

LEAD CONTAMINATION OF SOILS AND PLANTS ALONG
HIGHWAY GRADIENTS IN EAST CENTRAL-ILLINOIS¹

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ABSTRACT

One annual and one perennial species in each of three plant families and soils from 0-10 and 10-20 cm around each plant were examined for total lead content by atomic absorption spectrophotometry. Samples were taken along a highway in east-central Illinois with estimated traffic volume of 12,000 vehicles per day. Roots, unwashed foliage and washed foliage of plants were tested separately. Data were evaluated to determine the relationship between root and foliage lead content to plant lifeform (annual or perennial), family (Graminae, Fabaceae, and Compositae), soil lead, and distance from the highway. No significant differences in lead content of roots were found although the correlation between distance from the highway and root lead was highly significant for all but soybean roots. No effect due to family lifeform was found in lead content of washed foliage. Graminae had significantly less lead in unwashed foliage than Fabaceae or Compositae; the latter families were not significantly different. Significant species differences were noted in both washed and unwashed samples which showed the same relative relationships. The correlation with distance was significant in foliage of all species and for 10-20 cm soil depth but not for surface soil. Lead in nearly all tissues of all species was highly correlated to soil lead irrespective of distance. Data suggest that species exposed to similar conditions of lead contamination will manifest significant differences in absorbed lead and that both soil and fallout lead serve to contaminate plants.

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Numerous investigators have shown that the concentration of lead in soils and plants is significantly higher near highways and drops rapidly along gradients away from this source (Page et al. 1971, Motto et al. 1970, Ruhling and Tyler 1968, Suchdoller 1967, Martin and Hammond 1966, Kloke et al. 1966, Cannon and Bowles 1962). Although wind direction, speed and turbulence are important factors in determining the steepness of these lead gradients, Suchdoller (1967) reported that the lead gradient in beans and barley may be diminished to background within 30 to 40 meters from a highway.

Little is known at present about the forms of lead in the soil. Hirschler and Gilbert (1964) reported that inorganic lead particulates, in the form of $PbCl_2$ or ammonium halide-lead halide complexes, are exhausted into the air by automobiles using lead additives in the gasoline. These authors noted that lead halides were the prevalent form of lead from exhausts. Lead use as a gasoline additive in 1969 consumed 271,128 short tons, the second greatest use of lead in the United States (Borcina 1969). With the majority of this lead becoming deposited in narrow corridors along the streets and highways, it is not surprising that problems of lead contamination are developing.

Contamination of vegetation and soils near highways first was examined by Warren and Delavault (1962). Since then, there have been numerous investigations of this nature. Cannon and Bowles (1962) found lead concentrations of 100 to 700 ppm in the ash of grass samples collected on the edge of a major highway in Colorado. The lead content decreased with distance from the highway to a range of less than 5 to 50 ppm in ashed samples collected at distances of 500 to 1000 feet from the highway. Lead concentrations of 3000 ppm were reported in grass samples at the intersection of two heavily traveled highways while samples collected at the intersection of two less-traveled highways contained 300 to 500 ppm. Their conclusions were that the distribution of lead from an automobile source is controlled by two factors; traffic volume and the prevailing wind direction. Warren and Delavault (1962) determined lead in tree boles collected at locations remote from and adjacent to heavily traveled highways. Values for the remote area were 0.4 to 2.0 ppm (in oven-dry tissue) as compared with 2.0 to 50 ppm in the area of heavy traffic.

Motto et al. (1970) reported that lead content of soils and plants sampled along heavily traveled highways increases with traffic volume and decreases with distance from the highway. They also reported that the major effect of traffic was limited to the surface soil in a narrow zone within 100 feet of the road. In greenhouse and field studies, it was noted that plants can obtain lead through both leaves and roots with little translocation within the plant and that fruiting and flowering portions of contaminated plants contain the smallest amounts of lead (Motto et al. 1970).

