has difficulty separating out a single factor for study, but the worker's children serve this critical logical purpose. No one can neglect housedust Pb exposure to children after reading the literature on Pb-workers' children. OSHA subsequently required that workers shower and change clothes before leaving work, with the work clothing washed at the factory (even though the Rice et al. 1978 and Archer and Barratt, 1976 papers show this can not completely prevent carrying home the factory dust rich in metals).

Increased Blood Pb in Children Ingesting Urban Soil and Dust. As noted above, the literature on increases in blood Pb in children who ingest Pb-enriched soil and dust has grown rapidly in the last decade. A detailed reading of the childhood blood-Pb literature, and the heavy metals in urban soil and dust literature, shows that although some authors believed specific Pb-poisoning cases were caused by soil Pb, medical specialists could not identify the importance of this source until the incidence of Pb poisoning due to ingestion of Pb-paint chips had decreased. The increased blood Pb in urban vs. suburban and rural children led some researchers on the dust Pb path (Cohen et al., 1973; Sayre et al., 1974). The connection between smelter Pb emissions in soil and dust, and blood Pb in children, has been an important lesson, and a difficult political problem. Finally, the Pb ingestion by children of Pb workers, noted above, got the attention of most childhood Pb poisoning researchers.

Around Pb smelters, soil and housedust become greatly enriched in Pb. A very high incidence of excessive blood Pb was found at many smelter towns (Landrigan et al., 1975; Yankel et al., 1977; Roberts et al., 1974). In Belgium, Roels et al. studied children of several age groups over a period of years during which smelter Pb aerosol emissions were nearly eliminated. However, soil and dust Pb remained Pb-enriched. Roels et al. (1980) reported that blood Pb quickly fell in teen-agers and adults when air Pb fell; however, blood Pb fell only slightly in young children, demonstrating the predominance of ingestion of soil and dust Pb rather than inhalation of aerosol Pb.

In 1974, Needleman and Shapiro reported unusual tooth Pb and blood Pb levels in a group of parochial school children in Philadelphia who attended a school near a factory which emitted Pb. Dust in the playground and school was very rich in Pb. Children with low Pb exposure at home had high Pb exposure through soil and dust at school, and consequently had higher body burden of Pb. The Omaha, Nebraska (Angle and McIntire, 1979) and Arnhem, Netherlands

(Brunekreef, et al., 1981) Pb studies, where smelters are an important source, also found soil and housedust Pb were a very important source of Pb-exposure.

Methods were developed to better estimate Pb exposure via housedust. In one approach, Vostal et al. (1974) and Sayre et al. (1974) used a alcohol towelette or "wipe" to wash children's hands or house surfaces to estimate the quantity of Pb per hand or per ft² surface of floor, wall, or windowsill. Baker et al. (1977) used preweighed cotton balls, and Lepow et al. (1974) used preweighed adhesive labels to obtain weighed samples of dust, and could thus estimate Pb concentration in surface dust. As will be shown below, both results are important.

It became evident that house or hand dust Pb was related to blood Pb in some children (Lepow et al., 1975; Sayre et al., 1974). Charney (1982), Duggan (1983), and NRC (1980) have summarized these data. Independently, Shellshear (1973), and Shellshear et al. (1975) came to a similar conclusion, and connected the soil and dust Pb exposure to exterior paint. Children who played in high Pb soils, or who had pica for Pb-enriched soils, had higher blood Pb. Many specific cases of soil Pb as the source of Pb poisoning have been noted, again often for soils enriched in Pb from exterior paints (Orton, 1970; Fairey and Gray, 1970; Galke et al. 1977; Wedeen et al., 1978; Mielke et al., 1984; Stark et al., 1982; Charney et al., 1980; Hardy et al., 1971). Yaffe et al. (1983) connected the paint-to-soil-to-blood pathway with Pb isotope ratios (sites studied appear to have had low automotive Pb exposure). Of course, some to much of the Pb in housedust can come from automotive exhaust and fine particulate paint residues (e.g. Sayre and Katzel, 1979), and much of the effect of auto Pb emissions is believed to result through dust or soil ingestion (Millar and Cooney, 1982).

Another argument supporting Pb in soil and dust as one Pb source for children is recent examination of Pb in feces. When paint chip Pb was still a frequent cause of Pb poisoning, X-ray examination of intestines or feces revealed many opaque chips. The paint chips were not completely disintegrated during digestion. The massive educational program about paint chip Pb greatly reduced the incidence of overt Pb poisoning. A recent re-examination of fecal Pb found a relatively even distribution rather than discrete chips in most cases (Hammond et al., 1980). This indicates a fine particle size Pb source, such as Pb in soil and dust.

As will be discussed below, absorption of Pb from urban soil and dust depends on 1) nutritional factors; 2) amount of soil and dust Pb ingested, and 3) concentration of Pb in the ingested soil and dust. This severely complicates attempts to correlate exposure and blood Pb! Blood Pb depends on many socioeconomic factors, factors which affect nutritional status, child supervision, and housedust Pb levels (Charney et al., 1980; Stark et al., 1978; 1982)

One of the most important new findings is the report of Charney et al. (1983). Controlling housedust by regular cleaning reduced dust Pb per unit surface area, and also significantly lowered blood Pb in children living in these cleaner homes. Cleanliness is important when one lives in a Pb-rich environment where soil and dust Pb can be an important Pb exposure source. In the recent Yaffe et al. (1983) study, poor plumbing caused housedust Pb levels to be very high, which in turn contributed to the raised blood Pb in children.

The quantitative relationships between Pb concentration in housedust, amount of housedust Pb/unit surface area, and blood Pb levels vary among study populations depending on other Pb sources, and human behavior. Among the child specific factors which affect these studies were: Did parents make children wash their hands before eating? Did children suck their thumb or fingers? Did children play in Pb rich soils? Did parents clean the home regularly? Several research groups have attempted to use multiple regression analysis to relate the many "exposure" factors to blood Pb (Charney et al., 1980; Angle and McIntire, 1979; Stark et al., 1982; Yankel et al., 1977; Galke et al., 1977). The child specific factors caused a low correlation for the population studied, and R^2 for multiple regression equations has varied from 11 to over 50%. The low blood Pb relationship to soil Pb reported by Barltrop et al. (1975), may have resulted from local cultural factors (cleaning, hand washing, nutrition), since other populations have higher blood Pb per unit dust Pb exposure (Duggan, 1983).

Potential Health Effects of Ingested Pb.

Children with high blood Pb can experience anemia, because Pb interferes with insertion of iron into heme. Pionelli et al. (1982) recently reported that this interference begins at about 16.5 μg Pb/dL blood, lower than the average blood Pb in urban children. Then Zn-protoporphyrin accumulates, and this allows the inexpensive and convenient fluorescence screening method used in childhood Pb-poisoning prevention programs. Greater exposure, common when children eat chips of Pb-rich paint, can cause many symptoms (EPA, 1977; NRC, 1980). Encephalitis may develop, and this often causes death or severe mental retardation.

At the blood levels commonly found in urban children today, a new Pb health effect has been identified. By analyzing Pb in baby teeth, researchers were able to connect behavior problems in schools to historic Pb exposures. Blood Pb represents Pb absorption over about a 4 week period, and usually does not remain high in school age children who can be given psychological tests even though these children may have had higher blood Pb at ages 1-5. Needleman et al. (1980) found lower IQ and neurobehavioral impairment in children with high tooth Pb levels. Other populations have been studied with similar results (Winneke et al., 1981, 1982; Yule et al., 1981; Bellinger and Needleman, 1983). However, the U.S. government has not yet recognized these apparent effects of Pb as health effects of excessive Pb ingestion. When these are finally recognized, the urban soil Pb contamination problem will finally have to be solved.

POTENTIAL HEAVY METAL PHYTOTOXICITY IN URBAN GARDENS

If a plant root absorbs too much of an element, it can cause yield reduction or even death of the plant. This is called phytotoxicity. Some elements (Mn, Al) are normally present in soils, and can cause phytotoxicity only if soil pH falls below 5.2-5.5. Vegetable crops are especially sensitive to metals in acid soils, and soil pH should be between 6.5 and 7 for optimum yield of most vegetable crops. Of all the elements likely to pollute soils, Zn, Cu, and Ni are the only elements which have caused phytotoxicity in practice.

Metal sources which are more likely to supply enough Zn, Cu, or Ni to cause phytotoxicity if soil pH is low includes smelters, mining wastes, high metal content sewage sludges, galvanized fences and paint debris. The soil conditions which favor phytotoxicity are low pH, low organic matter, or low C.E.C. Dicotyledenous vegetable crops are the most sensitive; leafy vegetables are the most sensitive subgroup. If phytotoxicity is occurring, the seedling youngest leaves are chlorotic (yellow); this is an iron deficiency caused by the metals. The roots often grow through the toxic soil layers and plants green-up and grow normally later in the season. If one sees the young leaves yellow symptom, a soil test for pH and metals is appropriate.

Gardeners can identify this problem by getting their soil tested. If the soil is acid, or if moderate levels of metals are present, one may have to add enough limestone to achieve pH 7 or higher. Gardeners with highly metal enriched soil (due to sludge, smelters, or mining wastes) have suffered phytotoxicity even at pH 7 because the soil metals were very high (Davies et al., 1981; Davies and Ginnever, 1979; Chaney et al., 1981).

Phytotoxicity is an uncommon problem in gardens. Additional information can be obtained in Logan and Chaney (1984), Foy et al. (1978), or Chaney et al. (1978). With soil test results, Extension personnel can provide specific advice to gardeners.

EXPOSURE TO HEAVY METALS IN URBAN SOILS.

Introduction

The word garden has different meanings in the U.K. and U.S. In the U.K., "garden" is nearly equivalent to the U.S. use of the word "yard" (i.e. grass and ornamental non-food crops). In the U.S., "garden" is used to describe vegetable and flower gardens. Similarly, the British word "allotment" means the assigned area in a community vegetable garden in U.S. English.

Because of the inadvertent soil ingestion by children, Pb contamination of any soil where people walk, play, work, or garden is important. Phytotoxic levels of metals are important for any crops, while Cd is especially important in vegetable gardens.

Many different sources can contribute heavy metals to garden or yard soils. This review can not be comprehensive, but significant sources are noted to alert researchers and garden advisors of problems to be aware of in any site under consideration for gardening. A soil test is the best way to assure freedom from metal problems (see below).

Heavy Metal Levels in Baltimore Gardens

Baltimore Survey. We undertook a survey of heavy metal levels in gardens in Baltimore because: 1) we believed that the safety of garden crops could be evaluated more reliably if we knew the metal concentration in urban garden soils; 2) we were concerned about Pb ingestion by children resulting from family gardening; 3) we believed sources of metals could be identified if multielement analyses (fingerprinting) were conducted; 4) we hoped patterns of pollution within a city would help identify sources and aid Extension agents in advising gardeners in the need for soil analysis; and 5) we believed

advisory programs in other cities could learn from the experiences of a research study, and thus survey their city patterns at lower cost.

Mielke had been collecting soils for several years to study biogeography of metal pollution in cities. Students in his biogeography classes collected garden soil samples and obtained information about gardening practices and environmental data. Further samples were collected to fill in the city-wide survey, especially the inner-city neighborhoods where the Baltimore Urban Garden Program was cooperating with gardeners. As we learned more, we sampled other specific point sources.

We initially expected to use a computer mapping technique such as SYM-IAP, used by Davies and Roberts (1978) to describe the patterns of metal levels in Northeast Clwyd, Wales, resulting from historic mining and smelting activities. However, our sample points did not adequately resemble a grid pattern to allow valid use of SYM-IAP. Thus Mielke et al. (1983) evaluated the results of garden soil samples (0-20 cm) using a new technique which estimates the probability of the observed distribution occurring by chance alone. Table 4 reports the statistical distribution of these results. Between 7 and 15% of gardens contained enough Pb (500-1000 ppm) to warrant specific advice to the gardener about Pb.

Table 4. Statistical Distribution of Heavy Metal Concentrations^Z in 422 Garden Soils in Baltimore, Maryland (Mielke et al., 1983).

	Pb	Cd	Zn	Cu	Ni	pH
Mean	354	1.2	211	25	4.9	6.3
Std. Dev.	870	1.7	375	23	7.9	0.8
Minimum	1.0	0.02	0.3	0.7	0.5	4.1
10th	14.5	0.12	10.6	5.4	0.8	5.1
20th	21.4	0.19	18.8	7.4	1.4	5.5
30th	35.0	0.29	33.4	10.2	1.7	5.8
40th	55.5	0.41	55.6	13.4	2.4	6.1
50th - median	100.	0.56	92.	17.2	2.8	6.3
60th	167.	0.82	152.	22.6	3.5	6.5
70th	258.	1.33	212.	29.3	4.4	6.7
80th	421.	1.83	326.	41.1	5.5	6.9
90th	778.	3.17	521.	63.4	8.4	7.2
Maximum	10900.	13.6	4880.	96.7	53.4	8.2
Probability of clustering by chance	10-23	10-18	10-19	10-15	10-18	0.39

^Z Metals extracted using 1N HNO₃, 5g/50mL, 1 hr shaking procedure.

Table 5 shows the effect of distance from the city center on Pb levels in garden soils. The mean Pb level fell with distance, but some very high garden soils Pb levels were found to at least ten miles out. Davies (1978) and Davies et al. (1979) noted the effect of "years of residence", and distance from the center of London on Pb concentration in soils. These data indicate that human activities result in the addition of Pb to soils over time. "Distance from the city center" is similar to "time of residence" in relation to soil Pb accumulation because of the automotive exhaust and paint residues which are the dominant Pb sources.

