Urban Garden Soil Pb: Remediation of Phytoavailability and Bioavailability To Protect Children

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Lead in Urban Soils Workshop

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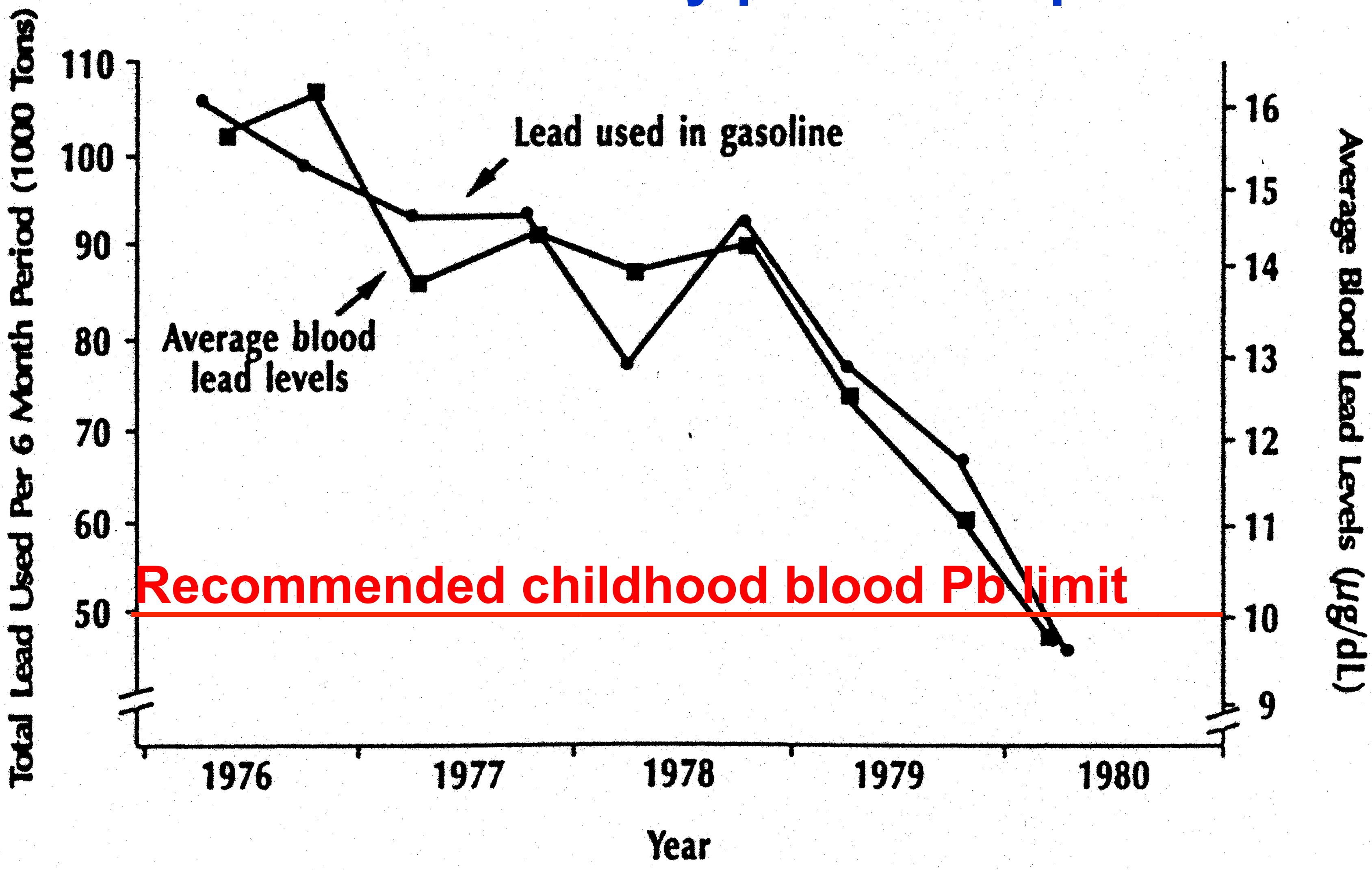
Gasoline Pb was only part of the problem!



Change in Blood-Pb Levels in Relation to Decline in Use of Leaded Gasoline, 1976-1980 (Annest, 1983).

Today

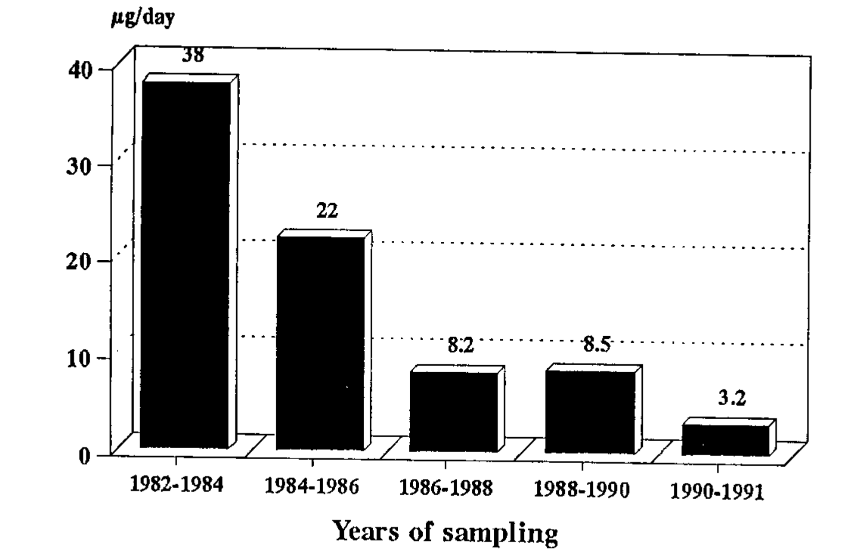


Figure 2. Lead intakes of 14–16-year-old males as measured by FDA Total Diet Study.

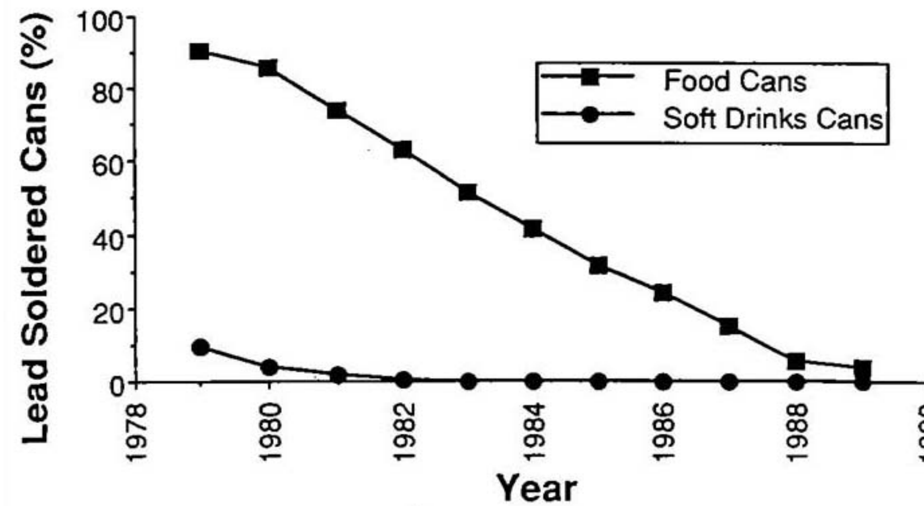


Figure 7 *Percent lead soldered cans of total cans shipped (United States) (CMI, 1990).*

Bolger et al-1996-Sources and Reduction in Dietary Pb

Bolger et al., 1991-Reductions in dietary Pb in US-FDA

Before gasoline Pb phasedown, Pb-B was >15 µg/dL
After gasoline Pb phasedown, Pb-B was only 10 µg/dL
Today GM Pb-B is 1.5 µg/dL for US children.

Interior (Paint) Pb sources to housedust explain high Pb-B. Although new paint is low in Pb, removal of old paint Pb occurs only when humans take action to remove the paint.