The relationship of automotive lead particulates to certain consumer crop species was studied by Schuck and Locke (1970). Five crop species were analyzed for lead content as well as the soil, water and air in contact with these crops. Although growing near heavily traveled highways

(up to 50,000 vehicles per day), the amount of lead associated with the five species was never greater than 1 μg of lead per gram of fresh weight. The combined findings suggest that lead is not concentrated in the edible portion of the crop.

Although considerable research has been done concerning relationships between automotive lead particulates and plants or soils, there have been no studies examining the relationship between these lead exposures and contamination of various plant species or families.

The purpose of this study was to verify the expected lead gradient along the major highway selected for study, examine the relationship between total lead in the soil and that on and in plants, and compare lead uptake by annuals and perennials in each of three representative plant families. Species selected for study are given in Table 1.

TABLE 1. Plant species² examined for lead contamination

Family	Annual	Perennial
Graminae	<u>Zea mays</u> (corn)	<u>Poa pratensis</u> (bluegrass)
Fabaceae	<u>Glycine max</u> (soybean)	<u>Melilotus officinalis</u> (yellow sweetclover)
Compositae	<u>Erigeron annuus</u> (flea-bane)	<u>Taraxacum officinale</u> (dandelion)

METHODS

The highway selected as the primary site for this study was State Route 45 between Urbana and Rantoul, Illinois. Illinois Division of Highways estimated the traffic volume for this road in 1967 to be 11,400 vehicles with a three percent increase per year. Transects were established primarily to the east (downwind) of the north-south road in fencerows and fields on silt-loam prairie soil. Soil pH ranged from 7.0 to 7.4. Effort was made to avoid forest and transition soils that also are present in the area. Plants of the species listed in Table 1 were carefully dug as they occurred along the transects to at least 200 meters from the edge of the pavement. Corn and soybeans were sampled from agricultural fields whereas the other species were sampled from adjacent fencerows and fallow field populations. Soil was removed from the roots and the plants were placed individually in clean plastic bags for transport to the laboratory. At each plant collection site, two composite soil samples were taken with a clean, stainless steel, soil bucket-auger, one sample at 0-10 cm depth and the second from 10-20 cm depth. Each sample was labeled and the distance from the pavement was recorded. Plant

²Nomenclature is that of Gleason and Cronquist (1963).

and soil samples were collected during a four week period from 8 July to 7 August 1969.

In the laboratory, each plant sample was separated into roots, and two foliage subsamples. The roots and one of the foliage subsamples of each sample were washed through deionized water, glass distilled water, and double glass distilled water baths, then rinsed in a double glass distilled water stream. Water baths were changed after each ten samples. Extreme care was taken to avoid contamination in handling or exposure to air. Each subsample was placed in layered paper towels and then in loosely packed plant presses. Presses were covered and placed in a drier powered with six 100 watt bulbs. After plants were dried, samples individually were sealed in new plastic bags. Soils were dried under cover and ground with a porcelain mortar and pestle and sieved through a brass 2 mm sieve. Equipment was scrupulously cleaned after each sample.

Both 100 ml pyrex beakers and 50 ml vycor crucibles were used as sample containers. In all cases the glassware was soaked in 1:1 constant boiling HCl and deionized water before usage to leach out any trace metals. The glassware was similarly treated between uses.

All standard solutions were kept in screw-top polyethylene bottles which were conditioned to the concentration for which they were to be used for approximately one week before use. All atomic absorption measurements were made using a Beckman 440 Atomic Absorption Spectrophotometer with a Beckman Hollow Cathode lamp.

An acid solution was prepared using the constant boiling fraction of an HCl distillation prepared in the laboratory. This fraction (6 M HCl) was diluted 1:1 by weight with deionized water. This solution (3 M HCl) will be referred to as the HCl solution.

Standard solutions were prepared from a 1000 ppm Pb stock solution or from a 100 ppm solution. The stock solution was prepared by dissolving 1.5985 g of reagent grade $Pb(NO_3)_2$ in enough deionized water to make 1000.00 g of solution. A 100 ppm Pb solution was made by a 1:10 dilution by weight of the stock solution, using deionized water. Standards of 10.0 and 5.0 ppm were prepared by dilutions of the 1000 ppm solution. Standards of 2.5, 1.0 and 0.50 ppm were prepared by dilutions of the 100 ppm solution. Solutions were remade weekly.