The Pb mean for our survey was higher than some others because we included the more highly polluted inner-city gardens. If we had separated the inner-city community gardens into individual garden plots, our means would have been even higher (each garden location was sampled by compositing many subsamples for that whole garden area).

Table 5. Effect of Distance From the Center of Baltimore on Lead Concentration in Garden Soils ².

Distance miles	Number	Mean	Min	Max
0-3	103	964	26	10900
3-5	112	319	11	4990
5-7	99	256	11	7820
7-10	61	70	10	958
10+	101	36	1	382

² Based on same data reported by Mielke et al., 1983.

Variability Within Gardens. Table 6 shows results for detailed sampling of three gardens. The gardens were marked into a 3 meter-by-3 meter grid pattern, and a bucket auger (a point sample) of soil was collected at the intersections of the grid. These gardens were community gardens on lots where buildings had been demolished. These results point up the difficulty of sampling urban gardens due to extreme variability. One can only afford so much testing, and we would recommend that gardeners have at least 2 samples analyzed per garden. Each sample should represent half the area, and be composited from about 20 subsamples evenly spaced in the half garden.

Not only is sampling difficult, but so is interpretation. If 20% of the points in an urban garden are over 1000 ppm Pb, but the average is less than 500 ppm, what advice should be given? If children play in soil at the high Pb points, they could be at risk. At this time, there is no comfortable answer for this problem. Hopefully, public health officials will address the risk of variable garden soil Pb since they must deal with the much worse case of houseside soils where the Pb remains highly concentrated in the surface 0-2 cm of soil. In gardens, metals are mixed into the tilled layer, 0-20 cm deep, and diluted compared to roadside or houseside surface soils.

Table 6. Variability of heavy metal concentrations within individual urban gardens.

	Garden A			Garden B	Garden C
	Pb	Zn	Cd	Pb	Pb
No. Samples	111	110	110	72	63
mean, ppm	740	404	2.45	626	261
C.V., %	56.2	58.2	60.5	70.3	207
geo. mean, ppm	626.	340.	2.06	508	171
median, ppm	640	362.	2.16	525	152
min., ppm	100	70.5	0.48	70	57
max., ppm	2040	1260.	9.53	2440	4080
% over 500 Pb	66.4	-	-	51.4	4.8
% over 1000 Pb	25.2	-	-	16.7	1.6

For Garden A: $Cd = -0.335 + 0.00693 Zn$ $r^2 = 81.0\%$
: $Cd = -0.944 + 0.00456 Pb$ $r^2 = 61.1\%$
: $Zn = -111. + 0.693 Pb$ $r^2 = 66.5\%$

Sources of Metals in Urban Soils

Natural Occurrence. Naturally metal-enriched soils occur at the earth's surface in specific locations, usually over ore bodies or down the hydrologic gradient from ore bodies. The practice of biogeochemical prospecting depends on this enrichment in heavy metals. Generally speaking, these soils are a very minor source of heavy metal exposure for the U.S. population. Specific examples of Zn, and Cu enriched soils are well known by phytotoxicity limitation of crop growth. Some local areas are so contaminated with Pb or Cd that human risks soil Pb ingestion and garden crop Pb and Cd were assessed, (Davies and Ginnever, 1979; Barltrop et al., 1975; Davies et al., 1979). Most of these sites have been mined at some time in history with much greater dispersal of the metals.

One area of the United States has local Cd enrichment of appreciable concern for gardeners. Soils influenced by Monterey Shale in California contain Cd at 2 to 20 times normal levels (Lund et al., 1981; Burau, 1980; Golling, 1983). This geochemical source is extremely unusual, because it is highly enriched in Cd without corresponding enrichment in Zn. Nearly every natural Cd occurrence is a Pb, Zn, or Ag ore body; Cd is usually 0.4 to 3.0% of the Zn level present. However, the Monterey Shale derived soils with high Cd have Cd/Zn ratios commonly above 10%. This high Cd/Zn ratio allows much higher crop Cd to be reached before Cd or Zn phytotoxicity becomes evident than with other Cd sources.

This geochemical anomaly extends at least from the Malibu Canyon area in Los Angeles, through San Louis Obispo, the Salinas Valley, and into Santa Cruz County. The northern area is generally higher in Cd and more acidic than the

more southern areas. Golling (1983) reported a community garden with up to 55 ppm Cd in leafy vegetables. Crop Cd was greatly reduced by adding limestone to this garden.

Perhaps the best survey of heavy metals in U.S. soils was conducted as part of a USDA-FDA-EPA survey of Pb and Cd in raw agricultural products and associated soils in the United States. Table 7 shows the statistical distribution of soil metal levels. The median soil Pb was only 11 ppm (mean = 18 ppm), difficult to find within several km of cities. The highest levels of Pb are for orchard soils; of Cd, for the California geochemical anomaly; and of Cu, for Cu amended peat soils. Comparison of results such as these is another approach to estimation of normal soil Pb, etc. Davies (1983) used a traditional geochemical graphical estimation procedure to separate normal and metal enriched soils. Davies indicates that soil Pb is statistically unusual when in excess of 110 ppm, while nearly 99% of U.S. cropland soils are below this level.

Table 7. Statistical Distribution of Heavy Metal Concentration in 3001 Surface (Ap) Samples of U.S. Cropland Soils (Holmgren et al., 1983).

	Cd	Zn	Pb	Cu	Ni	pH	Org-C	CEC
	ppm	ppm	ppm	ppm	ppm		%	meq/100g
Mean	0.272	57.6	17.7	29.9	24.3	6.25	4.27	26.7
Stand. Dev.	0.257	39.7	93.3	41.5	28.2	1.08	9.58	37.7
Minimum	.005	<3	0.2	<0.6	<0.6	3.9	0.08	0.3
1%	.005	<3	3.	1.3	2.0	4.3	0.23	1.2
5%	.035	7.3	4.	3.7	3.8	4.6	0.37	2.3
10%	.050	11.8	5.	5.3	5.6	4.9	0.46	3.4
25%	.105	28.3	7.0	10.2	9.9	5.4	0.68	7.7
50% = median	.20	54.	11.	18.7	18.6	6.1	1.09	14.4
75%	.34	77.	16.	30.6	27.6	7.1	2.02	25.8
90%	.57	106.	21.	63.	40.3	7.9	7.24	48.5
95%	.78	129.	26.9	96.	58.7	8.1	33.5	136.
99%	1.30	189.	120.	213.	154.	8.3	41.9	171.
Maximum	2.30	402.	3503.	735.	269.	8.9	63.0	204.

Pesticides. Pb, As, and Cu pesticides were applied to many orchards or vineyards until about 1950. Some old commercial orchards with high soil metal levels have been converted to housing developments. In the U.S. soil metal survey (Table 7), the higher Pb and Cu levels came from Pb and Cu pesticides used in apple orchards, and Cu used as a fertilizer and pesticide on potato or organic soils.

Merry et al. (1983), Veneman et al. (1982), Kenyon et al. (1979), and Elfving et al. (1978) each report on metal levels in old orchard soils. These sources will be hard to identify except by soil analysis because orchards are not reported in land records.

Smelters. Pb, Zn, and Cu smelters can emit high amounts of Pb, Zn, Cu, Cd, and As which can contaminate nearby soils. Kuo et al. (1983) reported metals in gardens in Ruston, WA, near a large Cu smelter. Phytotoxic levels of Cu and high levels of Zn, Cd, and As had accumulated. Health officials have advised gardeners in that area to add limestone to garden soils, and require developers to remove the contaminated surface soil when new homes are constructed.

Lagerwerff et al. (1973) reported Pb, Zn, and Cd levels in soils and crops near a Pb smelter in Kansas. Smelter emissions have enriched crop Pb, etc., near many Pb-smelters (Roberts et al., 1974; Tiller et al., 1976; Beavington, 1975; Keizer et al., 1982; Linzon et al., 1976; Wesolowski et al., 1979), but soil and dust Pb is probably of greater risk to children. Besides the smelter emissions, Dorn et al. (1975) and Hemphill et al. (1973) noted that ore concentrates can be wind-blown at a smelter or during transit to a smelter, and contaminate vegetables and soils. Rabinowitz and Wetherill (1972) measured Pb isotope ratios for gasoline and smelter emissions, and could measure both sources enrichment of pasture grass, soil, and horses.

Zn-smelters emit large amounts of Zn and Cd, but usually too little Pb to cause health problems. Landrigan and Baker (1981) and Hartwell et al. (1983) report soil Zn or Cd levels near several smelters. Beyer (1983) described several studies at the Palmerton, PA, Zn smelter. Chaney et al. (1981) found that gardens in Palmerton contained about 10,000 ppm Zn and 100 ppm Cd (Table 8); all gardeners had experienced Zn phytotoxicity, and had used large amounts of limestone and manure to increase garden productivity. Most gardens had become calcareous due to limestone application. Crop Cd was significantly higher than normal foods, but no appropriate research has yet been conducted to test for chronic health effects of Cd in Palmerton gardeners (requires analysis of Cd in kidneys or analysis of urine for B₂-microglobulin). Palmerton has recently been designated a Superfund site, and these analyses will be conducted to assess the need for remedial measures.

Open hearth steel furnaces are also an important smelter type metal emission source (Jacko et al., 1976). Electrostatic precipitators remove much of the potential emissions (97.6 to 99.5%), but allow metal rich particulates to be released (1.82% Pb, 11.2% Zn, and 426 ppm Cd). Scrap steel is often metal plated or galvanized, providing the Cd, Zn, and Pb which are vaporized in the furnaces.

Many cities have had Zn, Cd, or Pb smelters in the past, and soils remain highly contaminated. Little effort has been made to disclose these locations, test for residual garden metal contamination, or provide site specific advice. However, information on these locations can be found in reports to EPA and the older literature.

Refuse Incinerators. Research on aerosol emissions of refuse incinerators have shown this source to be the major source of Zn and Cd in urban air (Greenburg et al., 1978, 1979). Auto Pb accounts for about 90% of aerosol Pb, while incinerators make up 10%. Law and Gordon (1979) calculated that pre-separation of metals from the refuse before incineration would substantially reduce Zn, Cd, and Pb emissions. The burnable fraction of refuse (call Refuse-Derived-Fuel, or RDF) is being used as a fuel for power generation. Jackson and Ledbetter (1977) found Pb and Zn emissions from power

TABLE 8. Summary of Heavy Metal and pH Analyses of Palmerton Area Garden Soils (0-15 cm) Sampled in September 1980.

Area	n	pH in Soils		Cd in Soils mg/kg		Zn in Soils mg/kg		Cd/Zn Ratio %		Pb mg/kg	Cu mg/kg	Ni mg/kg
		Mean	Range	Mean	Range	Mean	Range	Mean	Range	Mean	Mean	Mean
Palmerton 1	7	6.5	5.9-7.0	58.	38-87	3530	1920-5030	1.7	1.13-2.53	205	40.5	2.51
Palmerton 2	6	6.6	5.9-7.7	43.	18-84	2990	1420-4240	1.4	1.15-1.99	192	51.2	2.56
Palmerton 3	10	6.8	6.2-7.8	107.	38-130	7530	1440-10200	1.5	1.32-2.67	370	78.0	2.74
Palmerton 4	6	7.1	6.7-7.6	84.	70-113	8880	3200-13100	1.1	0.71-2.22	359	57.8	6.12
Aquashicola 5	6	6.7	6.1-7.2	69.	74-108	5460	1690-9050	1.7	0.75-2.80	218	40.7	4.32
Bowmanstown 6	9	6.3	5.3-7.2	10.1	7-16	884	525-1440	1.2	0.85-1.68	279	47.3	6.37
Rural 7	6	5.6	5.0-6.0	9.3	4-15	334	170-545	2.7	2.05-3.51	38	10.0	7.62
"Median U.S."	-	6.1		0.20		54				11	19	19

near the source, and 1.0-2.0 kg, and 1.0-2.0 kg, respectively).

Table 9 shows the concentration of metals in particulates emitted by incinerators with modern pollution control devices. The Zn and Cd concentrations are very high, and the particles emitted are so small they remain suspended and mix in the general aerosol rather than contaminate nearby soils.

Roadside Soils. Automobiles emit Pb. Roadside soils can reach high Pb levels in the surface few cm, but crop contamination is of much greater importance. Automobile Pb emissions contain about 40% Pb (EPA, 1977). Pb concentration in the "dust" from parking garages averaged 4.6% Pb (Harrison, 1979). The Pb level in "street dirt" at the gutter (500-2000 ppm Pb) varies with traffic density, and with varied amounts of Pb and of "dirt" at each location. Lau and Wong (1982) compared metals in street dust and roadside soils, and found a poor relationship between Pb in roadside soil and Pb in street dust, although Pb concentration in both was significantly correlated with traffic density. Actually, cities appear to have a Pb pollution halo in surface soils where deposited automobile Pb declines with distance from the city center (Gulson et al., 1981). Lagerwerff and Specht (1970) extended the roadside pollution model to Cd, Zn, and Ni. Automotive emissions are not very rich in Zn and Cd since tire wear particulates are large enough to settle out on the roadway or very near to the road (Table 10).

Table 9. Concentration of metals in particulate emissions from three refuse incinerators (Greenberg et al., 1978) compared to a coal-fired power plant (Klein et al., 1975).