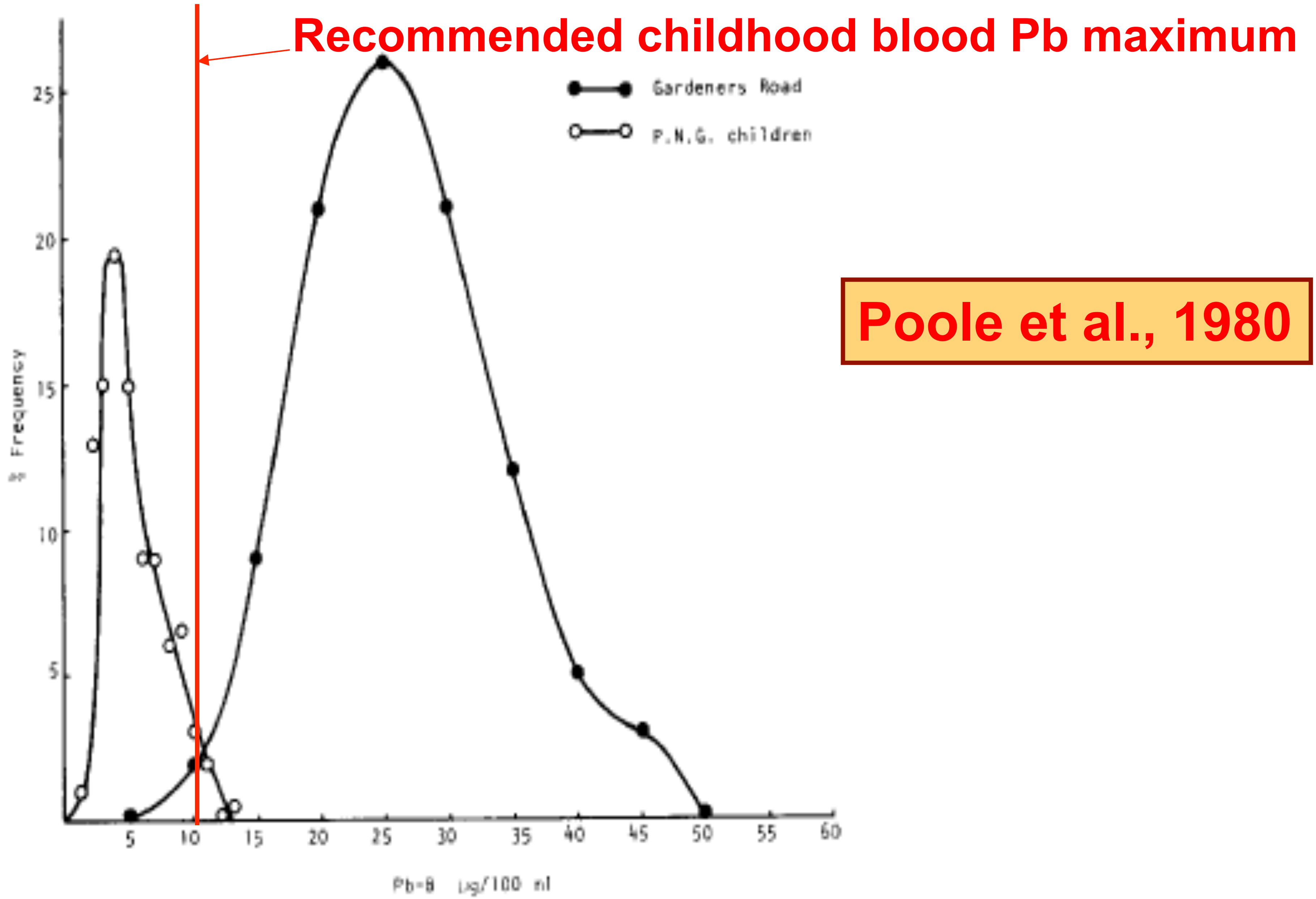


Fig. 2. Comparison of frequency distributions of Pb—B results from 400 Gardeners Road schoolchildren in August 1974 Survey [5, 6] and from 100 Papua New Guinea children.

Risk from Soil Pb is through Soil Ingestion, not from Garden Foods.

- **If Good Urban Gardening Practices are followed, garden crop Pb is increased only slightly when soil Pb is 500-1000 µg/g, and the Pb is in foods.**
- **Living in an area with soil Pb in excess of 400 (bare soil play area) to 1200 mg/kg (grassed soil) may increase children's blood Pb (HUD; EPA).**
- **Thus, the dominant pathway for soil Pb risk to humans is inadvertent housedust and soil ingestion by infants and children.**

- **The dominant source of Pb to Housedust is still interior paint particles with high bioavailability.**
- **Soil Pb is much less correlated with increased Pb-B in children compared to housedust Pb.**
- **We need to consider soil Pb BIOAVAILABILITY.**