Root and foliage samples, weighing between 0.8 g and 3.0 g, were placed in a beaker or crucible and dried in an oven at 105° C for a minimum of two hours. Drying time in excess of two hours was noted to have no further effect on weight loss of samples which had been previously dried after preliminary preparation. The dried samples were weighed on an analytical balance and placed in a muffle furnace at 450° C for a minimum of six hours. (Ashing times greater than six hours were investigated using duplicate samples and resulted in reproducible weight losses on ashing and reproducible concentrations of lead in the final determination.) The ash residues were weighed and the percent weight losses were calculated. The average weight loss for roots and foliage was 95 ± 1 percent, except for grasses (corn and bluegrass) where the loss was found to be 93 ± 2 percent.

Ash residues were treated with 20.00 g of HCl solution and warmed overnight, loosely covered, on a hot plate. The solutions were then brought back to a net weight of 20.00 g by the addition of deionized water. These solutions were analyzed for lead by the method of atomic absorption spectrophotometry.

Instrument parameters used were:

- 283.3 μm wavelength
- 20 ma lamp current
- 650-750 PM voltage
- 10:1 air to acetylene, usually with 20 lbs support triple pass, using mirrors to provide approximately 30 cm of flame

The 10:1 support to fuel ratio gave a slightly lean flame and was identified as the point at which the hydroxyl bands disappeared.

The concentration of lead in each 20.00 g solution was determined by comparison with a calibration curve of standards which were run on the instrument between each 5 or 6 samples. Soil samples were treated as above except that initial samples ranged in weight from 1 g to about 8 g. The average percent weight loss on ashing was found to be 7 ± 1 percent. No corrections were used for sample preparation losses because samples were checked by recovery. For each set of samples, a matrix factor correction was obtained by standard addition methods. Background was measured frequently during analysis of each batch of samples and was corrected by either reference to the nonresident lead line at 282.0 μm or the neon line at 280.2 μm .

RESULTS

The lead content of surface soils (0-10 cm) showed a nonsignificant ($P \leq 0.072$) negative correlation to the log of the distance from the highway (Fig. 1). The correlation between soil lead and distance accounted for 5.25 percent of the variance in the data. The correlation between the log of the distance from the highway and lead content of subsurface soil (10-20 cm) was significant ($P \leq 0.025$) but accounted for only 2.17 percent of the variance in observed lead content. The correlation between surface and subsurface soil lead also was significant ($P \leq 0.001$) and accounted for 50.4 percent of the variance (Fig. 2).

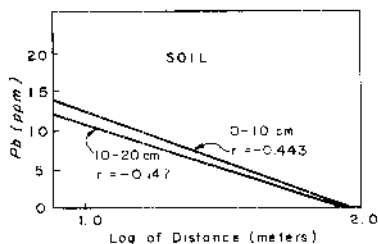


Figure 1. Relationship between soil lead and distance from highway.

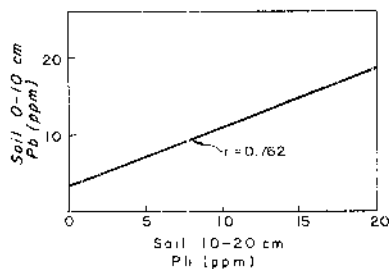


Figure 2. Relationship between surface-soil lead and subsurface soil (10-20 cm) lead for transect shown in Figure 1.

In nearly all species tested, lead in and/or on tissues was a function both of distance from the road and lead in the soil. Correlations with distance are summarized in Table 2 and with soil lead in Table 3. Lead content of all tissues examined, except soybean root, significantly was correlated to the log of the distance from the highway although the percent of the variance accounted for by the correlation often was very small.

