Chap. 2

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LEAD AND PLANTS

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Lead is a natural, but minor, constituent of soils and plants. Swaine (1955) estimated the average content of lead in the earth's crust to be 16 ppm and gave a range of lead in agricultural soils of 2 to 200 ppm. Most investigators report soil lead levels within these limits, however, a few have found lead in certain soils to exceed the limit suggested by Swaine (1955). From an examination of available literature it would appear that the native content of lead in agricultural soils is quite low, probably less than 40 ppm.

The lead content of the soil in a profile is not constant for all depths. It is normal for lead content of undisturbed soil to decrease with depth. Wright et al. (1955) working in Canada measured the lead in four different soil groups and found a range of from 6 to 108 ppm lead with the greatest concentration occurring in the surface horizons. The soil parent material averaged 15 ppm lead. The work of Motto et al. (1970), Schuck and Locke (1970) tended to confirm this trend.

Kloke and Riebartsch (1964) found the amount of lead in soils to be proportional to motor vehicle traffic in a number of locations near highways. They found an increase of from 6.4 to 36.5 ppm lead with a traffic increase of from 11,000 to 32,000 cars per 12 hours. The work of Motto et al. (1970) indicates a sharp decrease in the lead content of surface soil in the 75 feet adjacent to the highway. These facts illustrate the possibility of lead contamination of soils from pollution.

Plant uptake of lead from soil will probably be better related to soluble lead rather than total lead. Motto et al. (1970) reported that plants are capable of absorbing soluble lead from solutions. In a greenhouse experiment five crop plants (carrots a root crop, potatoes a tuber crop, tomatoes a fruit, corn a grain, and lettuce a leafy vegetable) were grown in acid-washed sand to which complete nutrient solutions were added daily until the plants were well established. After the plants were established in the sand culture, the sand was washed by leaching with distilled, deionized water. Each culture was then treated with nutrient solutions minus phosphorous but containing 0, 1, 2, or 4 ppm lead as lead nitrate. These solutions were added daily to the growing plants for a period of 1 week after which the sand was again washed and complete nutrient solution added for a period of 1 week. This was repeated until the crops were ready for harvest. All harvested plant parts were washed in distilled deionized water containing added detergent. The results of this experiment are recorded in Table 1. From these data it is clear that the roots of all crops absorbed soluble lead and translocated some of it to all above ground parts of the plant except to the fruits of tomatoes and the grain of corn. It is also clear that in lettuce, potatoes and tomatoes where the small feeder roots were analyzed, the lead content of these plant structures was very high, whereas, in corn and carrots where larger roots were used the lead content was considerably reduced.

The importance of soluble lead versus total lead is shown by a greenhouse experiment conducted by Marten and Hammond (1966) where an eight fold increase in total lead content of a soil did not result in a significant increase in the lead content of bromegrass grown therein.

Brewer (1966) in his review of studies on lead in plants and soils gives a general range of 0.05 to 5 ppm of soluble lead in soils. Keaton (1937) found a very high degree of fixation of lead in soils. Only 17 ppm soluble lead was found in soils three days after addition of 2784 ppm lead as lead nitrate. The amount of soluble lead increased with lead added, but decreased with time. In the large collection of lead values reported by Swain (1955) the average amount of lead extracted with acetate or acetic acid solutions from soils in Scotland was less than 1 ppm. Thus the soluble lead content of soils is very low compared to the total lead content.

Widely varying amounts of lead have been reported in plant material. Keaton (1937) found less than 3 ppm in plant tops, but almost 800 ppm in the roots of barley plants grown in soils treated with up to 800 ppm lead. Liebeg et al. (1942) reported as high as 890 ppm of lead in the roots of lemon cuttings grown in solution culture, whereas less than 3 ppm was found in the leaves of some corn plants, while Gamble (1963) found less than 0.3 to 30 ppm lead in the leaves of various plant species growing in three wooded areas in New Jersey. Warren and Delavault (1962) analyzed several crop plants for lead. They reported average values for all plants studied to be less than 10 ppm.