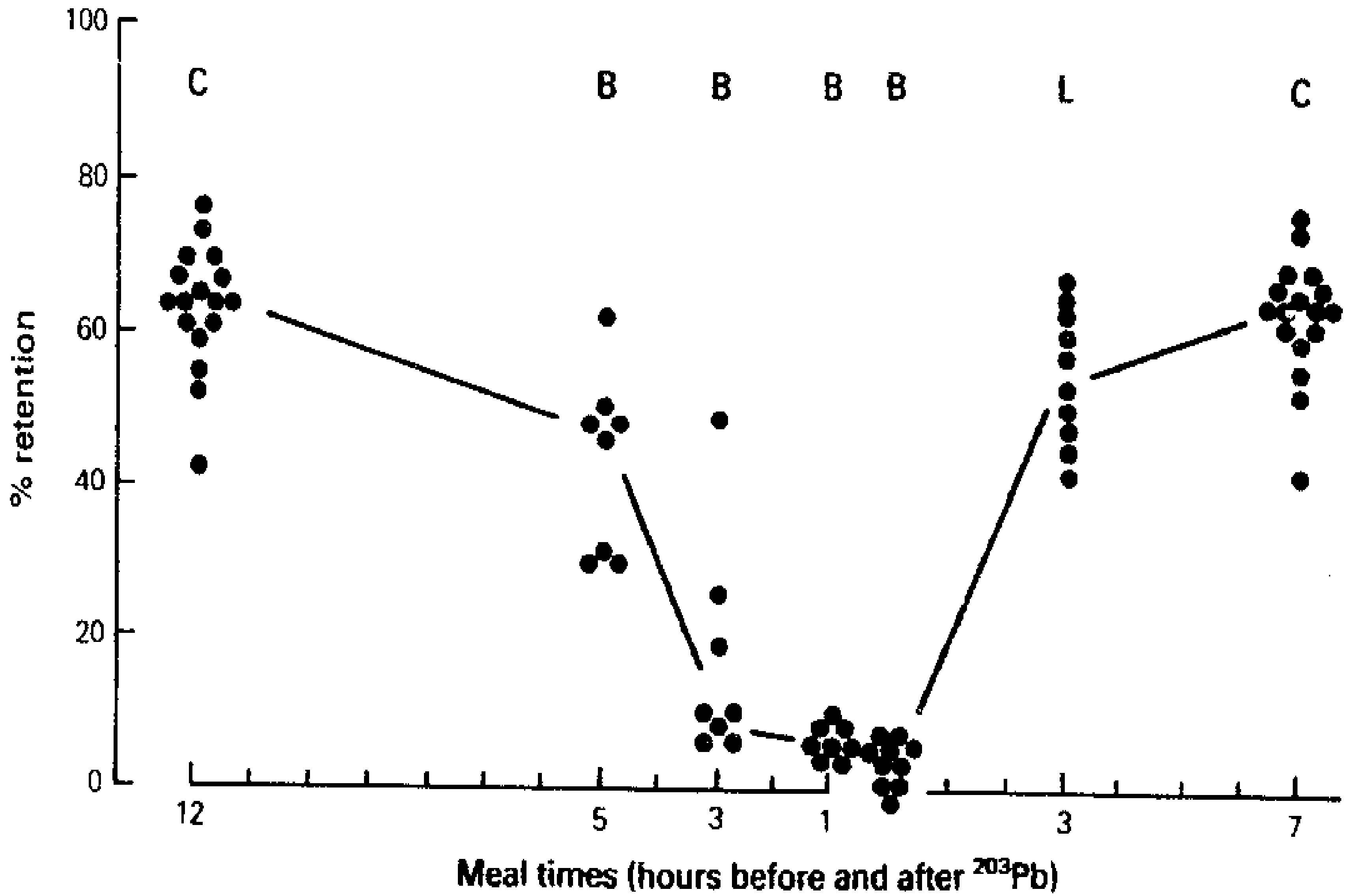
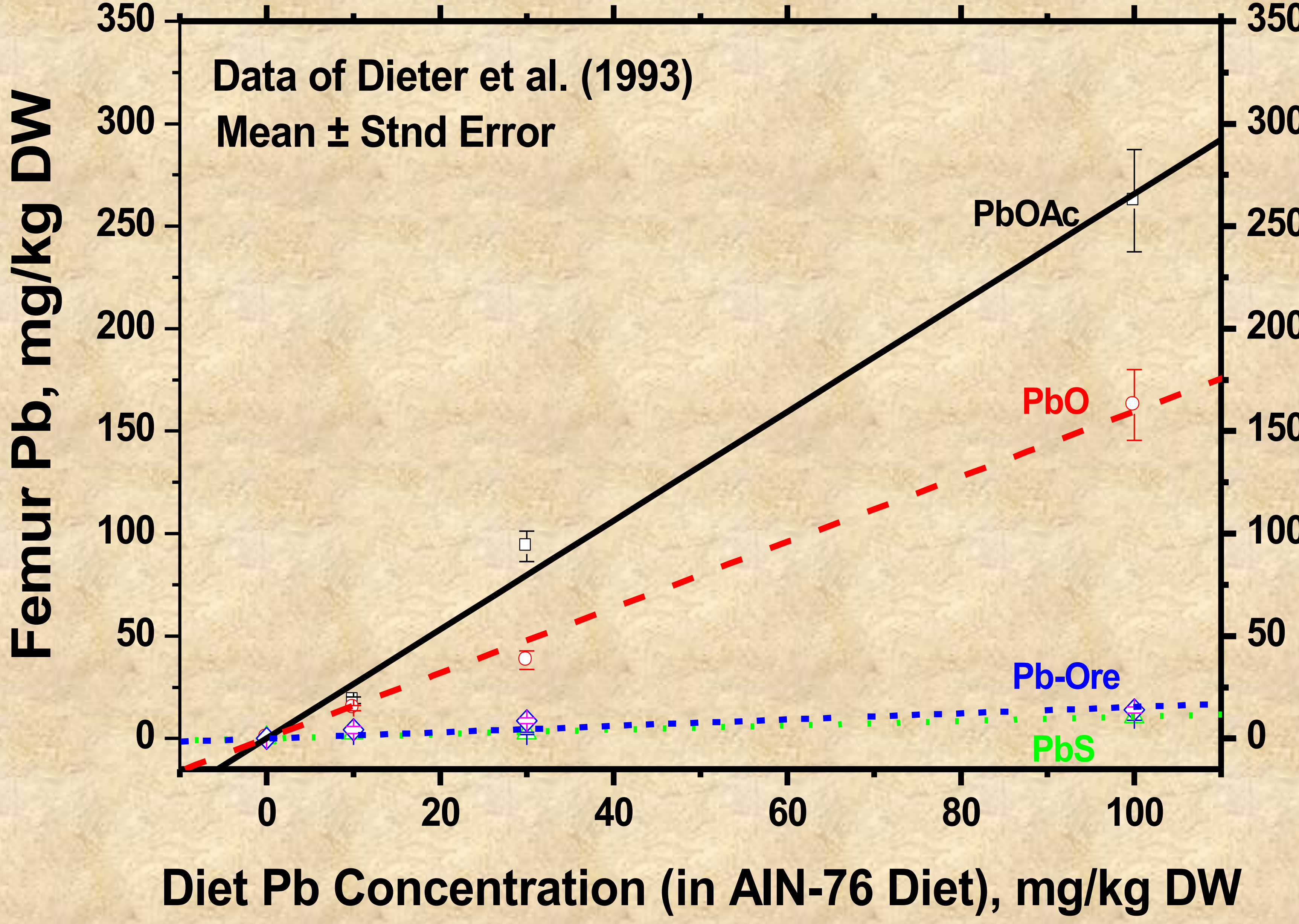
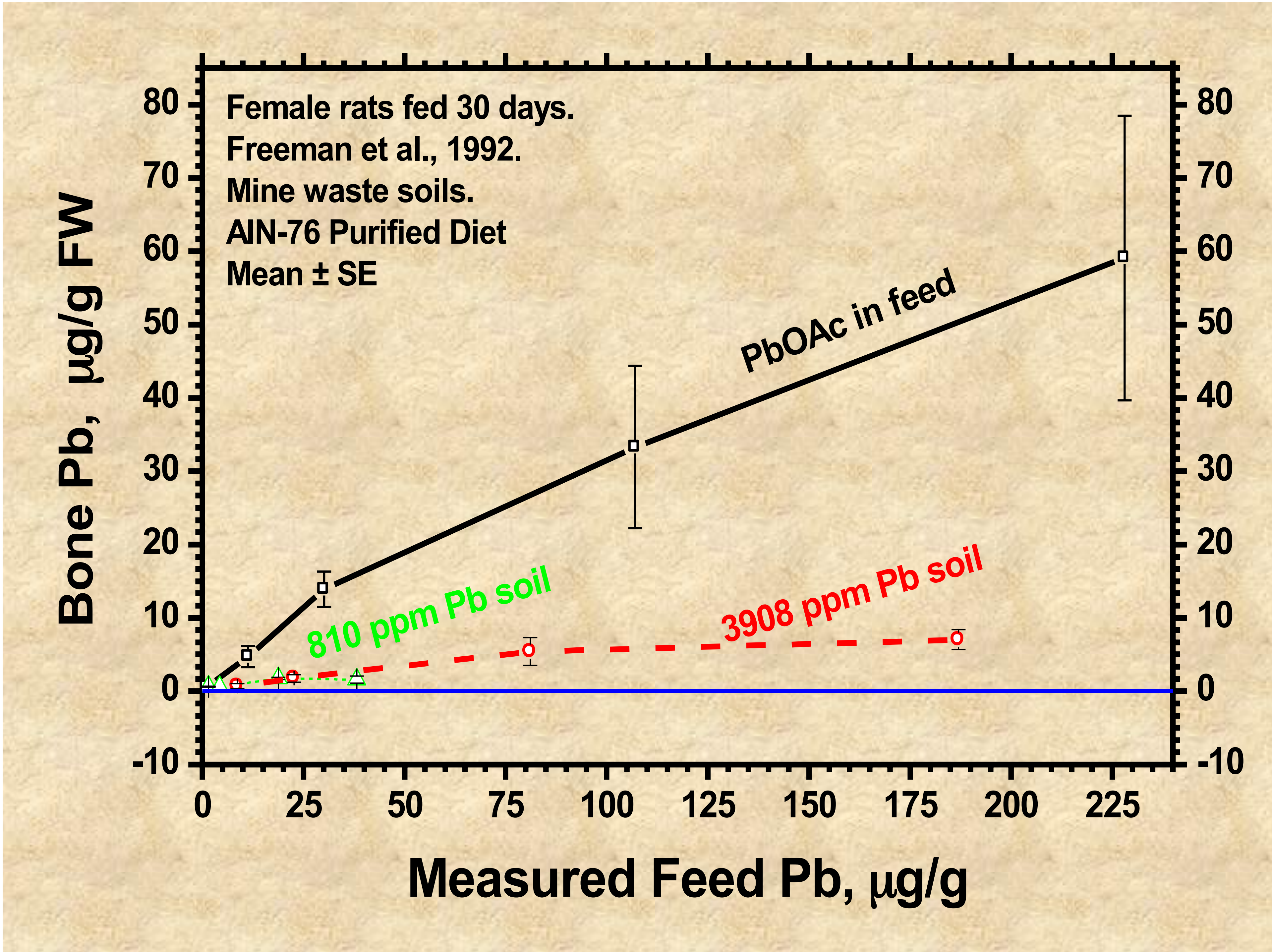


Figure 2 Effect of meal times on retention of ^{203}Pb. Breakfast (B) was eaten with ^{203}Pb or 1, 3 or 5 h before ^{203}Pb. Lunch (L) was eaten 3 h after ^{203}Pb. The control values (C) are illustrated as for meals eaten at the beginning and end of the 19 h fast

James et al., 1985


Data of Dieter et al. (1993)
Mean ± Stnd Error
PbOAc
PbO
Pb-Ore
PbS
Femur Pb, mg/kg DW
Diet Pb Concentration (in AIN-76 Diet), mg/kg DW
0
50
100
150
200
250
300
350
0
20
40
60
80
100



Female rats fed 30 days.
Freeman et al., 1992.
Mine waste soils.
AIN-76 Purified Diet
Mean ± SE
PbOAc in feed
810 ppm Pb soil
3908 ppm Pb soil
Bone Pb, µg/g FW
Measured Feed Pb, µg/g
80
70
60
50
40
30
20
10
0
-10
0
25
50
75
100
125
150
175
200
225

THE URBAN SOIL LEAD ABATEMENT STUDY

Boston Soil containing 1790 mg Pb/kg was replaced with low Pb soil in 3 City Study.