Element	Concentration in Particulates	
	Incinerators ^{1/}	Power Plant
Pb, mg/g	81. ± 11.	0.65
Zn, mg/g	120. ± 10.	5.9
Cd, mg/kg	1500. ± 400.	51.
Cu, mg/kg	1700. ± 300.	-
Ni, mg/kg	150. ± 60.	-
Fe, mg/g	6.5 ± 2.9	150.

^{1/} Emissions were 0.46, 2.8, and 4.0 kg/Mt refuse incinerated.

Table 10. Extractable metals in surface (0-15 cm) soils enriched by selected metal sources (Chaney and Mielke, unpublished).

Sample	Pb	Zn	Cd	Cu
Roadside Soil ^{1/}	725	20	0.8	4.
Houseside Soil ^{2/}	10600	550	1.3	90.
Burn Pile Garden ^{3/}	3930	2950	13.4	179.

^{1/} Collected at 3m from the edge of Route 1 at the Beltsville Agricultural Research Center front lawn.

^{2/} Collected within 1 m of a 100-year-old Pb-painted wooden house.

^{3/} Trash burn pile converted to vegetable garden.

can slowly agglomerate and settle to become urban soil and dust, or can be scrubbed from the air by vegetation and building surfaces. These particulates are called the "general urban aerosol", reflecting the many sources which contribute particles small enough to remain suspended and move around the city. Researchers have attempted to estimate the portion of the total metal level present in urban aerosols which is due to specific sources.

Deposition of air pollutants can supply substantial amounts of metals over a period of years. The problems from urban air even move into remote forested areas. Siccama and Smith (1978) found 0.32 kg Pb/ha/yr fell into an experimental forest in New Hampshire.

Hunt et al. (1971) measured metal deposition in residential, commercial, and industrial areas of 77 cities with 100,000 to 1,000,000 population. The geometric mean levels of deposition rates and concentration are shown in Table 11. Thus, approximately equal amounts of Pb and Zn occur in urban air settleable particulates.

Table 11. Geometric mean Pb, Zn, and Cd deposition and concentration in particulates in 77 midwestern U.S. cities (Hunt et al., 1971).

	<u>Residential</u>	<u>Commercial</u>	<u>Industrial</u>
<u>Amounts Deposited:</u>			
Pb g/ha/yr	629.	1530.	1180.
Zn g/ha/yr	691.	1130.	1510.
Cd g/ha/yr	4.8	7.6	9.0
<u>Concentration:</u>			
Pb ppm	1660	2340	1390
Zn ppm	1820	1730	1780
Cd ppm	12.7	11.6	10.6

Galloway et al. (1982) have recently reviewed the deposition of atmospheric heavy metals. Results such as those in Hunt et al. (1971) are commonly found in urban areas, with lower rates of deposition at more distant sites.

The levels of Pb and Zn in urban settled dust are commonly close, within a factor of 2. But automotive Pb emissions are not accompanied by much Zn. Hamerle and Pierson (1975) measured the levels of Pb, Zn, Br, etc. in air samples at Pasadena, CA every 2 hours for a month. Air was collected at 18.5 m above the street level, at least one mile from the nearest freeway. Pb and Br were highly correlated ($Br = -0.013 + 0.342 Pb$; $r = 0.983$), as were Pb and carbon monoxide. The Pb and Br were at ratios very close to that directly emitted by autos, showing that little time for Br loss and mixing with other air occurred before the air was sampled. The Zn and Pb were less well correlated, and Zn occurred at only 2% of Pb ($Zn = 0.033 + 0.020 Pb$; $r = 0.399$). The results for a roadside soil adjacent to a heavily traveled road (Table 10) also showed a low amount of Zn per unit Pb deposited. Thus,

automotive emissions do not account for the Zn (and Cd) in urban settled particulates.

Kowalczyk et al. (1978) estimated the contribution of coal power, oil power, refuse incineration, marine aerosol, soil, and motor vehicle exhaust to the element levels in the air in Washington, D.C. Motor vehicles provided about 94% of the Pb, and refuse incineration about 80% of the Zn and 88% of the Cd.

Other researchers have attempted to use other methods to identify the source of metals in urban soil and dust samples. As noted above, stable isotopes can be used to identify the Pb source if the sources had different enough isotope ratios. Smelter and automotive sources were traced by Rabinowitz and Wetherill (1972). Gulson identified auto exhaust Pb in soils surrounding Adelaide, Australia. And Yaffe et al. (1983) traced paint Pb to soils to housedust to blood of children, and discriminated between paint and auto Pb sources. These findings required that other Pb sources did not contribute enough Pb to confound the analyses.

Another approach was used by University of Illinois researchers. Solomon and Hartford (1976) characterized large amounts of Pb and Cd in settled dust around and in middle class domiciles. They found high concentrations of Pb adjacent to non-painted commercial buildings. They show a generalized map of an urban lot and house with levels of Pb in the dust and soil, with high levels near the road and near the house. All the homes studied were in good repair with low Pb levels in exterior paint.

Linton et al. (1980) used a combination of techniques (particle size; particle density; and particle ferromagnetism) to separate settled dusts into fractions and analyzed many elements in the fractions. They identified fractions characteristic of auto exhaust Pb and paint chip Pb from samples of street dust (9000 ppm Pb) and dust adjacent to a house with painted window frames (11,000 ppm Pb). They calculated that automotive exhaust contributed 10-20% of the Pb in the houseside dust sample. They further studied fractionated particles using scanning electron microscopy and X-ray analysis. These techniques identified auto exhaust particles rich in Pb, Br, and Fe, and paint chip particles rich in Pb, Ti, and Al. Automotive particles were clearly present in the houseside soils.

These findings strongly support the data and conclusion of Rolfe and Haney (1975) that building surfaces scrub particulates from the air (or slow air movement and allow particles to settle out). Rainfall or humans then wash particulates from the walls, and metals accumulate in the houseside soil and/or dust.

Data from Mielke et al.'s (1984) recent studies in Minneapolis also support this model (Table 12). Part of the homes had exterior painted surfaces, while others were unpainted brick or stucco. Soil Pb (0-5 cm) was about twice as high beside the painted houses, but both were sufficiently elevated to be cause for concern for children playing in the soil. The higher traffic and housing density, and shorter distance from house to streets in urban areas studied by Mielke et al. (1984), appear to provide the higher levels of Pb in inner-city houseside soils than the lower density residential areas studied by Rolfe and Haney (1975), Solomon and Hartford (1976), and Linton et al. (1980).

Table 12. Pb levels in surface (0-5 cm) soil adjacent to painted and non-painted domiciles in Minneapolis (Mielke et al., 1984).

Percentile	Painted Homes (24)	Non-painted Homes (20)
0	475	130
25	737	384
50	938	526
75	1253	965
100	6150	1840

These research findings illustrate further the difficulty of identifying sources for metals in urban soils. Soils near intense metal sources (roads, smelters, Pb-painted surfaces) may have a predominant source. But the continuing settling out and adsorption of small particulates from the many sources in urban areas will add metals to all soils, especially houseside soils. Patterns of air and pollutant movement in urban areas are so complex that one cannot quantitatively predict soil metal levels. However, these sources have very likely caused excessive metal accumulation in soils in the central urban areas of every city to levels already dangerous to children exposed to these soils and dusts (National Research Council, 1980; EPA, 1977).

Exterior Paint and Building Demolition Residues. Two related pollution sources strongly affect urban soils. Building demolition residues influence most large urban community gardens since these are usually established on cleared lots. When buildings burn and/or are demolished, any items of value are usually recovered. Thus, wood, metal, and often bricks are removed from the site. However, the paint and plaster are often left at the site, combined with the soil remaining or with some added fill dirt, and leveled to become the new lot.

Surface soil adjacent to an exterior surface covered with Pb-paint becomes enriched with Pb. Perhaps the most detailed study was that of Jordan and Hogan (1975) who sampled soils both with distance from the house and road, and with depth from the soil surface. Unless soils are tilled or mixed with depth, deposited Pb remains in the surface few cm. Paint Pb enrichment can reach to several meters from the painted surface, but soil Pb is highest near the wall.

Other researchers have looked at exterior paint as a Pb source for soils: Ter Haar and Aronow (1974), Hardy et al. (1971), Bertinsson and Clark (1973), Spittler and Feder (1979), Fairey and Gray (1970), Galke et al., (1977), and Preer et al. (1980c, 1984). Houseside soil Pb is a function of exterior construction type and painting (Jordan and Hogan, 1975). Houseside soil Pb is also a function of age of the domicile or of the paint used. Stark et al. (1982) show a pronounced effect of decade of construction, which correlates fairly well with Pb levels used in paints. Within a few years, paint chips are degraded by soil microorganisms and the pigment particles become part of the soil fine particles (Spittler and Feder, 1979).

Automobile Pb emissions can also contribute to houseside soil Pb, and dominates at the street side of a lot. Some aerosol Pb is adsorbed on the walls and roof of a domicile. Rainfall washes this Pb into the soil. Houses with exterior paint with low Pb concentrations have a few hundred ppm Pb in houseside soil (Rolfe and Haney, 1975). Soil can be substantially enriched in Pb at downspouts which discharge roof runoff (see section on metals in urban air).

The relative contribution of paint and automotive emissions to houseside Pb varies with site specific conditions. In our judgment, if soil samples (to 20 cm) contains over 500 ppm Pb, paint was very likely a major contributor. For shallower samples of unmixed soils, higher levels are needed to indicate paint Pb. The very high Pb levels seen in many inner city gardens could not have come from automotive emissions. A recent paper (Yaffe, et al., 1983) reports Pb isotope ratios for soil, exterior paint, aerosol deposits, and children's blood. These data indicate that houseside soil Pb, which largely came from exterior paint, was the major source of Pb in the blood of children with excessive blood Pb (air Pb was a minor source in their research.)

Another type of paint Pb is the primer used on metal surfaces. The primer is called "red lead", and contains over 50% Pb. When metal surfaces are scraped or sandblasted prior to repainting, extreme local Pb pollution occurs. Dust accumulated in the roof gutter across from a water tower being sandblasted in Battle Creek, MI, contained over 20% Pb. These paint residues usually are high enough in Pb to be declared "hazardous waste", but paint removal is seldom monitored by local government.

Municipal Sewage Sludge. Sludges are applied to cropland as N or P fertilizer, as Fe, Zn, or Cu fertilizer, and as a soil conditioner. Sludge application on cropland has come under EPA Regulation starting in 1979 (US-EPA, 1979), and some states have more conservative and more complete regulations. Regulation is needed because sludges may contain pathogenic organisms (bacteria, virus, and intestinal parasite ova). All sludges contain heavy metals, with some highly enriched by industrial discharge into the sewers. Table 13 shows the range of metal concentrations found in sludges, median levels, and maximum levels for domestic sludge (Logan and Chaney, 1984). The potential for creating excessive soil metal levels is very high when highly polluted sludges are utilized, and private users are advised to utilize only domestic quality sludges.

Two types of metal risks have been identified: 1) phytotoxicity from sludge Zn, Cu, or Ni, and 2) excessive Cd in food-chain crops. Advisory programs were established by USDA and most State Universities to prevent these potential problems. Based on research, metal loading limits were developed to protect cropland productivity and food safety. These recommendations (Table 14) have been incorporated into many State regulatory programs, although only the Cd limits are part of EPA regulations. Rather than Cd, cumulative Zn or Cu applications usually limit the amount of sludge which may be applied to a field under most regulatory programs.

The Cd limits were based on a worst case model of a gardener who: grows 50% of his garden foods; has the allowed maximum 5.0 kg Cd/ha in the garden soil; continuously has very acidic pH (5.5 or below); uses the garden from birth to age 50; and the individual is part of a sub-population especially sensitive to Cd exposure. Logan and Chaney (1984) note that individuals who

TABLE 13. Concentrations of selected trace elements in dry digested sewage sludges^{1/}.

Element	Reported Range		Typical Median Sludge	Typical Soil	"Maximum Domestic Sludge"
	min.	max.			
As, ppm	1.1	230.	10.	-	-
Cd, ppm	1.	3,410.	10.	0.1	25.
Cd/Zn, %	0.1	110.	0.8	-	1.5
Co, ppm	11.3	2490.	30.	-	200.
Cu, ppm	84.	17,000.	800.	15.	1000.
Cr, ppm	10.	99,000.	500.	25.	1000.
F, ppm	80.	33,500.	260.	200.	1000.
Fe, %	0.1	15.4	1.7	2.0	4.0
Hg, ppm	0.6	56.	6.	-	10.
Mn, ppm	32.	9,870.	260.	500.	-
Mo, ppm	0.1	214.	4.	-	25.
Ni, ppm	2.	5,300.	80.	25.	200.
Pb, ppm	13.	26,000.	500.	25.	1000.
Sn, ppm	2.6	329.	14.	-	-
Se, ppm	1.7	17.2	5	-	-
Zn, ppm	101.	49,000.	1700.	50.	2500.

^{1/} Composting using wood chips as a bulking agent generally produces composted sludge 50% as high in trace elements as a digested sludge from the same treatment plant.

TABLE 14. Recommended maximum cumulative sludge metal applications for privately-owned cropland.