Some investigators have considered the lead content of plants as affected by proximity to busy highways. Warren and Delavault (1962) determined lead in tree stems collected from an area remote from highway traffic and in stems of the same plant species collected from an area of heavy traffic. The values for the remote area ranged from 0.4 to 2.0 ppm and for the heavy traffic area from 2 to 5.2 ppm. Cannon and Bowles (1962) found 100 to 700 ppm in the ash of grass samples collected within five feet of highways. The lead content decreased with increasing distance from the highways to a range of 50 to 5 ppm in the ash of samples collected 500 to 1000 feet distance. Grass collected at the intersection of two heavily travelled highways contained 3000 ppm lead in the ash, while grass at the intersection of less travelled highways contained 500 ppm lead. ✓Cannon and Boeles state that the distribution of lead is controlled by traffic volume and wind direction.

Kloke and Riebartsch (1964) found an increase in lead in roadside grass tops from 16.2 to 57.0 ppm. Motto et al. (1970) analyzed for lead in grass clippings gathered at seven distances (0 to 225 ft.) from highways supporting 12,800 to 54,700 cars daily. All samples were divided and one portion washed in four changes of distilled deionized water to which a small amount of detergent was added to the first washing. The second portion was analyzed without washing. In this experiment the average lead content of unwashed orchard grass clippings gathered at the highway edge was more than 5 times as high (255 ppm) as grass gathered 225 ft (46.3 ppm) from the highway. It was of interest to note that this decrease in lead content was greatest close to the highway with the greatest decrease occurring in the first 75 ft from the highway. If the average lead content of the grass samples reported by Motto et al. was charted with distance from the highway as the abscissa, the curve would be very similar to the one charted by Daines et al. (1970) for atmospheric lead and distance from a highway. In this last study they reported a decrease in particulate lead in the atmosphere of over 50% between 10 and 150 feet from the highway.

Motto et al. (1970) further report that washing the grass removed lead from all samples studied, however, those gathered in the first 75 ft lost the greatest amount of lead (near 50%) from the washing. The fact that lead can be removed from leaves by washing demonstrates that all or a large portion of the lead on leaves coming from air pollution is, as stated by Schuck and Locke (1970) present "as a topical dust coating of which 50% can be removed by simple water washing."

Everett, Day, and Reynolds (1967) measured the lead content of privet leaves collected from two sites at many locations along main highways (site 1), and remote from highways (site 2), throughout England.

They found an average of 86 ppm from foliage collected at site 1, and 45 ppm from comparable foliage gathered from site 2.

They also report the lead of the privet foliage to be greater for the months of September through April than for the months of May through August. Mitchell and Reith (1966) also report higher foliage lead values for the winter months and suggests that the increase may be due to:

1. - Lead in roots translocated to tops during the winter months, or

2. - An increase in the lead level content would be expected as a result of the loss of organic matter due to respiration during the winter months.

In addition Daines et al. (1970) report an increase in atmospheric lead during the winter months hence increasing the opportunity for an increase in the lead deposit from air pollution. During the summer months plants are normally increasing in size, thus diluting the lead deposit on their leaves with new tissue. It would be expected that lead deposit on leaves would increase with increasing exposure time.

Leh (1966) compared rye and potato plants growing within 15 feet of traffic with similar plants growing more than 300 feet from the highway. The lead content of chaff and green tops from near the highway was higher by a factor of about two, while the content in kernels and tubers was not changed. In this connection Dedolph et al. (1970) reported that the lead content of the fleshy radish roots was unaffected by the lead in the air and soil in the experiments reported by them. Ter Harr (1970) states that edible portions of wheat, potatoes, tomatoes, sweet corn, carrots, cabbage, oats, rice, and leaf lettuce grown 30, 120, and 520 feet from a highway carrying 29,000 cars each 24 hours, "showing no correlation between lead concentration and distance from the road." He did report an increase (95% level of confidence) in the lead on the snap bean pods. Moto et al. (1970) grew five commercial crops (lettuce, tomatoes, corn, potatoes, and carrots) at locations along a highway supporting 12,500, 47,100, and 49,000 cars every 24 hours. These crops were grown 30,100, and 250 feet from the highway in each of the three locations and the soil in all locations was a sassafras loam. All plants were grown to usable maturity except the corn. It was harvested after the kernels had become hard. The data secured from this experiment are recorded in Table 2. From these data the effect of the highway on the lead in the air and soil is clearly demonstrated in all but the soil at the 47,100 car location. The soil in this field has been moved around considerably during grading operations. In addition the data demonstrate the tendency for lead from air pollution to accumulate on leaves and other exposed above ground structures. However, lead deposited on the leaves of plant adjacent to a highway carrying only 12,500 cars daily failed to show a correlation between lead deposits and distance from the road. At the locations where there were 47,100 and 49,000 cars, however, the correlation was highly significant. It is of interest to note that these washed samples indicate that the lead from the air or the soil did not increase in the portions of plants consumed by humans except for lettuce leaves. Here the samples gathered near the highway supporting 47,100 and 49,000 cars daily exhibited a highly significant increase in the lead present. However, the leaves of all these crop plants may be eaten by animals.