Blood-Pb declined 0.8-1.6 µg/dL due to the independent effect of soil replacement.

- **"... suggests that lead-contaminated soil abatement is not likely to be a useful clinical intervention for the majority of urban children in the United States with low-level lead exposure."**
- **Paint-Pb remains the most important source of Pb risk to urban children in the US.**
- **Possible that the effectiveness of the soil abatement may have been reduced because the children had been exposed to high Pb soil/dust before the abatement, and decline in Blood-Pb may not occur as rapidly as rise upon exposure.**

Bioavailability of Soil Pb to Humans Under Fasting or Fed Condition.

Results of human feeding studies with soil from the Bunker Hill Superfund Site (Maddaloni et al., 1998).

Group	Age	Weight	Pb Dose	Soil Dose	Bioavailability
N=6	yrs	kg	µg	mg	%
Fasted	28	59.7	213	72.9	26.2 (18.0-35.6)
Fed	28	67.9	242	82.9	2.52 (0.2-5.2)

Soil contained 2924 mg Pb/kg DW.

Effect of Soil on Availability of Pb to Rats, and Bioavailability of Pb in Urban Garden Soils.

TEST DIET	Tibia-Pb	% of $Pb(OAc)_2$
	mg/kg ash	
Basal	0.3 e	-
Basal + 5% Soil	0.0 e	-
Basal + $Pb(OAc)_2$	247. a	100
Basal + $Pb(OAc)_2$ + 5% Soil	130. bc	53
Basal + 706 ppm Pb Soil	40.0 de	16
Basal + 995 ppm Pb Soil	108. c	44
Basal + 1078 ppm Pb Soil	37.1 de	15
Basal + 1265 ppm Pb Soil	53.6 d	22
Basal + 10240 ppm Pb Soil	173. b	70

Pb added to supply 50 mg Pb/kg diet

Effect of Biosolids Processing Technology on Reducing Soil-Pb Bioavailability.

- Brown, Xue, Hallfrisch and Chaney/WERF.

- Baltimore urban soil = 2135 mg Pb/kg
- Mixed biosolids products at 10% dry weight or equivalent added biosolids matrix.
  - Incubated moist for 30 days; dried; mixed; < 1 mm.
- Added 5% soil to purified rat diet for 35 day feeding period -- simulates *pica* soil ingestion.
- Measured Pb in blood, bone, kidney, liver.
  - Compare to effect of equal Pb-acetate (soluble; 100% bioavailable) – dietary soluble or soil Pb which gives equal tissue Pb concentration.

Effect of Biosolids Processing Technology on Reducing Soil-Pb Bioavailability.

Treatment	Soil Pb	Diet Pb	Bone-Pb
	--------mg/kg dry weight--------		
Unamended	2135	125.3 a	144.6 a
Syracuse Raw	2099	82.4 cd	87.5 b-e
Syracuse Pellet.	2034	84.3 cd	86.7 cde
Syracuse Comp.	1768	116.7 ab	104.5 bc
Baltimore Comp.	2576	100.6 b	73.3 de
Compro-DC	2309	99.2 b	81.8 cde

Phosphate Amendment Reduced Soil Pb Bioavailability to Humans

Joplin Soils

Group	Age	Weight	Pb Dose	Soil Dose	Bioavailability
	yr	kg	µg	mg	%, Absolute
Untreated	29.6	62.2	238	45.7	42.2 (26.3-51.7)
P-Treated	34.5	72.2	261	61.5	13.1 (10.5-15.8)

Graziano, Maddaloni et al., 2001; unpublished.

PHOSPHATE INACTIVATION OF SOIL Pb IN JOPLIN TEST

Comparative Bioavailability Results--Pig, Rat, Human and *In vitro*

Method	Bioavailability
	%-Reduction
Pig (Casteel et al.)	29
Rat (Hallfrisch et al.)	40
Human (Graziaoni, Maddaloni et al.)	69
In vitro (pH 1.5)	18
In vitro (pH 2.5)	69

Soil tested 18 months after H_3PO_4 treatment in field.

ChloroPyromorphite: Does Pb Remain Non-Bioavailable?

- Scheckel and Ryan (2002) reacted phosphate with soluble Pb and examined the precipitate after 1 hr, 1 d, 1 wk, 1 mo, … 1yr.
- Examined EXAFS, XRD, and DGT properties of compounds formed; after 1 hr, no further reaction was observed.
- Examined dissolution in acid and found after 1 hr, rate not further reduced.
- In soil, extent of reaction increases with time and bioavailability only becomes lower.
- Reaction could occur during digestion or during bioaccessibility testing if P and Pb are mixed in soil.

In Practice, Incorporating Compost Reduces Pb Risks in Several Ways.

- Highest Pb is usually on soil surface. Incorporation of compost with rototiller mixes Pb with tillage depth, reducing risk from surface soil.
- Phosphate and Fe in compost transform soil Pb into forms with much lower bioavailability.
- Compost amendment supports strong growth of turfgrass, making it much more difficult to eat the soil or drag it into your house.
- One can measure highest Pb near house using XRF and remove high Pb soil to a landfill.
- Regular addition of soil amendments, tillage, and cropping hasten dilution and inactivation of soil Pb.

Effect of Soil Amendments on Pb Concentration in 'Tania ' Lettuce Grown in Urban Garden Soils in a Growth Chamber (Sterrett et al., 1994)

Treatment	Soil Pb Concentration, mg/kg DW			
	12	413	1334	5210
	----mg Pb/kg dry lettuce shoots----			
Control	2.8 a	15.7 a	17.7 a	37.8 ab
NPK	2.0 a	3.8 ab	8.4 a	26.6 bc
NPK + $CaCO_3$	1.8 a	9.3 ab	6.0 a	43.7 a
NPK + P	2.9 a	4.4 ab	10.5 a	17.2 c
NPK + 5% Comp.‡	2.2 a	2.4 b	6.5 a	16.1 c
NPK +10% Comp.‡	2.6 a	2.8 b	5.3 a	19.7 c

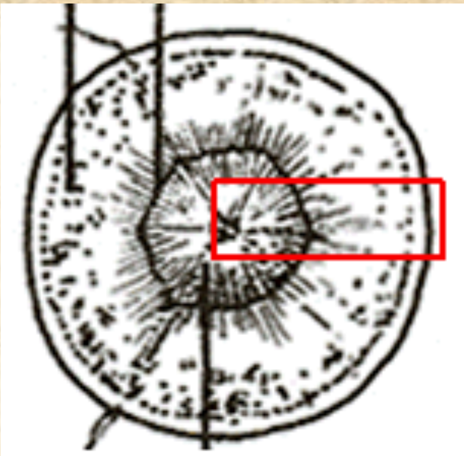
‡Composted Biosolids rich in $CaCO_3$, PO_4, and Fe oxides.

Accumulation of Pb in Carrots Growing in Orchard Soils (Codling et al., 2015)

Soil Series	Soil Pb	Pb in Carrot Tissue		
		Peeled Root	Peel	Shoots
		-----------mg kg^{-1} dry weight-----------		
Christiana	20	0.21 d	0.15 d	0.16 c
Bagstown	676	2.79 c	0.75 c	2.81 b
Hudson	435	3.53 b	0.97 bc	2.94 b
Spike	350	2.67 c	1.05 b	2.37 b
Cashmont	961	7.30 a	1.56 a	5.07 a

Bagstown, Hudson, Spike and Cashmont are old orchard soils from MD, NY, MI, and WA, respectively; Christiana is Maryland control soil.

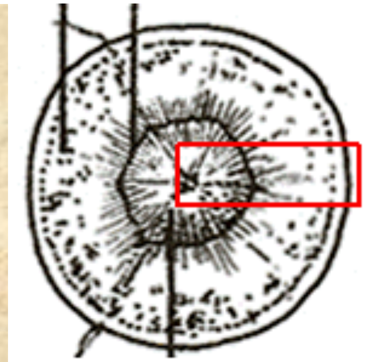
Carrot peel and slices showing central xylem and phloem/pulp areas.