Metal	Soil Cation Exchange Capacity		
	0-5	5-15	> 15 meq/100g
	maximum application, kg/ha		
Zn	250	500	1000
Cu	125	250	500
Ni	50	100	200
Cd	5	10	20
Pb	500	1000	1000

1. Annual Cd application should not exceed 2 kg/ha from dewatered or composted sludge, or 1 kg/ha from liquid sludge; sludge should not supply more crop available nitrogen than the crop requires.
2. Sludges with Cd over 25 ppm should not be applied unless the Cd/Zn is less than 0.015; if Cd/Zn exceeds 0.015, an abatement program to reduce sludge Cd should be initiated.
3. These recommendations apply only to soils that are adjusted to pH 6.5 or over when sludge is applied, and are to be managed to pH 6.2 or over thereafter.
4. Tobacco cropland should not receive sewage sludge application.
5. The cation exchange capacity is for unamended soil.
6. Soil Pb should not exceed 500 ppm after maximum cumulative sludge applications.

grow 50% of their garden foods learn about soil pH and maintain pH near 6.5 or above, greatly reducing Cd in foods. Under these regulations, individuals are highly protected from sludge-applied Cd and using low Cd sludges adds further protection (see also Ryan et al., 1982).

The remaining problem regarding sludge is that sludges have been historically given to gardeners who wanted organic fertilizers. Most sludges were low in Cd and other metals, but too many were very high. Soil analysis can identify soils with Cd concentrations (over 2.5 ppm in acidic gardens) which exceed present EPA regulations.

One sludge give-away program involved the high Cd "Nu-Earth" sludge from Chicago. As many as 100,000 gardens were affected before EPA stopped this program. Lettuce growing in a number of Nu-Earth amended and control gardens was sampled, and excessive Cd was found in the lettuce grown in Nu-Earth treated soils (Table 15). Lettuce Cd could have been much higher if these soils had been acidic. Products given to homeowners in truck load lots are especially likely to be applied at excessive rates. In research on long-term sludge utilization farms, Chaney and Hornick (1978) found sludges with over 1000 ppm Cd were given to gardeners in several cities in Pennsylvania. These programs were stopped when health officials learned of these practices.

On the other hand, many sludges can be applied at fertilizer rates for centuries before the maximum metal application limits are reached. Use of low metal sludges has been found to comprise far lower risk of phytotoxicity or

Table 15. Effect of Chicago's Nu-Earth sewage sludge on Cd in alkaline garden soils and lettuce.^{1/}

Garden	Soil ^{2/}		Leaf Lettuce	
	Cd, ppm	pH	Cd, ppm	
Control			Dry	Wet
A	<1	8.2	0.57	0.03
B	<1	7.2	<0.5	<0.02
C	2	7.8	0.63	0.04
D	<1	8.1	1.4	0.06
mean	0.9	7.8	$\bar{x} = 0.7$	0.04
Nu-Earth				
E	27	7.4	35.	1.5
F	37	8.1	19.	0.73
G	26	7.3	15.	0.75
H	24	8.6	14.	0.79
I	14	7.3	5.8	0.24
J	23	7.1	14.	0.80
K	94	7.3	44.	3.4
mean	37	7.6	21.	1.17

^{1/} Conducted by EPA, Region V, in 7/79. Nu-Earth was generally applied 3-4 years before lettuce was sampled.

^{2/} Soil collected along row of lettuce.

excessive plant Cd even when equal amounts of metals are applied (e.g. Table 16). The sludge adds organic matter, clay, and iron oxides to soil which help adsorb the sludge applied Cd, and reduce plant uptake (Chaney et al., 1982; Logan and Chaney, 1984). EPA, FDA, and USDA (1981) prepared a Policy Statement on use of high quality sludge in production of fruits and vegetables, and noted that crops grown with good practices have no more Cd or Pb than normal crops.

Composted sewage sludge is becoming an article of commerce in several states. Composting technology to assure proper stabilization and complete pathogen kill was developed by USDA (Willson et al., 1980). Thus, no waiting period is needed between application of approved sludge composts and growing crops eaten uncooked (a waiting period is required when sludges do not receive a Process to Further Reduce Pathogens, such as composting). A USDA bulletin describes methods to use compost safely and effectively (Hornick et al., 1984). Composted low metal domestic sludge can also be used very effectively in media to grow transplants and bedding plants (Sterrett et al., 1983; Chaney et al., 1980).

Composted municipal refuse, with or without sludge addition to improve composting, is a common soil amendment in Europe. Composting costs compared to landfill costs has discouraged refuse composting in the U.S. If low metal sludges are used to make the mixed compost, crops remain low in metals (Hoffmann and Schweiger, 1983). If high metal sludges or refuse is used, compost may not be safe for use on cropland or gardens. Regulations are

Table 16. Effect of sludge quality and soil pH on microelement concentrations in Romaine lettuce grown in 1983.

Treatment	Sludge Rate	Soil pH	Pb	Cd	Zn	Cu	Ni	Mn
	Mt/ha		-----mg/kg dry weight-----					
Control	0	5.3	3.0 abc	0.76 e	56	11.0	1.6	267
Control	0	6.2	4.5 a	0.90 e	37	10.3	1.1	124
Control	0	7.4	3.1 abc	0.54 e	28	11.4	0.9	42
A	448	7.7	1.9 c	0.81 e	38	12.0	0.7	33
B	224	7.7	3.3 abc	0.61 e	43	11.6	1.4	35
C	224	6.2	2.0 c	1.01 e	82	10.1	1.2	85
C	224	5.3	2.1 c	2.10 de	191	10.7	3.7	271
D	672	7.3	1.9 c	0.60 e	52	12.3	1.0	41
E	45	6.8	2.5 bc	8.39 cd	90	11.4	2.4	72
E	45	5.6	2.3 bc	15.7 b	197	13.2	6.6	138

Sludges A-E contained 4.9, 5.9, 13.4, 7.2, and 210 ppm Cd, and 215, 217, 369, 272, and 865 ppm Pb. A, B, C, and D applied in 1976; E, in 1978. Soil pH obtained for soil where lettuce grew; collected in October 1983. Soil is Christiana fine sandy loam.

needed for refuse compost similar to those used in some states for composted sludges.

Other Sources. Numerous other metal sources can contaminate garden soils directly or indirectly. The list shown here have been noted by various authors as sources of metal pollution.

Metal plated tools, fences, tomato cages, electric power towers, etc., contaminate soils slowly but surely. Galvanized fences often develop a no vegetation zone in acid soils as soil Zn near the fence kills plants. Soils used for community gardens under an electric power right of way were highly Zn enriched (low Cd/Zn ratio) near the towers (Jones, 1983). Sometimes Cu from electric wires enriched soils with Cu, but Cu phytotoxicity has not been reported.

We also looked at plastic covered steel wire. The plastic is PVC, and for several commercial fences, the PVC was Cd stabilized. Polyethylene and polypropylene materials were low in metals. One can use ordinary concrete reinforcing wire (made from steel) for tomato cages rather than galvanized wire; the steel wire may rust, but can function for over 10 years.

Wood ashes were traditionally dumped in the garden because wood ashes are a rich K fertilizer, and can increase the permeability of clayey soils. These ashes can be high in Pb, Zn, Cd, Cr, and other elements if the wood was painted. Revived usage of wood stoves in the U.S. has encouraged burning waste wood; some is painted and these ashes may be very rich in Pb. Bonfires also often use waste painted wood and leave a contaminated soil. Home rubbish burn piles are very metal enriched. We found a home where, after a few years, the burn pile was used for gardening since it was so "black and rich looking". This soil contained over 5000 ppm Pb, and high Zn and Cd. Some individuals burn rubber tires, and end up with Zn toxic soil since rubber contains 0.5 to 4% Zn. Others burn the covering from Cu wire to recycle the copper; soils can become Cu toxic from this practice. Used motor oil has often been burned or simply dumped on soils. Used motor oil is very high in Pb, and contains a Zn compound as a lubricant.

Newspaper is often used as a mulch in gardens. Until recently, most color printed paper contained Pb, Cr, and Zn pigments (Eaton et al., 1975; Elfving et al., 1979). Even now, more expensive color printing often contains metal pigments. However, the old advice "don't use color-printed newspaper pages" is no longer necessary. The industry has stopped using metal colors, and uses non-toxic organic colors which can be readily reproduced across the country. They stopped using Pb and Cr because of potential toxicity to workers and children. Thus newspaper pages can be safely used as mulch, but advertising circulars and magazines still should not be.

Organic amendments can be a source of metal pollution. The most obvious is sewage sludge discussed above. No one should use a sludge material unless it is approved for home use by the State Health and Environmental Departments. Sludges had been used as a component of a few other commercial organic fertilizers. A few states now regulate all use of sludge, but most do not and the Federal government has not yet adopted regulations for the distribution and marketing of sludge products. Maryland, Virginia, Ohio, and a few other States enforce effective regulations on these practices.

In addition to sludge, another often metal-enriched organic amendment is leaf compost. Urban tree leaves have relatively high Pb levels, especially near the street. Leaves are often gathered by local governments at the curb where street dust high in Pb is also collected. Hornick et al. (1980) noted high Pb levels (300 ppm) in leaf compost. In suburban areas home made leaf, lawn clipping, and garden trash compost is a wonderful low metal organic amendment if street sweepings are not included (usually below 10 ppm Pb). These composts can be amended with limestone and chemical fertilizer to obtain optimum conservation of organic matter and good fertility.

Manure is usually a low metal organic amendment. However, near cities with smelters, manures are heavily contaminated and should not be used. Some modern swine and poultry feeding programs incorporate high levels of Cu and Zn to increase feed use efficiency, and generate manure with as much Cu as sewage sludge (Mullins et al., 1982).

In some cities, storm run-off water is channeled from the streets to runoff ponds where the water slowly percolates to a stream and sediment is collected on the surface soil. Because street dust is metal rich, the soil in runoff ponds is metal rich. In New York City, a "topsoil" purveyor was selling soil from runoff ponds; this "topsoil" contained 400-700 ppm Pb (personal communication, K. K. A. Davies).

Even limestone and phosphate fertilizers can be rich in metals. In Pennsylvania and Tennessee, limestone is a byproduct of Zn ore enrichment. The "Horsehead" limestone at Palmerton contains about 2500-4580 ppm Zn, 3.6-8.4 ppm Cd, and 2-41 ppm Pb. Some Pb ores also generate waste limestone which can cause Pb, Zn, and Cd enrichment. Western phosphate resources are often quite enriched in Cd (Wakefield, 1980). There are no regulations on maximum levels of Pb, Zn, or Cd allowed in limestone or P fertilizers. Nearly all limestone and P-fertilizer now used in the U.S. is low in metals and completely safe for use in gardens. We believe some disclosure should be made to potential purchasers when these amendments are rich in metals.

BIOAVAILABILITY OF FOOD AND SOIL LEAD

After Pb is ingested, it can only produce health effects if it is absorbed. A major aspect of childhood Pb poisoning is the 50% absorption of ingested Pb by susceptible children. Adults usually absorb less than 5% of dietary Pb, but can absorb a higher percentage if iron deficient. Thus both dietary factors and Pb-source factors may affect whether a particular level of ingested Pb is of health significance.

Factors Affecting Pb Absorption by Animals.

Researchers have examined dietary factors which affect Pb absorption. Mahaffey (1983) has recently summarized these findings. Low Fe status causes greater Pb absorption (see also Flanagan et al., 1979). Low Ca status increases both Pb absorption and relative distribution of Pb between soft tissues (kidney, blood, etc.) and bone, the normal sink for absorbed Pb. Diets low in calories, protein, Zn, and vitamin C, or high in fat tend to increase Pb absorption. Chisolm (1981) has recently noted interactions among Pb, Zn, and Fe in children.

These results complicate any attempt to evaluate the bioavailability of Pb from an environmental source. Further, when rats are fed a nutritionally adequate purified diet, Pb absorption is much greater than when the same amount of Pb is fed in rat chow. Kostial and Kello (1979) found that the bioavailability of Pb added to many human foods was like that of Pb added to purified diets. Although Pb in paints containing Pb pigments was bioavailable to rats fed rat chow, Pb octoate was not (Mylroie et al., 1978); when Pb octoate was added to a purified complete diet, Pb was readily absorbed. Rat chow contains high levels of Fe, Ca, and fiber compared to National Research Council specified complete purified diets for rats.

Bioavailability of Pb in Soil and Dust.

Three research studies on bioavailability of soil or dust Pb have been reported. Dacre and Ter Haar (1977) added Pb acetate, roadside soil (2300 ppm Pb), or houseside soil (990 ppm Pb) at about 50 ppm added Pb to a lab chow type diet for rats, and fed it for 30 or 90 days. Pb in bone and kidney indicated that soil Pb was significantly, but slightly less bioavailable than Pb acetate; soil averaged about 70% as available as Pb acetate.

Stara et al. (1973) reported studies on bioavailability of street dust Pb using a quite different approach, and using purified diets. Bone and blood Pb reached much higher levels, and dust Pb was about as bioavailable as Pb acetate. Relative bioavailability was not computed.

In research at Beltsville, we collected soil from 5 urban gardens and compared these with control soil and Pb acetate in a rat feeding experiment (Table 17). A complete purified casein-sucrose diet was used, and all Pb sources were added at 50 mg Pb/kg dry diet. Addition of 5% uncontaminated soil to the Pb acetate diet reduced bone Pb by 47%, probably by adsorbing Pb in the intestine. The bioavailability of garden soil Pb varied from 16 to 70% that of Pb acetate; bone Pb for 2 soils were not significantly different than the control, while the highest soil Pb was 70% of, and significantly less than, Pb acetate.