In an effort to gain information on the contributions from the lead in soil and air to that found on vegetation near highways, soil from the surface 6 inches of field plots beside a highway carrying 47,100 cars was transferred to the greenhouse, mixed, screened, and placed in 3 gallon glazed porcelain pots (Motto et al. 1970). Plants growing in this soil generally showed more lead in the roots than in the leaves, and the differences in lead in leaves was not significant between plants growing in the soil from the plot close to the highway as compared with the soil from the plots 100 and 250 feet from the traffic. The lead content of the soil near the highway was 164 ppm, while that at 100 feet was 95 and a 250 feet 76 ppm.

The plants in question usually showed more lead in the root than in the leaves, and in almost all cases the root-lead from soils gathered at 30 feet from the highway was considerably higher than from the roots from the other locations.

Although a considerable volume of literature is devoted to the studies of lead in soils and plants, there seems to be no reliable evidence indicating that lead injures plants in nature. During the period when lead arsenate was used as an insecticide on tree fruits, injury to apple and peach foliage was common. However, this phytotoxicity was produced by the arsenical and not the lead part of the compound.

During and immediately following the second World War, the chronic disease "Itai-Itai" (ouch-ouch), unknown until modern times, occurred in very limited areas bordering water ways near cadmium, zinc, lead mines. In addition, rice plants in fields flooded by river water, located in the same areas as the "Itai-Itai" disease is reported by Kobayashi (1970) as having been damaged and the harvest decreased. In 1955 the mine (area of greatest plant damage) constructed a dam, impounding the muddy waste water from the flotation plant in a lagoon. Following this the disease of humans rapidly decreased and the injury to the rice plants was gradually corrected.

Studies on the cause of injury to rice plants was limited to chemical analysis. The results of which is recorded in Table 3 while feeding studies according to Kobayashi, indicated that cadmium was the cause of the "Itai-Itai" disease. From these data, which do not identify the cause of the injury, it is of interest to note the low lead content of the rice, and the accumulation of lead in the roots. Kobayashi in his discussion pointed out that the ash from the roots contained more cadmium, zinc, and lead than the soil.

From studies using *Alluim cepa* (onions), *Zea mays* (corn), and *Vicia faba* (broad bean) Hammett (1928, 1929), in his studies on the "Biology of Metals," reports the concentration of lead within the nuclei and cell walls of the growing portions of roots. In this location he reported lead retarded cell proliferation while allowing cells to increase in size. In further studies Hammett reported that the mitotic (dividing) "nucleus of the growing roots have a special avidity for lead." In a subsequent report Hammett reported that continuing studies indicated a reaction between lead and an organic sulphydral occurred in the area of normal rapid elongation. Of interest is the comment that "the sulphydral group stimulates cell proliferation in mammals and in lower organisms."

Koeppe and Miller (1970), using corn mitochondria, found that lead chloride (50 to 62 micromoles per liter) in either KCl or sucrose-containing mediums stimulated oxidation of exogenous reduced nicotinamide-adenine dinucleotide. This increased oxidation was not affected by the presence of phosphate. These studies further indicated that lead chloride (12.5 micromoles per liter) inhibited oxidation of succinate in the absence of phosphate. Since phosphate is an essential for plant growth, the effect on succinate oxidation would seldom be encountered in nature.

CONCLUSIONS

1. Plants can absorb soluble lead through the roots and translocate some to above ground portions of the plant.

2. The lead naturally occurring in soils is largely unavailable to plants, as is the lead in soils coming from air pollution along busily travelled highways.

3. Plants growing near busy highways (75 feet range) show significant increases in lead on their leaves. There is little or no evidence that this lead can be translocated downward to the underground portions of the plant.

4. Since about 50% of the lead on leaves of plants growing near busy highways can be removed by a water wash, it must be concluded that much of the lead is present as a surface deposit. Although the lead particles in the are are small enough to enter the open stomata of plants, unless prevented by electrostatic forces, there is no evidence to prove that lead particles from air pollution enter the leaf.

5. Lead from soil is present in largest concentrations in the small roots of the plant. Lead from the air accumulates on the above-ground portions of the plant such as the leaves. This accumulation is largest close to busy highways and the deposit should be increased by extending the length of exposure.