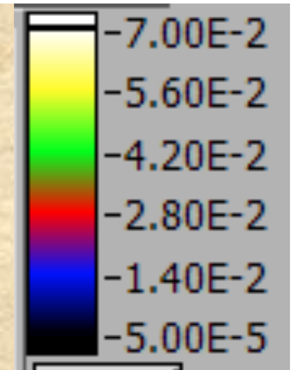
Orchard Soil: Map size 8mm x 2 mm, 20 µm step sizes, and 0.5 sec integration.

Garden Soil: Map size 10 mm x 2.5 mm, 20 µm step sizes, and 0.5 sec integration.

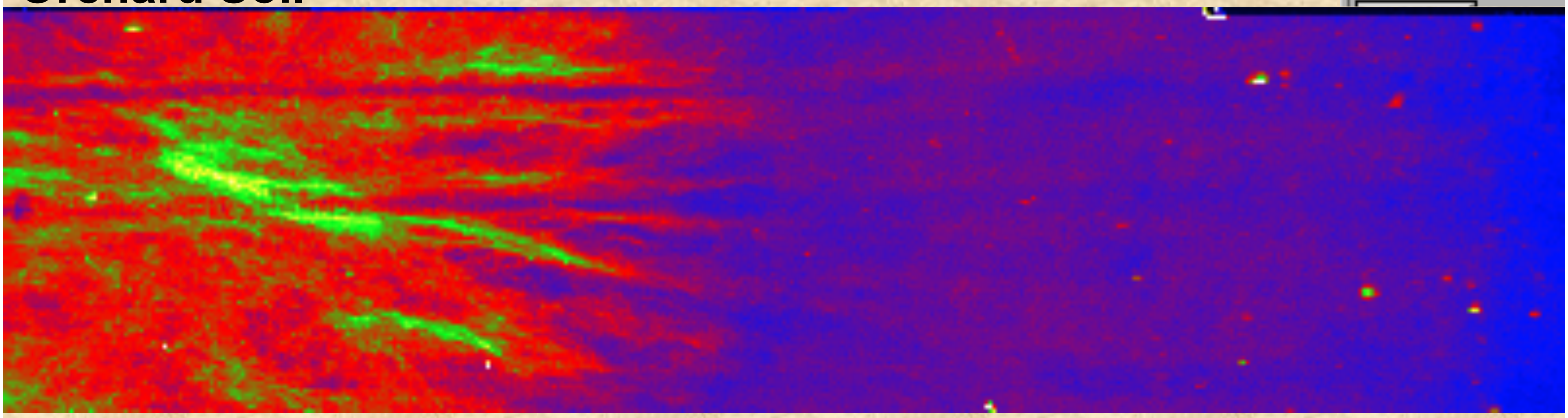
Pb



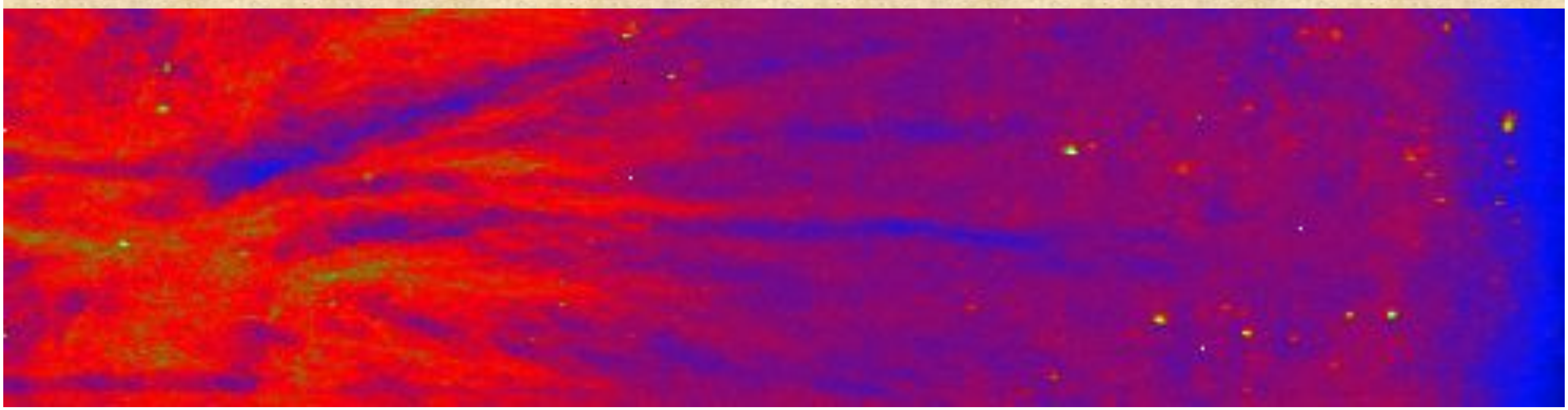
Map size 8mm x 2 mm, 20 µm step sizes, and 0.5 sec integration.



Orchard Soil



Urban Garden Soil



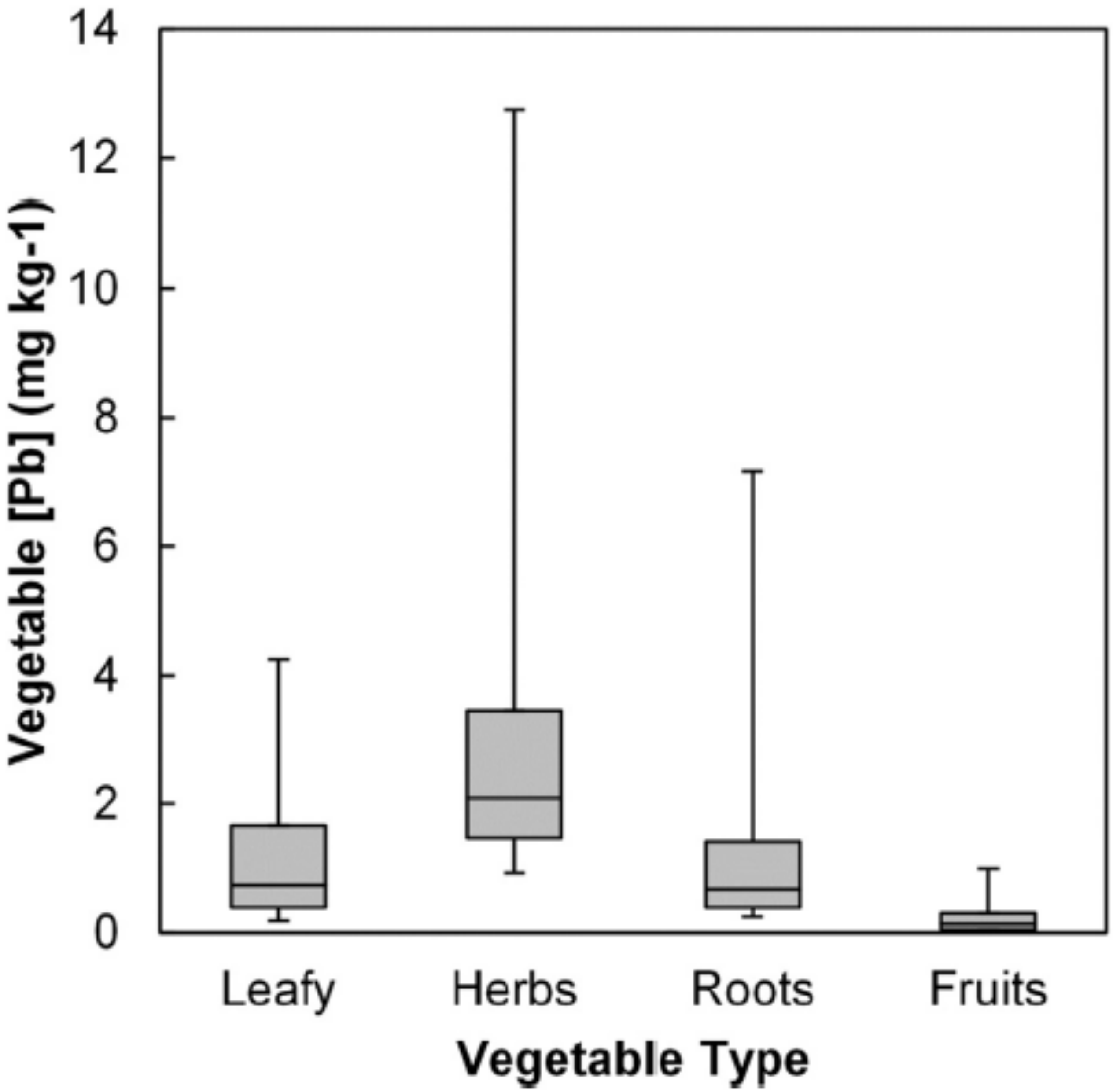


Fig. 1. Pb concentrations in garden-grown vegetables by crop type (mg kg^{-1} d.w.). Boxes represent 25th, 50th and 75th percentiles. Whiskers extend to 5th and 95th percentiles.