TABLE 2. Summary of correlations between log of distance from highway and lead in plants. Probabilities are based on a "Z" distribution.

	Correlation coefficient	Significance (P ≤)	Percent of variance accounted for by correlation
Corn			
root	-0.417	0.0014	17.4
washed foliage	-0.657	0.0000	43.1
unwashed foliage	-0.612	0.0000	37.5
Bluegrass			
root	-0.424	0.0154	18.0
washed foliage	-0.674	0.0005	45.5
unwashed foliage	-0.793	0.0000	63.0
Soybean			
root	-0.094	0.2546	0.9
washed foliage	-0.727	0.0000	52.9
unwashed foliage	-0.681	0.0000	46.4
Sweetclover			
root	-0.392	0.0051	15.4
washed foliage	-0.640	0.0000	41.0
unwashed foliage	-0.668	0.0000	44.7
Fleabane			
root	-0.412	0.0020	17.0
washed foliage	-0.770	0.0000	59.4
unwashed foliage	-0.722	0.0000	52.2
Dandelion			
root	-0.591	0.0089	35.0
washed foliage	-0.638	0.0054	40.8
unwashed foliage	-0.792	0.0015	62.8

TABLE 3. Summary of correlations between lead in soil and lead in plants. Probabilities are based on a "Z" distribution.

	Surface Soil (0-10 cm)			Subsurface Soil (10-20 cm)		
	Correlation coefficient	Significance (P ≤)	Percent of variance	Correlation coefficient	Significance (P ≤)	Percent of variance
Corn root	0.723	0.0000	52.3	0.449	0.0010	20.1
washed foliage	0.169	0.1335	2.9	0.370	0.0060	13.7
Bluegrass root	0.421	0.1335	17.7	-0.119	0.3520	1.4
washed foliage	0.680	0.0359	46.3	-0.161	0.3050	2.6
Soybean root	0.305	0.0217	9.3	0.324	0.0150	10.5
washed foliage	0.373	0.0136	13.9	0.432	0.0043	18.7
Sweetclover root	0.035	0.4325	0.1	0.170	0.2119	2.9
washed foliage	0.248	0.1112	6.2	0.112	0.3015	1.2
Fleabane root	0.170	0.1539	2.9	0.383	0.0139	14.7
washed foliage	0.322	0.0301	10.4	0.288	0.0548	8.3
Dandelion root	0.367	0.1112	13.5	-0.077	0.3974	0.6
washed foliage	0.641	0.0166	41.1	-0.170	0.2877	2.9

Lead in corn and soybean roots, and that in bluegrass, soybean, fleabane and dandelion foliage was significantly correlated to lead content of surface soil (0-10 cm). Lead in roots of corn, soybean and fleabane were significantly correlated to subsurface soil lead (10-20 cm); lead in foliage of corn and

soybeans were similarly correlated. Variances accounted for by these correlations were small. Within every sampled population, variance was high, suggesting either extreme fluctuation of lead content within the gradient from the highway and lack of consistent association between soil lead and plant uptake, or experimental error.

Figures 3 through 8 show the relationship between soil lead and plant tissue lead. Note that only grass (corn and bluegrass) shows a strong positive relation suggesting that soil lead may be the primary source of lead in tissues of these species.

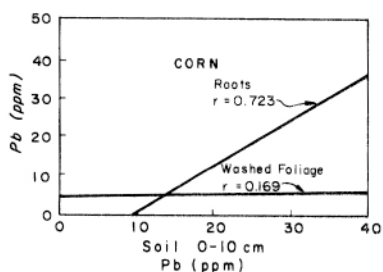


Figure 3. Relationship between soil lead and lead in foliage and roots of corn at time of tasseling.

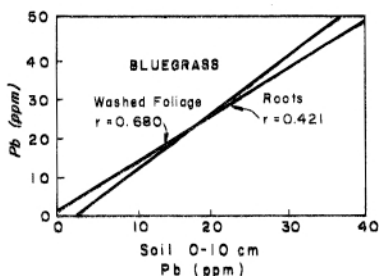


Figure 4. Lead in foliage and roots of bluegrass as related to soil lead.