Although much more research is needed, it appears that the bioavailability of soil Pb is related to the concentration of Pb in the soil. One would have predicted this result based on metal adsorption chemistry. Perhaps this double relationship -- higher Pb ingested per unit soil ingested, and higher Pb bioavailability at higher soil Pb -- contribute to the general conclusion that soil and dust Pb begin to significantly contribute to blood Pb when the Pb concentration in the soil or dust exceeds 500 to 1000 ppm (EPA, 1977; NRC, 1980; Stark et al., 1982). Certainly the socioeconomic and cultural factors affecting child nutrition can affect the potential blood Pb level of children living in environments with high soil and dust Pb.

METHODS FOR SOIL METAL ANALYSIS

Traditionally, two general types of soil analysis have been used in agriculture. The first is total metals, with use of strong oxidizing acids plus HF to dissolve silicates. The second is plant available metals, in which any extractant can be used if plant uptake correlates well with extractable soil metals. These total metals methods require special facilities and safety procedures, and are expensive. Plant-available metal extracts often require special equipment, but use mild reagents with little need for special safety procedures.

Table 17. Effect of Soil on Availability of Pb to Rats, and Bioavailability of Pb in Urban Garden Soils. (Levander, Welsh, Chaney, Mielke, and Leech. Unpublished).

Diet ^{1/}	Pb in Tibia				% of Pb Acetate
	mg/kg tibia ash <u>±</u> S.E.				
Basal	0.3	<u>±</u>	0.3	e ^{2/}	-
Basal + 5% Soil ^{3/}	0.0	<u>±</u>		e	-
Basal + Pb Acetate	247.	<u>±</u>	10.1	a	100
Basal + Pb Acetate + 5% Soil ^{3/}	130.	<u>±</u>	29.5	bc	53
Basal + 706 ppm Pb Soil	40.0	<u>±</u>	6.1	de	16
Basal + 995 ppm Pb Soil	108.	<u>±</u>	26.3	c	44
Basal + 1078 ppm Pb Soil	37.1	<u>±</u>	7.3	de	15
Basal + 1265 ppm Pb Soil	53.6	<u>±</u>	7.4	d	22
Basal + 10240 ppm Pb Soil	173.	<u>±</u>	21.8	b	70

^{1/} Fed to Fisher rats for 30 days. A purified casein-based complete diet was fed; Pb acetate and garden soils were added to supply 50 mg Pb/kg dry diet.

^{2/} Means followed by the same letter are not significantly different (P 0.05) according to Duncan's Multiple Range Test.

^{3/} Unpolluted farm soil near Beltsville, MD, similar to original soil in the urban gardens used in this trial.

Analysis of urban soils, on the other hand, must address the important risk of soil ingestion, not just plant uptake of Pb. Although soil factors which affect bioavailability of soil Pb to animals have not been well characterized, it is clear that the acid environment of the mammalian stomach can readily dissolve soil Pb (Day et al., 1979). Thus, existing research supports the need to use a total method for Pb, the most important health risk metal in urban soils. Other elements are important in relation to food chain contamination (Cd), or phytotoxicity (Zn, Cu, Ni). However, total analyses for these elements plus soil pH provide sufficient information to allow extension service personnel to prepare the needed advice for citizens requesting soil tests. Preparation of a soil extract is often the most expensive part of soil metal analysis, so it is important that soil total Pb, Cd, Zn, Cu, and Ni, plus soil pH provides sufficient diagnostic information. Soil testing labs could add this test to their routine testing for pH, fertility, and lime requirement.

Early in our research program, we recognized the need to identify economically feasible, convenient, and safe soil analysis methods which provided useful soil total Pb. Lagerwerff et al. (1973) and others have used 1N HCL, and 0.1 N HCl had been used to measure plant available metals in many states. However, when extracting soils with very high Pb levels, we found that the limited solubility of PbCl₂ could lead to underestimation of soil Pb compared to hot HNO₃, or 1 N HNO₃. John (1971) had used a 1 N HNO₃, 2g soil/10mL, 30 min. extraction to evaluate soil Pb.

We also learned that within sample variability could be a problem in analyzing urban soils. Roadside soils, after crushing and sieving to less than 2 mm (normal preparation for agricultural soil analysis), have a low coefficient of variation because the Pb source is finely divided. The Pb has accumulated over many years and has equilibrated with the soil. Similar low variation is seen in smelter polluted soils, and sludge amended soils after several years. However, houseside soils, or especially soils contaminated by building demolition wastes, contain particulate paint chips. During sieving, one sees and crushes the paint chips to pass the 2 mm sieve. For several years, one can still see the color of the paint in the chips. The Pb-rich particulates cause an intolerable coefficient of variation if small soil samples are required for the method of analysis to be used. Most total methods use small samples, and scientists have ground and/or sieved soils, street dust, etc. to very small particle size before analysis (Day, 1977; Day et al., 1975; Tinsley et al., 1983; Jones and McDonald, 1983).

Thus, we designed a soil total metal analysis method appropriate for analyses of urban gardens and other urban soils (Chaney et al., 1981). We used 5 g of air dry soil crushed to pass a 2 mm sieve, plus 50 mL of 1 N HNO_3 . The slurry is shaken in an oscillating, a wrist-action, or a reciprocating shaker for 1 hr. Although any clean glass or plastic container could be used, we found that disposable plastic 4 oz. urine specimen containers with screw cap lids were a very convenient and inexpensive container with no need for acid washing before use. The 5 g/50 mL was selected to provide adequate acid to acidify nearly every conceivable soil, and to provide a filtered solution which allows atomic absorption analysis across a wide range (use turned atomic absorption burner and/or less sensitive lines for analysis of very high soil Pb), while low or normal soils are easily identified. A 500 ppm soil Pb yields 50 ppm Pb in the filtered solution (5g soil/50mL acid); this solution would give over 1.0 absorbance at the 217 nm line (0.2 absorbance at 5 ppm with unturned burner), or about half this absorbance at the 283.3 nm line used in Pb analysis. Very high Zn levels have to be diluted since no alternative line with lower sensitivity is available.

To test this method, and compare it with other methods commonly used for total or available metals, we analyzed 7 soils with quite different properties (5 were urban garden soils from Baltimore). The methods and results are shown in Table 18. The Pb concentration found in a hot HNO_3 extract (comparable to Preer et al., 1980; Davies, 1983) is considered the real total Pb result. The concentration found for the other methods is shown as % of the hot HNO_3 method. Our 1N HNO_3 method gave nearly 100% of total for all soils, while X-ray fluorescence conducted by volunteers in Boston was more variable. The DTPA methods gave about 20% of total and were variable, while the 0.1 N HCl and 0.5 M acetic acid methods extracted about 50% and 10%, respectively, of total Pb except for the soil containing CaCO_3 which neutralized the dilute HCl. The 0.05 M EDTA method developed in Britain for soil Cu, etc., and used by Davies (1978) and Davies et al. (1979) to analyze garden soils, extracted about 70% of total Pb. Thus, either a hot HNO_3 extract or our 1N HNO_3 extract can successfully and reliably be used to measure total Pb and identify high Pb soils which could be dangerous to children.

Other researchers have compared methods of analysis. Nicklow et al. (1981) hoped to use the "Morgan soil test solution" (pH 4.8 Na acetate) used to measure plant available nutrients in several States, and analyzed 161 soils

Table 18. Relative extraction of soil Pb by several methods from soils with varied properties.

METHOD		-----mg Pb/Kg dry soil-----						
1	4N HNO ₃ , 100°, 16 hr	15.1 ^Z	371 ^Y	433 ^Y	1440 ^Y	6250 ^Y	673 ^Y	123 ^X
		----- % of Method 1 -----						
"Total" Methods								
2	1 N HNO ₃ , 5g/50 mL, 1 hr	77	106	95	93	83	97	96
3	Dry Ash 500°, HNO ₃ , HCl	103	131	98	128	91	110	93
4	X-ray Fluorescence	290	102	68	56	62	88	85
"Available" Methods								
5	DTPA 15g/30 mL, 2 hr	30	23	25	30	8	16	8
6	DTPA 5g/50 mL, 2 hr	21	27	25	35	16	15	8
7	0.1 N HCl 5g/50 mL, 2 hr	41	81	73	74	44	45	4
8	0.05 M EDTA, British	37	82	69	83	41	67	43
9	0.5 M acetic acid, British	61	7	4	12	12	5	6

^Z unpolluted farm soil near Beltsville, MD.

^Y urban garden soils from Baltimore, MD.

^X Christiana sl + 300T composted limed raw sludge/A.

by both Morgan test and x-ray fluorescence. An equation was developed relating these results, but the Morgan test dissolved too little and too variable Pb to be used in an urban soil analysis program. Veneman et al. (1982) subsequently compared our 1N HNO₃ method, a 1N HCl method, a HNO₃-HClO₄ method, and a HNO₃-HClO₄-HF total soil method on Pb contaminated orchard soils. The slopes for the regression of the result for the extraction procedures vs the total method were 1.01, 1.00, and 0.94, respectively, with each having a correlation coefficient over 0.99. Weak acid (1 N HNO₃) methods can not dissolve any metals present in the silicates (which can be dissolved by HF methods), and may not dissolve CuS (which is dissolved by hot HNO₃).

Thus, at least two approaches to urban soil analysis meet the requirements: hot HNO₃ digestion, and our 1.0 N HNO₃, 5 g/50 mL, 1 hr extract. We believe this method can be used safely by relatively untrained personnel, and is inexpensive. The least expensive method of multi-element elemental analysis is plasma emission spectrometry, a relatively new analytical technique in which many elements are analyzed on a single sample during about 1 minute of aspiration. Plasma emission has a very wide working concentration range compared to atomic absorption, and the multiple metal analyses can be obtained at lower cost than with atomic absorption. Boon and Soltanpour (1983) used a modified DTPA extract to evaluate silver mining waste polluted soils in Aspen, Colorado, and found plasma emission to be convenient and inexpensive. The modified DTPA extract Pb gave a good correlation with plant uptake of Pb, but was not appropriate for total soil Pb risk to

children. This new elemental analytical technique can be easily used on either diluted hot HNO_3 digests or 1N HNO_3 extracts of urban soils, and is the lowest cost analytical method yet identified (lowest cost per sample, but the instrument is much more expensive than atomic absorption).

RECOMMENDATIONS FOR LIMITING HEAVY METAL EXPOSURE FROM URBAN GARDEN SOIL AND CROPS.

Urban gardeners need to consider both automotive Pb emissions, and heavy metals in their soil from various other sources. Government could help solve the urban soil pollution problem and prevent it from recurring. Certainly enough research information exists to provide the information/methods to prevent further Pb-poisoning, etc., due to historic metal pollution of urban soil and dust. The following advice summarizes best practices developed in Boston, MA, (McDonough, 1979) and other available information.

First, there are the general things an individual can do to protect his/her family:

- 1) Prevent pica by children;
- 2) obtain soil test for garden or suspect polluted play areas;
- 3) provide children a balanced diet with adequate Fe and Ca.

If you grow food crops in a garden:

- 1) Grow leafy and root vegetables at least 50-100 ft from busy streets;
- 2) wash all vegetables to remove soil and dust; peel root crops; discard older or outer leaves during food preparation;
- 3) control soil pH near 6.5-7.0; add limestone and organic matter;
- 4) if near very heavy traffic, use tall hedges or fences to reduce Pb fallout.

If your garden soil analysis indicates Pb is over 500-1000 ppm:

- 1) Replace contaminated soil if possible;
- 2) use mulch to reduce soil splash on crops;
- 3) wash childrens' hands, reduce house dust, and reduce hand-to-mouth play of young children.
- 4) take care to prevent bringing soil into the house on clothes and shoes.

If soil test is very high in Pb:

- 1) Replace or cover soil;
- 2) plant bare areas with grass;
- 3) using deep tillage to lower Pb concentration may be a suitable alternative if removal of soil is not possible.

Local government could also help citizens protect themselves and their families from heavy metals in urban soil. Educational programs could be offered to teach safe gardening practices, and on the risks of Pb in soil and dust, including housedust. The removal of Pb from gasoline could be completed to alleviate this part of the Pb risk. Useful soil tests could be offered at the local health department, or at the Land Grant College or University (which usually offer soil fertility tests already). Surveys could be conducted to establish patterns of metal contamination in cities or larger areas (Culbard et al., 1983).

Government agencies could help provide methods to alleviate the urban soil heavy metal problem: 1) help identify and replace contaminated soil; 2) change zoning to remove demolition debris and contaminated soil and replace with 12 inches of uncontaminated soil; and 3) determine city wide patterns of metal pollution and advise local citizens of need for precautions. Although some of these may be expensive, the potential cost to society of a Pb-injured child is also very expensive. Citizens may have to communicate their concerns so these problems can be solved soon, before more children are exposed to urban Pb.

Several states have prepared Extension Service advisory leaflets regarding lead and gardening in urban areas (e.g. McDonough, 1979; Davies, 1978; McClurg et al., 1979). These provide many of the recommendations noted above. Popular publications have reported these concepts and recommendations (Anonymous, 1981; De Crosta, 1981; Silverman, 1984). Interested gardeners can contact their local Extension Service representative for advice on this and other gardening advice.

ACKNOWLEDGEMENT.

We gratefully acknowledge our collaborators and our colleagues with whom we discussed research interpretations (N. Beyer, B. E. Davies, W. A. Feder, S. B. Hornick, O. A. Levander, J. C. Patterson, J. P. Preer, S. O. Welsh), and the technical staff who performed most of the research summarized in this paper (C. E. Gifford; M. M. Leech; C. A. Lloyd; P. T. Hundemann; M. C. Morella; and P. J. Mastradone). Pam King and other Baltimore Urban Garden Program Extension Staff were especially helpful in obtaining urban garden samples and information from gardeners. Our urban garden research was supported by the Small Farm Research Program of the USDA-ARS-Northeast Region.