McBride et al., 2013

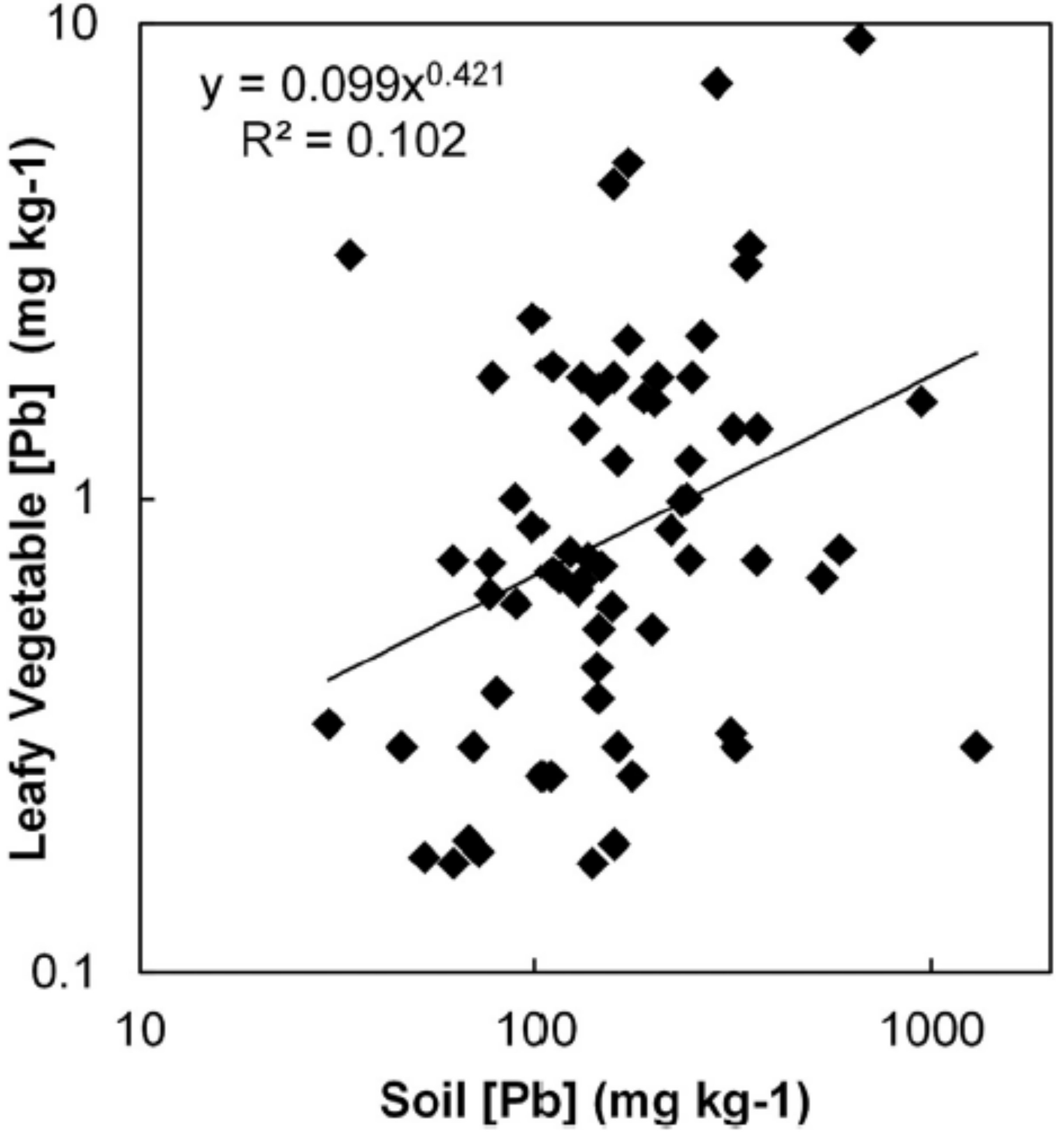


Fig. 2. Relationship of leafy vegetable Pb concentrations (mg kg^{-1} d.w.) to soil total Pb concentration.

McBride et al., 2013

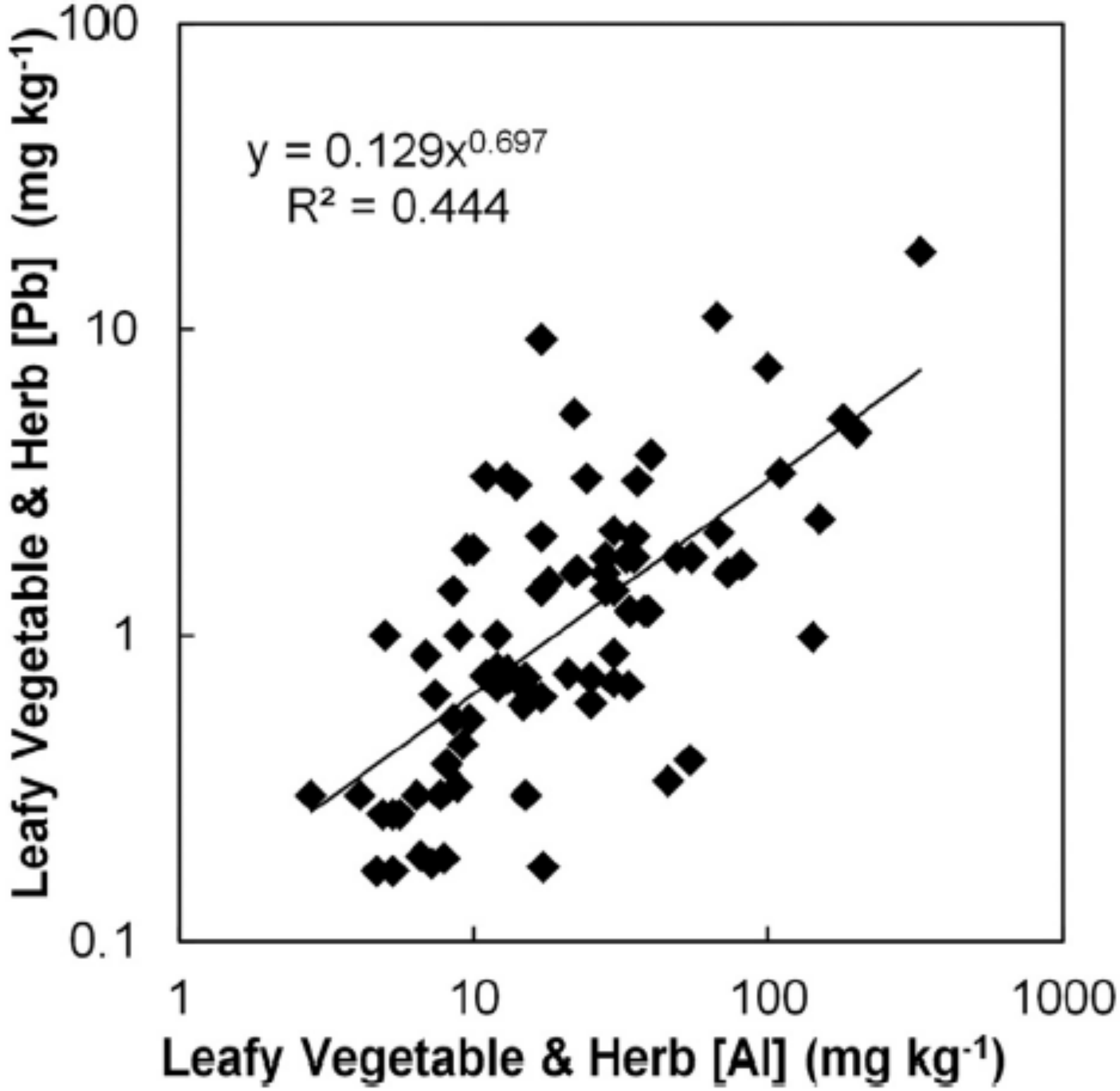


Fig. 3. Relationship of Pb concentrations (mg kg^{-1} d.w.) in leafy vegetables and herbs to Al concentrations in leafy vegetables and herbs.