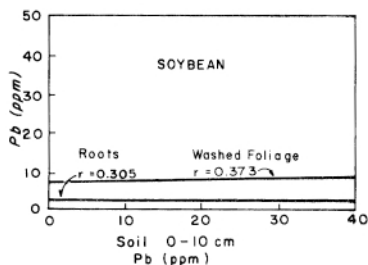


Figure 5. Relationship of lead in soybean roots and foliage as a function of soil lead.

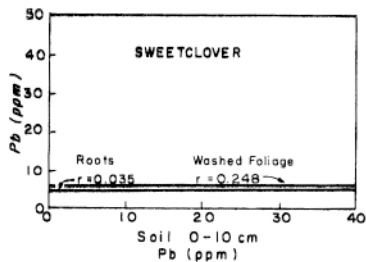


Figure 6. Relationship of lead in sweetclover roots and foliage as a function of soil lead.

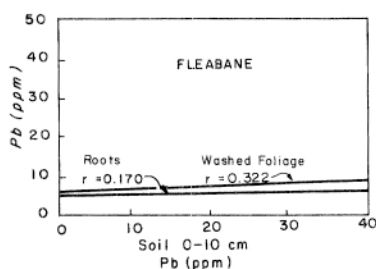


Figure 7. Lead in foliage and roots of fleabane as related to soil lead.

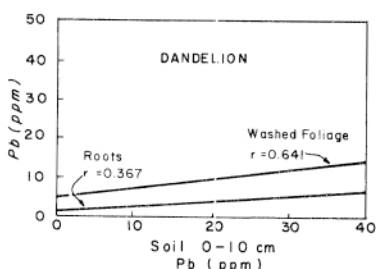


Figure 8. Relationship of lead in dandelion roots and foliage as a function of soil lead.

Analyses of variance were run to determine if there were significant differences ($P \leq 0.05$) in lead content of families (3) or lifeforms (2) (i.e., annual or perennial); lifeform-family interactions were tested and variance attributed to distance was isolated. No significant differences were found in root lead. With washed foliage, the lifeform-family interaction was significant. Table 4 shows the interpretation of the significant interaction.

TABLE 4. Analysis of significant lifeform-family interaction of lead in washed foliage using Tukey's w-procedure at $P \leq 0.05$. Values are mean lead levels in ppm. A common underline indicates no significant difference.

<u>Soybean</u>	<u>Dandelion</u>	<u>Bluegrass</u>	<u>Fleabane</u>	<u>Sweetclover</u>	<u>Corn</u>
11.4	9.6	8.6	6.8	6.0	6.0

A similar analysis of variance for lead content of unwashed foliage showed significant differences between families as well as lifeform-family interaction. Interpretation of the interaction is given in Table 5.

TABLE 5. Analysis of significant lifeform-family interaction of lead in unwashed foliage using Tukey's w-procedure at $P \leq 0.05$. Values are mean lead levels in ppm. A common underline indicates no significant differences.

<u>Soybean</u>	<u>Dandelion</u>	<u>Bluegrass</u>	<u>Fleabane</u>	<u>Sweetclover</u>	<u>Corn</u>
14.7	14.0	10.7	8.9	6.7	6.5

DISCUSSION

As noted in the results, a significant correlation routinely was found between lead in soil, lead in and/or on plants, and the log of the distance from the highway. This confirms the conclusion of all earlier workers, cited above. Correlation coefficients, however, or percent of variance accounted for by the correlation, generally was small, indicating a great amount of variance in the data of a species or soil that was unrelated to distance. Much of this variance undoubtedly was real, indicating much irregularity in the distribution of lead in the field. Experimental error, resulting from accidental contamination of samples during collecting and processing, and analytical error certainly contributed some of the variance. Careful control of the analytical procedures allows us to assume an accuracy of at least one part per million. Likewise, field methods and processing of samples were applied with extreme care to avoid contamination. Therefore, we assume that most of the variance observed was not introduced by experimental error. The high amount of variation in the distribution of lead along highway gradients greatly reduces the predictive ability of models for lead distribution in the environment. Our data suggest that lead in soil can be predicted from information on traffic and distance from source with less than 50 percent accuracy.