References

- Angle, C. R. and M. S. McIntire. 1979. Environmental lead and children: The Omaha, Nebraska, USA study. *J. Toxicol. Environ. Health* 5:855-870.
- Anonymous. 1981. Children, Gardens, and Lead. *Mother Earth News* 70:38-41.
- Archer, A., and R. S. Barratt. 1976. Lead levels in Birmingham dust. *Sci. Total Environ.* 6:275-286.
- Baker, Jr., E. L., D. S. Folland, T. A. Taylor, M. Frank, W. Peterson, G. Lovejoy, D. Cox, J. Housworth, and P. J. Landrigan. 1977. Lead poisoning in children of lead workers. Home contamination with industrial dust. *New Engl. J. Med.* 296:260-261.
- Barltrop, D., C. D. Strehlow, I. Thornton, and J. S. Webb. 1975. Absorption of lead from dust and soil. *Postgrad. Med. J.* 51:801-804.
- Baumhardt, G. R. and L. F. Welch. 1972. Lead uptake and corn growth with soil-applied lead. *J. Environ. Qual.* 1:92-94.
- Beavington, F. 1975. Heavy metal contamination of vegetables and soil in domestic gardens around a smelting complex. *Environ. Pollut.* 9:211-217.
- Bellinger, D.C., and H. L. Needleman. 1983. Lead and the relationship between maternal and child intelligence. *J. Pediatr.* 102:523-527.
- Bertinuson, J. R., and C. S. Clark. 1973. The contribution to lead content of soils from urban housing. *Interface* 2:6.
- Beyer, N. 1983. The smoke that settled over Palmerton. *New Jersey Audubon* 9(3):14-16.
- Biggins, P. D. E. and R. M. Harrison. 1979. Atmospheric chemistry of automotive lead. *Environ. Sci. Technol.* 13:558-565.
- Bogden, J. D., M. M. Joselow, and M. P. Singh. 1975. Extraction of lead from printed matter at physiological values of pH. *Arch. Environ. Health* 30:442-444.
- Boon, D. Y., and P. N. Soltanpour. 1983. The ammonium bicarbonate-DTPA soil test for determination of plant available lead, cadmium, and molybdenum in mine tailings and contaminated soils. *Agron. Abstr.* 1983:29.
- Brunekreef, B., S. J. Veenstra, K. Biersteker, and J. S. M. Boley. 1981. The Arnhem lead study. I. Lead uptake by 1 to 3-year-old children living in the vicinity of a secondary lead smelter at Arnhem, The Netherlands. *Environ. Res.* 25:441-448.
- Bureau, R. G. 1980. Current knowledge of cadmium in soils and plants as related to cadmium levels in foods. pp. 65-72. In *Proc. TFI Cadmium Seminar*, The Fertilizer Institute, Washington, D.C.
- Cannon, H. L. and J. M. Bowles. 1962. Contamination of vegetation by tetraethyl lead. *Science* 137:765-766.

- Carlson, R. W., F. A. Bazzaz, and J. J. Stukel. 1976. Physiological effects, wind reentrainment, and rainwash of Pb aerosol particulate deposited on plant leaves. *Environ. Sci. Technol.* 10:1139-1142.
- Chamberlain, A. C. 1983. Fallout of lead and uptake by crops. *Atmos. Environ.* 17:693-706.
- Chaney, R. L. 1980. Health risks associated with toxic metals in municipal sludge. pp. 59-83. In G. Bitton, et al. (eds.). *Sludge -- Health Risks of Land Application*. Ann Arbor Science Publ., Inc., Ann Arbor, MI.
- Chaney, R. L., W. N. Beyer, C. E. Hirsch, and L. Sileo. 1981. Heavy metals in soils, crops, and livestock near a zinc smelter at Palmerton, PA. Presented at Third Intern. Cadmium Conference, Miami, FL.
- Chaney, R. L. and S. B. Hornick. 1978. Accumulation and effects of cadmium on crops. pp. 125-140. In *Proc. First International Cadmium Conference*. Metals Bulletin Ltd., London.
- Chaney, R. L., P. T. Hundemann, W. T. Palmer, R. J. Small, M. C. White, and A. M. Decker. 1978. Plant accumulation of heavy metals and phytotoxicity resulting from utilization of sewage sludge and sludge composts on cropland. pp. 86-97. In *Proc. Natl. Conf. Composting Municipal Residues and Sludges*. Information Transfer, Inc., Rockville, MD.
- Chaney, R. L., J. B. Munns, and H. M. Cathey. 1980. Effectiveness of digested sludge compost in supplying nutrients for soilless potting media. *J. Am. Soc. Hort. Sci.* 105:485-492.
- Chaney, R. L., S. B. Sterrett, and C. H. Gifford. 1981. Heavy metal enrichment of urban soils: Sources and pathways to humans. *Agron. Abstr.* 1981:22.
- Chaney, R. L., S. B. Sterrett, M. C. Morella, and C. A. Lloyd. 1982. Effect of sludge quality and rate, soil pH, and time on heavy metal residues in leafy vegetables. pp. 444-458. In *Proc. Fifth Annu. Madison Conf. Appl. Res. Pract. Municipal and Industrial Waste*. Univ. Wisconsin - Extension, Madison.
- Charney, E. 1982. Lead poisoning in children: the case against household lead dust. pp. 79-88. In J. J. Chisolm and D. M. O'Hara (eds.) *Lead Absorption in Children: Management, Clinical, and Environmental Aspects*. Urban and Schwartenberg Press, Baltimore.
- Charney, E., B. Kessler, M. Farfel, and D. Jackson. 1983. A controlled trial of the effect of dust-control measures on blood lead levels. *N. Engl. J. Med.* 309:1089-1093.
- Charney, E., J. Sayre, and M. Coulter. 1980. Increased lead absorption in inner city children: where does the lead come from. *Pediatrics* 65:226-231.
- Chisolm, J. J., Jr. 1981. Dose-effect relationships for lead in young children: Evidence in children for interactions among lead, zinc, and iron. pp. 1-7. In D. R. Lynam, L. G. Piantanida, and J. F. Cole (eds.) *Environmental Lead*. Academic Press, New York.

- Cohen, C. J., G. H. Bowers, and M. L. Lepow. 1973. Epidemiology of lead poisoning. A comparison between urban and rural children. *J. Amer. Med. Assoc.* 226:1430-1433.
- Collet, P. 1978. Lead contamination of plants adjacent to highways and the protective influence of wind screens (in German). *Qual. Plant. - Pl. Fds. Hum. Nutr.* 28:187-194.
- Cox, W. J. and D. W. Rains. 1972. Effect of lime on lead uptake by five plant species. *J. Environ. Qual.* 1:167-169.
- Crump, D. R., and P. J. Barlow. 1982. Factors controlling the lead content of a pasture grass. *Environ. Pollut.* 83:181-192.
- Crump, D. R., P. J. Barlow, and D. J. VanRest. 1980. Seasonal changes in the lead content of pasture grass growing near a motorway. *Agric. Environ.* 5:213-225.
- Culbard, E., S. Mooncroft, J. Watt, I. Thornton, and J. F. A. Thomas. 1983. A nationwide reconnaissance survey of metals in urban dusts and soils. *Miner. Environ.* 5:82-84.
- Dacre, J. C. and G. L. Ter Haar. 1977. Lead levels in tissues from rats fed soils containing lead. *Arch. Environ. Contam. Toxicol.* 6:111-119.
- David, D. J. and C. H. Williams. 1975. Heavy metal contents of soils and plants adjacent to the Hume Highway near Marulan, New South Wales. *Aust. J. Exp. Agric. Anim. Husb.* 15(74):414-418.
- Davies, B. E. 1978. Plant-available lead and other metals in British garden soils. *Sci. Total Environ.* 9:243-262.
- Davies, B. E. 1983. A graphical estimation of the normal lead content of some British soils. *Geoderma* 29:67-75.
- Davies, B. E., D. Conway, and S. Holt. 1979. Lead pollution of London soils: A potential restriction on their use for growing vegetables. *J. Agric. Sci.* 93:749-752.
- Davies, B. E., and R. C. Ginnever. 1979. Trace metal contamination of soils and vegetables in Shipham, Somerset. *J. Agric. Sci.* 93:753-756.
- Davies, B. E., and R. C. Ginnever, and J. M. Lear. 1981. Cadmium and lead contaminated soils in some British metal mining areas. *Trace Substances Environ. Health* 15:323-332.
- Davies, B. E., and L. J. Roberts. 1975. Heavy metals in soils and radish in a mineralized limestone area of Wales, Great Britain. *Sci. Total Environ.* 4:249-261.
- Davies, B. E., and L. J. Roberts. 1978. The distribution of heavy metal contaminated soils in Northeast Clwyd, Wales. *Water, Air, Soil Pollut.* 9:507-518.

- Davies, B. E., and H. M. White. 1981. Trace elements in vegetables grown on soils contaminated by base metal mining. *J. Plant Nutr.* 3:387-396.
- Davies, K. A. A. 1978. Good gardening practices where lead is a concern. Suffolk County Extension Service, Boston, MA.
- Day, J. P. 1977. Lead pollution in Christchurch. *N.Z. J. Sci.* 20:395-406.
- Day, J. P., J. E. Fergusson, and T. M. Chee. 1979. Solubility and potential toxicity of lead in urban street dust. *Bull. Environ. Contam. Toxicol.* 23:497-502.
- Day, J. P., M. Hart, and M. S. Robinson. 1975. Lead in urban street dust. *Nature* 253:343-345.
- DeCrosta, T. 1981. How heavy metals pollute our soils -- Lead and especially cadmium are poisoning home grown produce. *Organic Gardening*, June 1981, pp. 72-81.
- Dolcourt, J. L., H. J. Hamrick, L. A. O'Tuama, J. Wooten, and E. L. Baker, Jr. 1978. Increased lead burden in children of battery workers: asymptomatic exposure resulting from contaminated work clothing. *Pediatrics* 62:563-566.
- Dorn, C. R., J. O. Pierce, G. R. Chase, and P. E. Phillips. 1975. Environmental contamination by lead, cadmium, zinc, and copper in a new lead-producing area. *Environ. Res.* 9:159-172.
- Duggan, M. J. 1983. Contribution of lead in dust to children's blood lead. *Environ. Health Perspect.* 50:371-381.
- Eaton, D. F., G. W. A. Fowles, M. W. Thomas, and G. B. Turnbull. 1975. Chromium and lead in colored printing inks used for children's magazines. *Environ. Sci. Technol.* 9:768-770.
- Edwards, W. C., and B. R. Clay. 1977. Reclamation of rangeland following a lead poisoning incident in livestock from industrial airborne contamination of forage. *Vet. Human Toxicol.* 19:247-249.
- Egan, D. A., and T. O'Cuill. 1970. Cumulative lead poisoning in horses in a mining area contaminated with Galena. *Vet. Rec.* 86:736-738.
- Elfving, D. C., C. A. Bache, and D. J. Lisk. 1979. Lead content of vegetables, millet, and apple trees grown on soils amended with colored newsprint. *J. Agr. Food Chem.* 27:138-140.
- Elfving, D. C., W. M. Haschek, R. A. Stehn, C. A. Bache, and D. J. Lisk. 1978. Heavy metal residues in plants cultivated on and in small mammals indigenous to old orchard soils. *Arch. Environ. Health* 33:95-99.
- EPA-FDA-USDA. 1981. Land application of municipal sewage sludge for the production of fruits and vegetables. A statement of federal policy and guidance. U.S. Environmental Agency Joint Policy Statement SW-905. 21 pp.

- Ewing, B. B., and J. E. Pearson. 1974. Lead in the environment. *Adv. Environ. Sci. Technol.* 3:1-126.
- Fairey, F. S. and J. W. Gray, III. 1970. Soil lead and pediatric lead poisoning in Charleston, S.C. *S. Carolina Med. Assoc. J.* 66:79-82.
- Feder, W. A., R. L. Chaney, C. E. Hirsch, and J. B. Munns. 1980. Differences in Cd and Pb accumulation among lettuce cultivars, and metal pollution problems in urban gardens. Abstract. p. 347. In G. Bitton et al. (eds.). *Sludge-Health Risks of Land Application*. Ann Arbor Sci. Publ., Ann Arbor, MI.
- Fergusson, J. E., K. A. Hibbard, and R. L. H. Ting. 1981. Lead in human hair: General survey -- Battery factory employees and their families. *Environ. Pollut.* 82:235-248.
- Flanagan, P. R., D. L. Hamilton, J. Haist, and L. S. Valberg. 1979. Interrelationships between iron and lead absorption in iron-deficient mice. *Gastroenterol.* 77:1074-1081.
- Fries, G. F., G. S. Marrow, and P. A. Snow. 1982. Soil ingestion by dairy cattle. *J. Dairy Sci.* 65:611-618.
- Galke, W. A., D. I. Hammer, J. E. Keil, and S. W. Lawrence. 1977. Environmental determinants of lead burdens in children. *Proc. Int. Conf. Heavy Metals in the Environment.* III:53-74.
- Galloway, J. N., J. D. Thornton, S. A. Norton, H. L. Volchok, and R. A. N. McLean. 1982. Trace elements in atmosphere deposition: A review and assessment. *Atmos. Environ.* 16:1677-1700.
- Giguere, C. G., A. B. Howes, M. McBean, W. N. Watson, and L. E. Witherell. 1977. Increased lead absorption in children of lead workers -- Vermont. *Morbidity Morality Weekly Report* 26(8):61-62.
- Golling, R. C. 1983. Santa Cruz County soil cadmium study: The natural occurrence of high-cadmium soils and the levels of cadmium incorporated into associated field grown leafy vegetables. Santa Cruz County Planning Dept., Santa Cruz, CA.
- Greenberg, R. R., G. E. Gordon, W. H. Zoller, R. B. Jacko, D. W. Neuendorf, and K. J. Yost. 1978. Composition of particles emitted from the Nicosia municipal incinerator. *Environ. Sci. Technol.* 12:1329-1332.
- Greenberg, R. R., W. H. Zoller, and G. E. Gordon. 1978. Composition and size distributions of particles released in refuse incineration. *Environ. Sci. Technol.* 12:566-573.
- Gulson, B. L., K. G. Tiller, K. J. Mizon, and R. H. Merry. 1981. Use of lead isotopes in soils to identify the source of lead contamination near Adelaide, South Australia. *Environ. Sci. Technol.* 15:691-696.
- Hammerle, R. H. and W. R. Pierson. 1975. Sources and elemental composition of aerosol in Pasadena, Calif., by energy-dispersive X-ray fluorescence. *Environ. Sci. Technol.* 9:1058-1063.