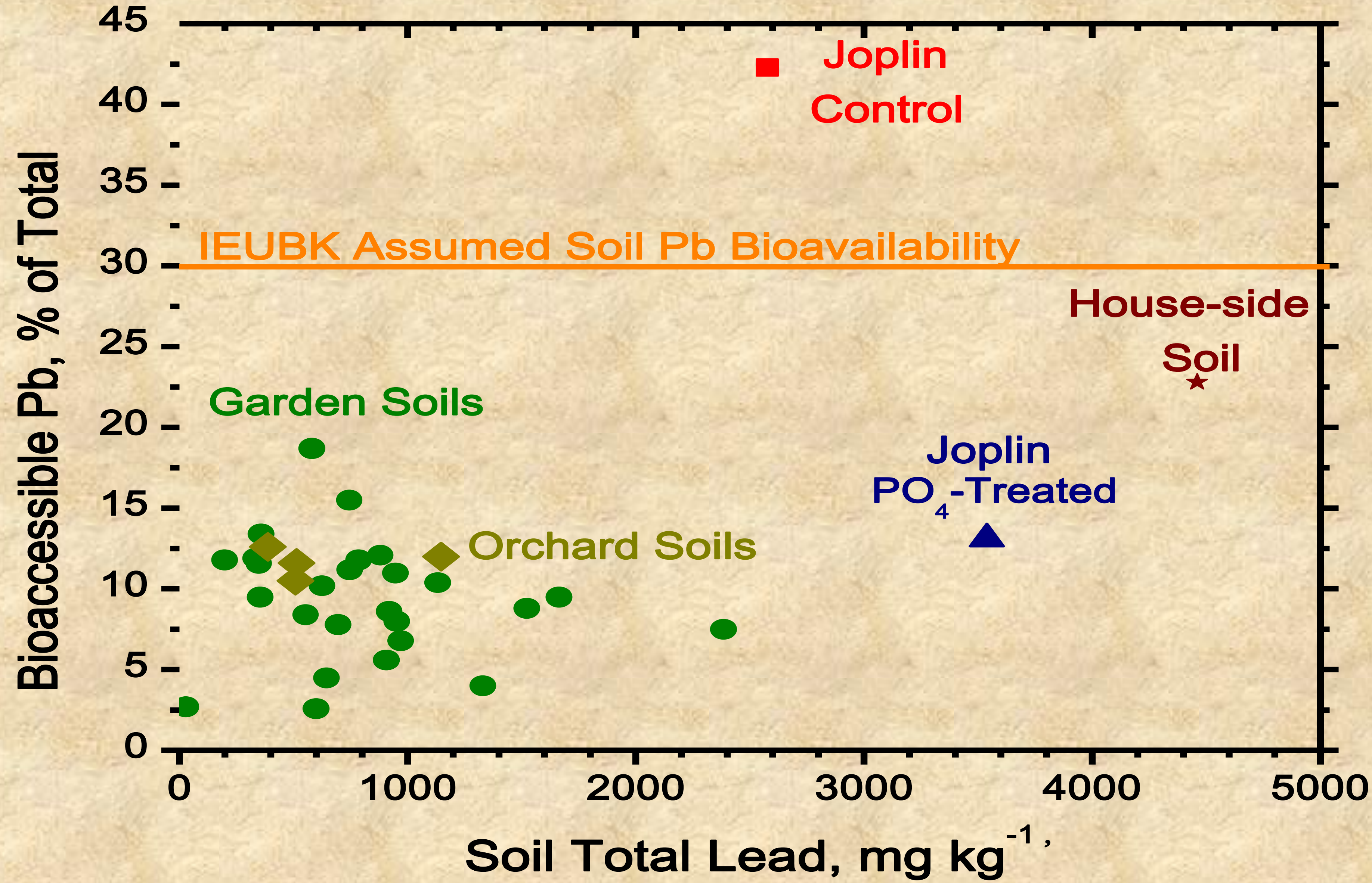
Correlation of Al and Pb in leafy crops shows soil particle contamination of leaf surfaces with all soil elements (McBride et al., 2014).

Crop Selection for High Pb Soils

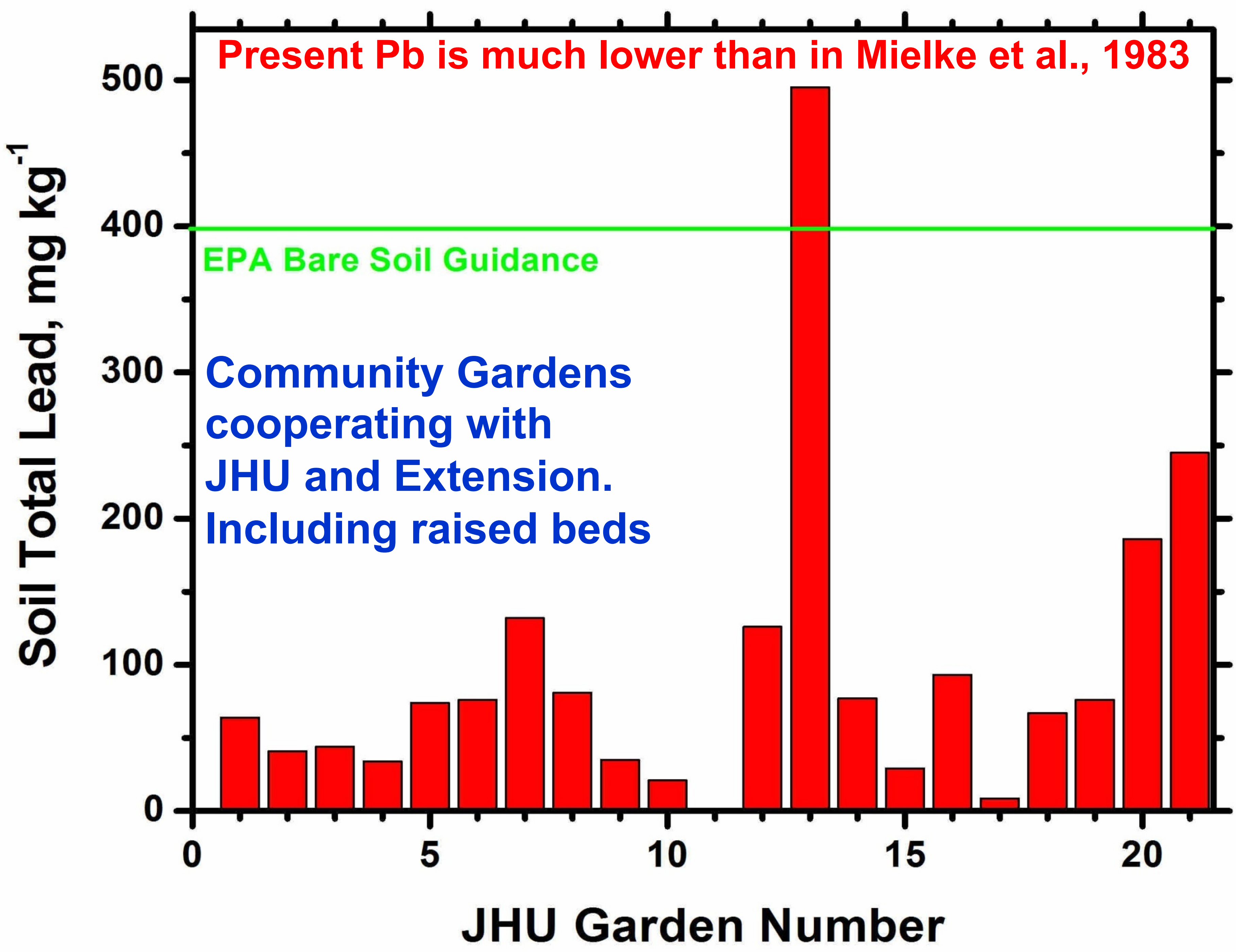
- Soil < 500 mg total Pb/kg dry weight:
  - Grow any crop you want; wash well before cooking or eating fresh.
- Soil 500 to 1500 mg Pb/kg dry weight:
  - Limit low growing leafy vegetables (or use raised beds)
    - No lettuce, spinach, chard, herbs (collards, kale, cabbage okay)
  - Limit storage root crops (potato safe if washed well)
  - Gardeners need to keep soil out of homes.
  - All other crops safe for families; wash well.
- Soil >1500 mg Pb/kg dry weight
  - If soil has low soil Pb bioaccessibility, continue cropping; Do not grow leafy and root crops.
  - Take extra care to keep soil out of home
  - Wash crops well to remove soil particles before cooking
    - Running water; care of home cook.