Given only a known content of lead in soil, our data further suggest that only a poor prediction can be made of lead in plants growing in the soil. This prediction is only slightly improved by noting the species or lifeform of the plant. In general, it appears that the rate plants absorb lead is a function of much more than lead content of the soil and the species.

As indicated in the data in Table 3, lead in the surface soil (0-10 cm) was much better correlated to plant tissue lead levels than subsurface soil (10-20 cm) lead. This was true for "weedy" species, often growing in irregularly tilled soil, and for crop species where tillage mixes lead deposited on the surface into the plow layer. Apparently, roots in the top 10 cm of the soil are much more important in lead uptake than roots at 10 to 20 cm. One possible interpretation of these data that seems justified is that some significant translocation does occur from roots to foliage, in

at least some species, bluegrass and soybeans, for example. This is in contrast to the summary of Motto et al. (1970). Although there were no significant differences in root lead among the species tested, corn root lead was much more highly correlated to soil lead than was lead in roots of other species. Similarly, lead in bluegrass and dandelion foliage was better correlated to soil lead, although the average content of lead in foliage of these species apparently was not as great as that in soybeans.

Lead in many species showed a higher correlation to distance from the highway than to actual soil lead. This is not unexpected with lead from unwashed tissue where leaf surface contamination is important, but was not expected in washed tissues, especially roots. This suggests that experimental error in soil analyses was compounded by experimental error in plant tissue analysis resulting in lower correlation between these parameters than between tissue lead and distance which was relatively free of experimental error.

Data in Tables 4 and 5 suggests either that surface contamination of plants by lead is relatively small or that our techniques were inefficient for removing lead. Probably both interpretations apply. It is apparent from the data that washing did remove some lead (Table 6). Because the

TABLE 6. Lead removed from plant foliage by two washings and double distilled water for the final rinse. Data are mean lead levels of all samples.

<u>Species</u>	<u>Unwashed foliage</u>	<u>Washed foliage</u>	<u>Difference</u>	<u>Percent</u>
Soybean	14.7	11.4	3.3	23
Dandelion	14.0	9.6	4.4	31
Bluegrass	10.7	8.6	2.1	19
Fleabane	8.9	6.8	2.1	24
Sweetclover	6.7	6.0	0.7	10
Corn	6.5	6.0	0.5	8

amount of lead removed by washing, as indicated in Table 6, did show a trend parallel to the amount present in the unwashed samples, one must reserve judgment on the significance of lead in plant tissue based on washed samples. Washing tended to reduce differences between species and, perhaps, more thorough washing would eliminate significant differences. Thus, soybeans may appear to absorb more lead merely because the pubescent leaves are more difficult to wash. On the other hand, dandelion probably did have more lead than sweetclover or corn, all of which have relatively smooth surfaces that are washed easily. Recall that roots, which are much more comparable in texture, showed no significant differences between species.

All species examined tended to have less lead in roots than in washed foliage throughout the 200 m gradient from the highway. Plants within 30 m of the highway had, on the average, about twice as much lead in roots and three times as much lead in foliage as plants 100 m or more away from the

highway. Beyond 100 m downwind there was no apparent trend in lead level, a conclusion that confirms the reports by Suchdoller (1967) and Motto et al. (1970).

Additional studies are underway to determine factors influencing lead absorption from soil by plants. We expect from our data that species differences in lead uptake occur, yet unknown environmental factors apparently influence lead uptake beyond species differences. Because our study was conducted on the same soil type within a relatively small area, physical characteristics of soil were quite similar. Therefore, we believe that chemical characteristics of soils, such as pH and phosphorus level, may be more important in determining the rate of uptake by plants than texture or structure.

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