- Hammond, P. B., C. S. Clark, P. S. Gartside, O. Berger, A. Walker, and L. W. Michael. 1980. Fecal lead excretion in young children as related to sources of lead in their environments. *Intern. Arch. Occup. Environ. Health* 46:191-202.
- Harbourne, J. F., C. T. McCrea, and J. Watkinson. 1968. An unusual outbreak of lead poisoning in calves. *Vet. Rec.* 83:515-517.
- Hardy, H. L., R. I. Chamberlin, C. C. Maloof, G. W. Boylen, Jr., and M. C. Howell. 1971. Lead as an environmental poison. *Clin. Pharmacol. Therap.* 12:982-1002.
- Harrison, R. M. 1979. Toxic metals in street and household dusts. *Sci. Total Environ.* 11:89-97.
- Hartwell, T. D., R. W. Handy, B. S. Harris, S. R. Williams, and S. H. Gehlbach. 1983. Heavy metal exposure in populations living around zinc and copper smelters. *Arch. Environ. Health* 38:284-295.
- Hassett, J. J., and J. E. Miller. 1977. Uptake of lead by corn from roadside samples. *Commun. Soil Sci. Plant Anal.* 8:49-55.
- Haye, S. N., D. J. Horvath, O. L. Bennett, and R. Singh. 1976. A model of seasonal increase of lead in a food chain. pp. 387-393. In D. D. Hemphill (ed.) *Trace Substances in Environmental Health - IX*. Univ. Missouri, Columbia, MO.
- Heichel, G. H. and L. Hankin. 1976. Roadside coniferous windbreaks as sinks for vehicular lead emissions. *J. Air Pollut. Contr. Assoc.* 26:767-770.
- Hemphill, D. D., C. J. Marienfeld, R. S. Reddy, W. D. Heilage, and J. O. Pierce. 1973. Toxic heavy metals in vegetables and forage grasses in the Missouri Lead Belt. *J. Assoc. Office. Anal. Chem.* 56:994-998.
- Hibben, C. R., S. S. Hagar, and C. P. Mazza. 1984. Comparison of cadmium and lead content of vegetable crops grown in urban and suburban gardens. *Environ. Pollut.* 87:71-80.
- Hoffmann, G., and P. Schweiger. 1983. Cd- and Pb-contents of vegetables grown on soils of former vineyards treated with municipal waste-compost. *Acta Horticulturae* 133:173-178.
- Holmgren, G. G. S., M. W. Meyer, R. B. Daniels, J. Kubota, and R. L. Chaney. 1983. Cadmium, lead, zinc, copper, and nickel in agricultural soils of the United States. *Agron. Abstr.* 1983:33.
- Hornick, S. B., J. C. Patterson, and R. L. Chaney. 1980. An evaluation of urban garden soil, vegetation, and soil amendments. In *Proc. Second Conf. Scientific Research in National Parks*. 3:158-167.
- Hornick, S. B., L. J. Sikora, S. B. Sterrett, J. J. Murray, P. D. Millner, W. D. Burge, D. Colacicco, J. F. Parr, R. L. Chaney, and G. B. Willson. 1984. Utilization of sewage sludge compost as a soil conditioner and fertilizer for plant growth. *USDA Agricultural Information Bulletin*. 26 pp. (In press).

- Hunt, W. F., Jr., C. Pinkerton, O. McNulty, and J. Creason. 1971. A study in trace element pollution of air in 77 midwestern cities. *Trace Substances in Environ. Health* 4:56-68.
- Jacko, R. B., D. W. Neuendorf, and F. Faure. 1976. Fractional collection efficiency of electrostatic precipitator for open hearth furnace trace metal emissions. *Environ. Sci. Technol.* 10:1002-1005.
- Jackson, J. W., and J. O. Ledbetter. 1977. Stack emissions from refuse-derived fuel admix to boiler coal. *J. Environ. Sci. Health* A12:465-473.
- John, M. L. 1971. Lead contamination of some agricultural soils in Western Canada. *Environ. Sci. Technol.* 5:1199-1203.
- Jones, R. 1983. Zinc and cadmium in lettuce and radish grown in soils collected near electrical transmission (hydro) towers. *Water, Air, Soil Pollut.* 19:389-395.
- Jones, L. H. P., S. C. Jarvis, and D. W. Cowling. 1973. Lead uptake from soils by perennial ryegrass and its relation to the supply of an essential element (sulphur). *Plant Soil* 38:605-619.
- Jones, K., and A. McDonald. 1983. The efficiency of different methods of extracting lead from street dust. *Environ. Pollut.* 86:133-143.
- Jordan, L. K., and D. J. Hogan. 1975. Survey of lead in Christchurch soils. *N.Z. J. Sci.* 18:253-260.
- Judel, G. K., and W. Stelte. 1977. Pot experiments on lead uptake by vegetable plants from the soil (in German). *Z. Pflanzenernahr. Bodenk.* 140:421-429.
- Keizer, M. G., M. Hooghiemstra-Tielbeek, and F. A. M. deHaan. 1982. Contamination of soil and street dust with lead and cadmium near a lead smelter at Arnhem, Netherlands. *Neth. J. Agric. Sci.* 29:227-235.
- Kenyon, D. J., D. C. Elfving, I. S. Pakkala, C. A. Bache, and D. J. Lisk. 1979. Residues of lead and arsenic in crops cultured on old orchard soils. *Bull. Environ. Contam. Toxicol.* 22:221-223.
- Klein, D. H., A. W. Andren, J. A. Carter, J. F. Emery, C. Feldman, W. Fulkerson, W. S. Lyon, J. C. Ogle, Y. Talmi, R. I. VanHook, and N. Bolton. 1975. Pathways of thirty-seven trace elements through coal-fired power plant. *Environ. Sci. Technol.* 9:973-979.
- Kneip, T. J. 1978. Concentrations of lead and cadmium in garden vegetables grown in New York City. *Proc. Toxic Element Studies -- Food Crops and Urban Vegetable Gardens.* Cornell University Extension Service, Ithaca, NY.
- Kostial, K., and D. Kello. 1979. Bioavailability of lead in rats fed "human" diets. *Bull. Environ. Contam. Toxicol.* 21:312-314.

- Kowalczyk, G. S., C. E. Choquette, and G. E. Gordon. 1978. Chemical element balances and identification of air pollution sources in Washington, D.C. *Atmos. Environ.* 12:1143-1153.
- Kuo, S., P. E. Heilman, and A. S. Baker. 1983. Distribution and forms of copper, zinc, cadmium, iron, and manganese in soils near a copper smelter. *Soil Sci.* 135:101-109.
- Lagerwerff, J. V., D. L. Brower, and G. T. Biersdorf. 1973. Accumulation of cadmium, copper, lead, and zinc in soil and vegetation in the proximity of a smelter. In D. D. Hemphill (ed.) *Trace Substances in Environ. Health* 6:71-78.
- Lagerwerff, J. V., and A. W. Specht. 1970. Contamination of roadside soils and vegetation with cadmium, nickel, lead, and zinc. *Environ. Sci. Technol.* 4:583-586.
- Landrigan, P. J., and E. L. Baker. 1981. Exposure of children to heavy metals from smelters: Epidemiology and toxic consequences. *Environ. Res.* 28:204-224.
- Landrigan, P. J., S. H. Gehlbach, B. F. Rosenblum, J. M. Shoults, R. M. Candelaria, W. F. Barthel, J. A. Liddle, A. L. Smrek, N. W. Staehling, and J. F. Sanders. 1975. Epidemic lead absorption near an ore smelter. The role of particulate lead. *New Engl. J. Med.* 292:123-129.
- Lau, W. M., and H. M. Wong. 1982. An ecological survey of lead contents in roadside dusts and soils in Hong Kong. *Environ. Res.* 28:39-54.
- Law, S. L., and G. E. Gordon. 1979. Sources of metal in municipal incinerator emissions. *Environ. Sci. Technol.* 13:432-438.
- Lepow, M. L., L. Bruckman, M. Gillette, S. Markowitz, R. Robino, and J. Kapish. 1975. Investigations into sources of lead in the environment of urban children. *Environ. Res.* 10:415-426.
- Lepow, M. L., L. Bruckman, R. A. Robino, S. Markowitz, M. Gillette, and J. Kapish. 1974. Role of airborne lead in increased body burden of lead in Hartford children. *Environ. Health Perspect.* 7:99-102.
- Linton, R. W., D. F. S. Natusch, R. L. Solomon, and C. A. Evans, Jr. 1980. Physiochemical characterization of lead in urban dusts. A microanalytical approach to lead tracing. *Environ. Sci. Technol.* 14:159-164.
- Linzon, S. N., B. L. Chai, P. J. Temple, R. G. Pearson, and M. L. Smith. 1976. Lead contamination of urban soils and vegetation from secondary lead industries. *J. Air Pollut. Contr. Assoc.* 26:650-654.
- Logan, T. J., and R. L. Chaney. 1984. Utilization of municipal wastewater and sludge on land -- Metals. pp. 235-326. In *Proc. 1983 Workshop on Utilization of Municipal Wastewater and Sludge on Land*. Univ. California, Riverside, CA.

- Lund, L. J., E. E. Betty, A. L. Page, and R. A. Elliott. 1981. Occurrence of naturally high cadmium levels in soils and its accumulation by vegetation. *J. Environ. Qual.* 10:551-556.
- MacLean, A. J., R. L. Halstead, and D. J. Finn. 1969. Extractability of added lead in soils and its concentration in plants. *Can. J. Soil Sci.* 49:327-334.
- Mahaffey, K. R. 1983. Biotoxicity of lead: Influence of various factors. *Fed. Proc.* 42:1730-1734.
- Mahaffey, K. R., T. A. Banks, C. L. Stone, S. G. Capar, J. F. Compton, and H. H. Gubkin. 1977. Effect of varying levels of dietary calcium on susceptibility to lead toxicity. *Proc. Intern. Conf. Heavy Metals in the Environment III*:155-164.
- McClurg, C. A., D. A. VanZandt, and V. A. Bandel. 1979. Coping with lead in the garden. *Univ. Maryland Coop. Ext. Serv. Leaflet* 135.
- McDonough, E. 1979. Heavy metals and the urban garden. *Brooklyn Botanic Record* 35 (Spring):62-64.
- Merry, M. H., K. G. Tiller, and A. M. Alston. 1983. Accumulation of copper, lead, and arsenic in some Australian orchard soils. *Aust. J. Soil Res.* 21:549-561.
- Mielke, H. W., J. C. Anderson, K. J. Berry, P. W. Mielke, R. L. Chaney, and M. Leech. 1983. Lead concentrations in inner-city soils as a factor in the child lead problem. *Am. J. Public Health* 73:1366-1369.
- Mielke, H. W., B. Lake, S. Burroughs, and N. Hassinger. 1984. Urban lead levels in Minneapolis: The case of the Hmong children. *Environ. Res.* 34: (In press).
- Millar, I. B. 1978. Monitoring of lead in the environment. *J. Epidemiol. Community Health* 32:111-116.
- Millar, I. B., and P. A. Cooney. 1982. Urban lead--A study of environmental lead and its significance to school children in the vicinity of a major trunk road. *Atmos. Environ.* 16:615-620.
- Miller, J. E., J. J. Hassett, and D. E. Koeppe. 1975a. The effect of soil properties and extractable lead levels on lead uptake by soybeans. *Commun. Soil Sci. Plant Anal.* 6:339-347.
- Miller, J. E., J. J. Hassett, and D. E. Koeppe. 1975b. The effect of soil lead sorption capacity on the uptake of lead by corn. *Commun. Soil Sci. Plant Anal.* 6:349-358.
- Mitchell, R. L. and J. W. S. Reith. 1966. The lead content of pasture herbage. *J. Sci. Food Agric.* 17:437-440.
- Motto, H. L., R. H. Daines, D. M. Chilko, and C. K. Motto. 1970. Lead in soils and plants: Its relationship to traffic volume and proximity to highways. *Environ. Sci. Technol.* 4:231-238.