Crops Differ Greatly in Pb Accumulation in Edible Plant Tissue

- Low growing leafy vegetables both accumulate Pb from soil, and soil-Pb is splashed onto leaves.
  - Lettuce, spinach, chard, herbs, etc.
- Root vegetables which are enlarged hypocotyls can accumulate Pb within their xylem tissue.
  - Carrot, beet, turnip, radish, etc.
- Tubers are phloem fed and very low in Pb.
  - Potato
- Fruit and Seed crops are very low in Pb even when grown in high Pb soils.
- Further, Pb in foods has much lower absorption by humans than assumed by EPA.

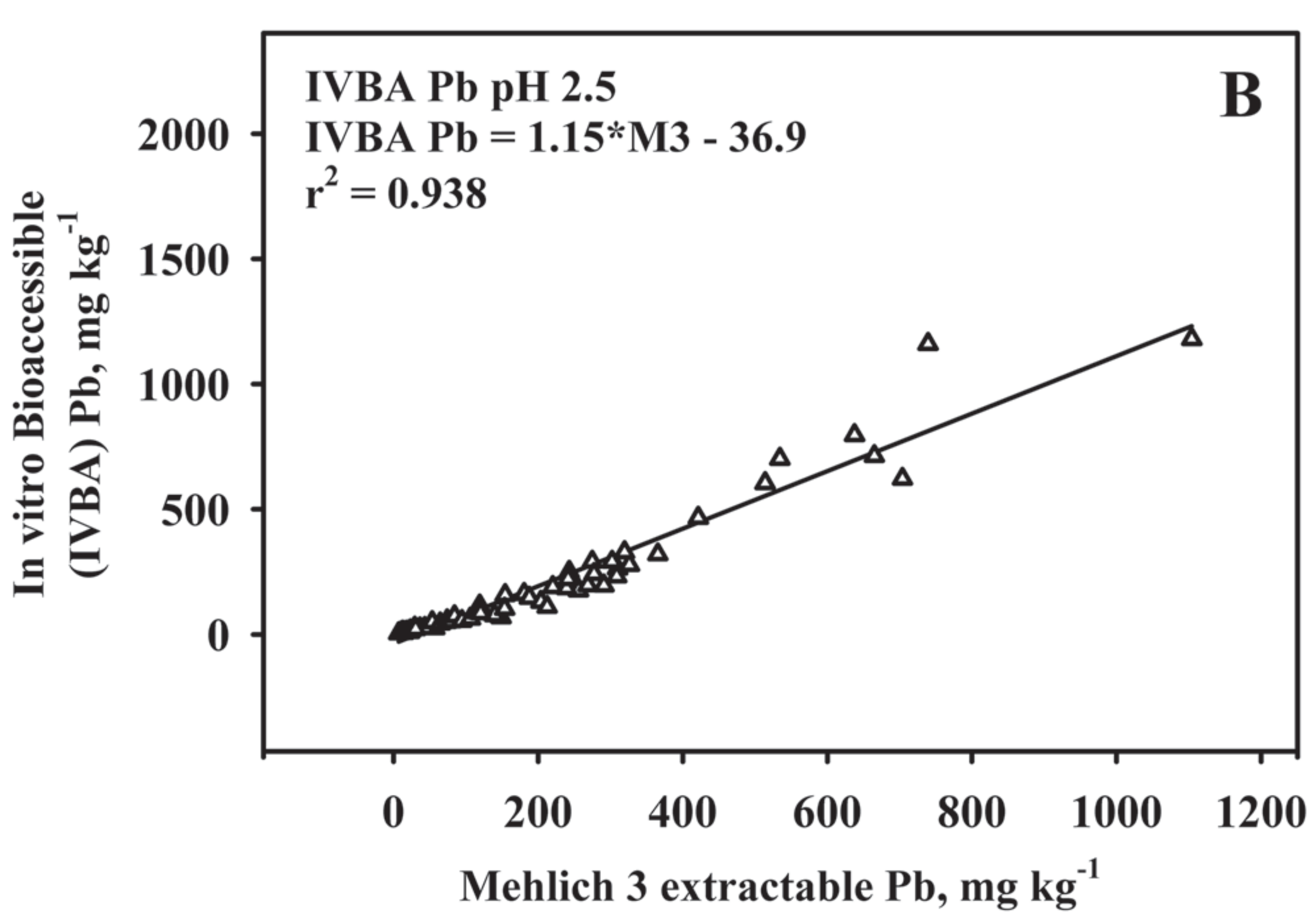


Bioaccessibility of Pb in Urban Garden soils is much lower than assumed by US-EPA in the IEUBK Model



Present Pb is much lower than in Mielke et al., 1983
EPA Bare Soil Guidance
Community Gardens
cooperating with
JHU and Extension.
Including raised beds
Soil Total Lead, mg kg^{-1}
JHU Garden Number
0
100
200
300
400
500
0
5
10
15
20

Using Mehlich-3 Soil Test for Pb



Relationship between bioaccessible Pb (pH 2.5) and Mehlich-3 Pb
(Minca, Basta & Scheckel, 2013; J. Environ. Qual. 42:1518-1526).

Summary: Urban Soils are Rich in Pb

- Many urban and orchard soils are enriched in Pb from historic use of leaded gasoline, Pb-pesticides, and Pb-paint - Human Activities.
- Among all garden crops, carrot and low-growing leafy vegetables have been found to accumulate significant levels of Pb when grown in high Pb soils (soil contamination/splash, or uptake).
- Mulching limits soil splash contamination!
- The Pb in carrots is within the xylem elements which run thru carrot storage roots.
- Other storage root crops (expanded hypocotyls) also have xylem thru the edible root and accumulate Pb (radish, redbeet, turnip, etc.)

Crop Pb Risk is Complex

- Research has shown that Pb consumed with meals has much lower bioavailability (2-5%) compared to soluble Pb in water (60-80%).
- One feeding test with Pb absorbed in spinach shoots (with roots removed in order to get much Pb into the crop) found very lower bioavailability.
- The first limit on garden soil Pb concentration is to protect children from ingested soil.
- Depending on bioavailability of Pb in soil, the maximal soil Pb is recommended by EPA & HUD to be 400 mg/kg for bare play area soils, and 1200 mg/kg for the rest of the yard. But this is based on assuming that soil Pb is 30% absolute bioavailablity

Gardens Soils Have Low Pb Bioavailability

- Garden soils have been found to have much lower bioavailability of Pb than presumed by US-EPA when they established the 400 mg/kg guidance.
- EPA assumed 30% absolute Pb bioavailability for soil and housedust, while many urban garden soils with 500-2500 mg Pb/kg have 5-10% absolute bioavailability.
- The second limit is the need to limit Pb accumulation in low-growing leafy vegetables (lettuce, spinach, herbs) and root vegetables such as carrot, beet, turnip and radish; Grow these in clean soil raised beds. Fruit and seed crops remain low in Pb even on high Pb soils.

Example raised bed vegetable gardens from web.

Common Sense Gardening and Pb

- Identify previous land use and contamination sources before choosing location of garden.
- Look for bricks and other urban debris in soil.
- Analyze garden and yard soils (multiple locations in property) for Pb, As, Cd and Zn levels and pH, and place garden where metals are lower – Away from houseside areas (> 1 m).
  - Ohio State; Penn State; Univ. Delaware; etc.
  - Total or Mehlich-3 extractable nutrients, Pb, Zn, Cd, As
- If bare soil total Pb exceeds 400 mg/kg or estimated total from Mehlich-3 test, seek analysis of bioaccessible Pb; limit exposure of young children.