- Mullins, G. L., D. C. Martens, W. P. Miller, E. T. Kornegay, and D. L. Hallock. 1982. Copper availability, form, and mobility in soils from three annual copper-enriched hog manure applications. *J. Environ. Qual.* 11:316-320.
- Mylroie, A. A., L. Moore, B. Olyai, and M. Anderson. 1978. Increased susceptibility to lead toxicity in rats fed semipurified diets. *Environ. Res.* 15:57-64.
- National Research Council. 1980a. *Lead in the Human Environment*. National Academy of Sciences, Washington, D.C. 525 pp.
- Needleman, H. L. 1980. Lead and neuropsychological deficit: Finding a threshold. pp. 43-51. In H. L. Needleman (ed.) *Low Level Lead Exposure: The Clinical Implications of Current Research*. Raven Press, New York.
- Needleman, H. L., C. E. Gunnoe, A. Leviton, R. Reed, H. Peresie, C. Mader, and P. Barrett. 1979. Deficits in psychologic and classroom performance of children with elevated lead levels. *N. Engl. J. Med* 300:689-695.
- Needleman, H. L., and I. M. Shapiro. 1974. Dentine lead levels in high and low risk groups. *Environ. Health Perspect.* 7:27-31.
- Nicklow, C. W., P. H. Comas-Haezelbrouck, and W. A. Feder. 1983. Influence of varying soil lead levels on lead uptake by leafy and root vegetables. *J. Amer. Soc. Hort. Sci.* 108:193-195.
- Nicklow, C. W., W. A. Norvell, and T. Spittler. 1981. Predicting total soil lead from an acetic acid-sodium acetate buffered solution. *Commun. Soil Sci. Plant Anal.* 12:239-245.
- Olsen, K. W., and R. K. Skogerboe. 1975. Identification of lead compounds from automotive sources. *Environ. Sci. Technol.* 9:227-230.
- Orton, W. T. 1970. Lead poisoning among children in Haringey. *The Medical Officer* 123:147-152.
- Page, A. L., T. J. Ganje, and M. S. Joshi. 1971. Lead quantities in plants, soil, and air near some major highways in Southern California. *Hilgardia* 41:1-31.
- Piomelli, S., C. Seamen, D. Zullo, A. Curran, and B. Davidow. 1982. Threshold for lead damage to heme synthesis in urban children. *Proc. Natl. Acad. Sci.* 79:3335-3339.
- Preer, J. R., J. O. Akintoye, and M. L. Martin. 1984. Metals in downtown Washington, D.C. gardens. *Biol. Trace Element Res.* 6:79-91.
- Preer, J. R., and W. G. Rosen. 1978. Lead and cadmium content of urban garden vegetables. *Trace Subst. Environ. Health* 11:399-405.
- Preer, J. R., H. S. Sekhon, J. Weeks, Jr., and B. R. Stephens. 1980a. Heavy metals in garden soil and vegetables in Washington, D.C. *Trace Subst. Environ. Health* 14:516-521.

- Preer, J. R., H. S. Sekhon, and B. R. Stephens. 1980b. Uptake of heavy metals by urban garden vegetables. pp. 60-65. In Proc. Nat. Conf. Municipal and Industrial Sludge Utilization and Disposal. Information Transfer, Inc., Silver Spring, MD.
- Preer, J. R., H. S. Sekhon, B. R. Stephens, and M. S. Collins. 1980c. Factors affecting heavy metal content of garden vegetables. Environ. Pollut. 81:95-104.
- Rabinowitz, M. B., and G. W. Wetherill. 1972. Identifying sources of lead contamination by stable isotope techniques. Environ. Sci. Technol. 6:705-709.
- Ratcliffe, D., and A. Beeby. 1980. Differential accumulation of lead in living and decaying grass on roadside verges. Environ. Pollut. 23:279-286.
- Rice, C., A. Fischbein, R. Lillis, L. Sarkozi, S. Kon, and I. J. Selikoff. 1978. Lead contamination in the homes of employees of secondary lead smelters. Environ. Res. 15:375-380.
- Roberts, T. M., T. C. Hutchinson, J. Paciaga, A. Chattopadhyay, R. E. Jervis, J. VanLoon, and D. K. Parkinson. 1974. Lead contamination around secondary smelters: Estimation of dispersal and accumulation by humans. Science 186:1120-1122.
- Roels, H. A., J.-P. Buchet, R. R. Lauwreys, P. Bruaux, F. Claeys-Thoreau, A. Lafontaine, and G. Verduyn. 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.
- Rolfe, G. L., and A. Haney. 1975. An ecosystem analysis of environmental contamination by lead. Univ. Ill. Inst. Environ. Studies. 133 pp.
- Ryan, J. A., H. R. Pahren, and J. B. Lucas. 1982. Controlling cadmium in the human food chain: A review and rationale based on health effects. Environ. Res. 28:251-302.
- Sayre, J. W., E. Charney, J. Vostal, and I. B. Pless. 1974. House and hand dust as a potential source of childhood lead exposure. Am. J. Dis. Child. 127:167-170.
- Sayre, J. W., and M. D. Katzel. 1979. Household surface lead dust: Its accumulation in vacant homes. Environ. Health Perspect 29:179-182.
- Scialdone, R., D. Scognamiglio, and A. U. Ramunni. 1980. The short and medium term effects of organic amendments on lead availability. Water, Air, Soil Pollution 13:267-274.
- Shellshear, I. D. 1973. Lead poisoning in childhood: A case report with environmental implications. N. Z. Med. J. 78:251-254.
- Shellshear, I. D., L. D. Jordan, D. J. Hogan, and F. T. Shannon. 1975. Environmental lead exposure in Christchurch children: Soil lead a potential hazard. N. Z. Med. J. 81:382-386.

- Shuck, E. A., and J. K. Locke. 1970. Relationship of automotive lead particulates to certain consumer crops. *Environ. Sci. Technol.* 4:324-332.
- Siccama, T. G., and W. H. Smith. 1978. Lead accumulation in a Northern hardwood forest. *Environ. Sci. Technol.* 12:593-594.
- Silverman, J. 1984. Soil lead. This insidious danger may be lurking in your own backyard. *Horticulture* (April):24-30.
- Smith, W. H. 1976. Lead contamination of the roadside ecosystem. *J. Air Pollut. Contr. Assoc.* 26:753-766.
- Solomon, R. L., and J. W. Hartford. 1976. Lead and cadmium in dusts and soils in a small urban community. *Environ. Sci. Technol.* 10:773-777.
- Spittler, T. M., and W. A. Feder. 1979. A study of soil contamination and plant lead uptake in Boston urban gardens. *Commun. Soil Sci. Plant Anal.* 10:1195-1210.
- Stara, J., W. Moore, M. Richards, N. Barkely, S. Neiheisel, and K. Bridbord. 1973. Environmentally bound lead. III. Effects of source on blood and tissue levels of rats. pp. 28-29. In EPA Environmental Health Effects Research Series A-670/1-73-036.
- Stark, A. D., J. W. Meigs, R. F. Quah, and E. R. DeLouise. 1978. Family operational co-factors in the epidemiology of childhood lead poisoning. *Arch. Environ. Health* 33:222-226.
- Stark, A. D., R. F. Quah, J. W. Meigs, and E. R. DeLouise. 1982. The relationship of environmental lead to blood-lead levels in children. *Environ. Res.* 27:372-383.
- Stark, A. D., R. F. Quah, J. W. Meigs, and E. R. DeLouise. 1982. Relationship of socioeconomic factors to blood lead concentrations in New Haven children. *J. Epidemiol. Community Health* 36:133-139.
- Sterrett, S. B., C. W. Reynolds, F. D. Schales, R. L. Chaney, and L. W. Douglass. 1983. Transplant quality, yield, and heavy-metal accumulation of tomato, muskmelon, and cabbage grown in media containing sewage sludge compost. *J. Am. Soc. Hort. Sci.* 108:36-41.
- Ter Haar, G., and R. Aronow. 1974. New information on lead in dirt and dust as related to the childhood lead problem. *Environ. Health Perspect.* 7:83-89.
- Thornton, I., and P. Abrahams. 1981. Soil ingestion as a pathway of metal intake into grazing livestock. pp. 267-272. In *Proc. Int. Conf. Heavy Metals in the Environment*. CEP Consultants, Edinburgh.
- Tiller, K. G., M. P. C. deVries, L. R. Spouncer, L. Smith, and B. Zarcinas. 1976. Environmental pollution of the Port Pirie region. 3. Metal contamination of home gardens in the city and their vegetable produce. CSIRO Division of Soils Divisional Report No. 15, 18 pp.

- Tinsley, D. A., A. R. Baron, R. Critchley, and R. J. Williamson. 1983. Extraction procedures for atomic absorption spectrometric analysis of toxic metals in urban dust. *Intern. J. Environ. Anal. Chem.* 14:285-298.
- U.S. Environmental Protection Agency. 1977. Air Quality Criteria for Lead. EPA-600/8-77-017.
- U.S. Environmental Protection Agency. 1979. Criteria for classification of solid waste disposal facilities and practices. *Federal Register* 44(179):53438-53464.
- Veneman, P. L. M., S. M. Bodine, J. R. Murray, and J. H. Baker. 1982. Effectiveness of three rapid digestion methods to estimate total lead in orchard soils. *Commun. Soil. Sci. Plant Anal.* 13:585-592.
- Vostal, J. J., E. Taves, J. W. Sayre, and E. Charney. 1974. Lead analysis of house dust: A method for the detection of another source of lead exposure in inner city children. *Environ. Health Perspect.* 7:91-97.
- Wakefield, Z. T. 1980. Distribution of cadmium and selected heavy metals in phosphate fertilizer processing. Tennessee Valley Authority National Fertilizer Development Center Bulletin Y-159. 12 pp.
- Ward, N. I., R. D. Reeves, and R. R. Brooks. 1975. Lead in soil and vegetation along a New Zealand state highway with low traffic volume. *Environ. Pollut.* 9:243-251.
- Ward, N. I., R. D. Reeves, and R. R. Brooks. 1975. Lead from motor-vehicle exhausts in sweet-corn plants and soils along a highway in Hawke's Bay, New Zealand. *N.Z.J. Sci.* 18:261-267.
- Wedding, J. B., R. W. Carlson, J. J. Stukel, and F. A. Bazzaz. 1975. Aerosol deposition on plant leaves. *Environ. Sci. Technol.* 9:151-153.
- Wedding, J. B., R. W. Carlson, J. J. Stukel, and F. A. Bazzaz. 1977. Aerosol deposition on plant leaves. *Water, Air, Soil Pollut.* 9:545-550.
- Wedeer, R. P., D. K. Mallik, V. Batuman, and J. D. Bogden. 1978. Geophagic lead nephropathy: Case report. *Environ. Res.* 17:409-415.
- Wesolowski, J. J., C. P. Flessel, S. Twiss, R. L. Stanley, M. W. Knight, G. C. Coleman, and T. E. Degarmo. 1979. The identification and elimination of a potential lead hazard in an urban park. *Arch. Environ. Health* 34:413-418.
- Willson, G. B., J. F. Parr, E. Epstein, P. B. Marsh, R. L. Chaney, D. Colacicco, W. D. Burge, L. J. Sikora, C. F. Tester, and S. B. Hornick. 1980. Manual for composting sewage sludge by the Beltsville aerated-pile method. EPA-600/8-80-022 (Available from NTIS). 65 pp.
- Winneke, G., A. Brockhaus, U. Kramer, U. Ewers, G. Kujanek, H. Lechner, and W. Janke. 1981. Neuropsychological comparison of children with different tooth lead levels. Preliminary report. pp. 553-556. In *Proc. Int. Conf. Heavy Metals in the Environment*. CEP Consultants, Edinburgh.

- Winneke, G., K.-G. Hrdina, and A. Brockhaus. 1982. Neuropsychological studies in children with elevated tooth-lead concentrations. I. Pilot study. *Int. Arch. Occup. Environ. Health* 51:169-183.
- Wolnick, K. A., F. L. Fricke, S. G. Capar, G. L. Braude, M. W. Meyer, R. D. Satzger, and E. Bonnin. 1983. Elements in major raw agricultural crops in the United States. I. Cadmium and lead in lettuce, peanuts, potatoes, soybeans, sweet corn, and wheat. *J. Agr. Food Chem.* 31:1240-1244.
- Yaffe, Y., C. P. Flessel, J. J. Wesolowski, A. D. Rosario, G. H. Guirguis, V. Matias, T. E. Degarmo, J. W. Gramlich, G. C. Coleman, and W. R. Kelly. 1983. Identification of lead sources in California children using the stable isotope ratio technique. *Arch. Environ. Health* 38:237-245.
- Yankel, A. J., I. H. von Lindern, and S. D. Walter. 1977. The Silver Valley lead study: The relationship between childhood blood lead levels and environmental exposure. *J. Air Pollut. Contr. Fed.* 27:763-767.
- Yule, W., R. Landsdown, I. B. Millar, and M. A. Urbanowicz. 1981. The relationship between blood lead concentrations, intelligence, and attainment in a school population: A pilot study. *Dev. Med. Child Neurol.* 23:567-576.
- Zimdahl, R. L. 1976. Entry and movement in vegetation of lead derived from air and soil sources. *J. Air Pollut. Contr. Assoc.* 26:655-660.
- Zimdahl, R. L., and J. M. Foster. 1976. The influence of applied phosphorus, manure, or lime on uptake of lead from soil. *J. Environ. Qual.* 5:31-34.
- Zimdahl, R. L., D. T. McCreary, and S. M. Gwynn. 1978. Lead uptake by plants --The influence of lead source. *Bull. Environ. Contamin. Toxicol.* 19:431-435.