6. Deposits found on leaves are greater in winter than in summer months.

7. Lead from soil and air tends not to accumulate in edible fruits, grains, tubers, and fleshy roots. The evidence indicates, however, that there is an accumulation of lead on leaves of plants grown within 75 feet of highways supporting 47,100 to 49,000 cars daily. However, no such significant accumulation occurred along highways carrying 12,800 or 29,000 cars per 24 hour period.

8. Evidence showing lead, as it occurs in nature, to be toxic to vegetation is lacking. However, in studies using roots of certain plants, lead has been reported to concentrate in cell walls and nuclei in mitosis, to inhibit cell proliferation and allows the continued increase in the size of cells. In addition, using corn mitocondria, it has been reported that lead chloride stimulated the oxidation of exogenous reduced nicotinamide-adenine dinucleotide, and reduces the oxidation, in the absence of phosphate of succinate. Since phosphate is an essential element for

plant life, the importance of the effect of lead chloride on the oxidation of succinate in plant cells is uncertain.

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Table 1. Lead content of plants grown in acid washed sand in the greenhouse in 1968.

	Treatment (ppm Pb)			
	0 ppm Pb	1	2	4
Carrot				
Tops	8.7	16	19	27
Roots	3.1	7.9	18	21
Corn				
Tassel	7.8	8.1	7.4	9.2
Leaves	11	19	39	88
Stalk	0.6	11	28	44
Husk	...	...	...	...
Outer	2.9	7.9	15	23
Inner	3.9	7.3	13	16
Roots	3.7	12	22	35
Kernel	1.0	1.7	2.8	3.3
Cob	2.4	2.7	4.3	10
Lettuce				
Leaves	5.7	12	16	37
Roots	7.6	108	182	332
Potato				
Leaves	11	7.8	12	12
Stems	7.6	29	55	123
Roots	30	200	451	764
Tuber	1.0	0.6	2.6	1.2
Tomato				
Leaves	8.1	8.1	15	16
Stem	3.6	24	89	87
Root	17	418	690	739
Fruit	3.6	2.5	2.3	2.1

Table 2. Lead content of five crops grown at three field sites in 1968.

Traffic volume	12,500/24 hr.			47,100/24 hr.			49,000/24 hr.		
Distance from highway (ft.)	30	100	250	30	100	250	30	100	250
Air (ug. Pb/m^3)	1.4	1.1	1.0	4.5	2.7	2.4	5.2	3.3	2.5
Soil Pb (ppm 0-6")	54	38	33	134	138	300	229	130	89
Carrot									
Tops	18	11	14	37	26	21	53	22	17
Roots	3.8	5.3	3.9	6.2	9.5	9.4	9.1	10	5.0
Corn									
Tassel	31	7.4	7.8	179	144	69	...	...	...
Leaves	19	17	14	86	47	36	88	51	40
Stalk	3.6	3.7	0.9	5.6	3.6	0.2	6.2	3.4	3.6
Husk	...	...	...	3.0	5.0	2.6	...	...	...
Outer	11	5.0	6.8	...	...	...	...	...	...
Inner	5.0	5.2	2.4	...	...	...	...	...	...
Roots	6.0	3.9	5.4	19	14	19	54	19	...
Kernel	3.8	3.6	3.1	0.0	0.2	0.2	...	...	...
Cob	8.0	3.2	2.6	0.4	00.0	0.4	...	...	...
Lettuce									
Leaves	12	13	...	24	21	14	56	35	...
Roots	16	15	...	24	27	39	61	32	...
Potato									
Leaves	36	31	21	87	47	29	...	...	...
Stems	12	8.4	7.8	15	11	14	...	...	...
Roots	22	23	18	33	49	58	...	...	...
Tuber	0.5	1.5	1.0	2.6	3.0	3.0			
Tomato									
Leaves	36	25	17	76	82	40	88	52	44
Stem	9.0	9.8	6.9	27	25	31	29	13	7.7
Root	11	15	14	27	35	50	37	12	9.6
Fruit	2.8	3.0	2.4	4.6	2.7	2.8	3.6	1.2	3.2

Table 3. Heavy metals in paddy soils, rice roots, and polished rice collected from the disease district (ppm in ash).

	Soil average of 5 samples	Root average of 5 samples	Rice average of 17 samples
Zn	1,125	2,600	4,700
Cd	6	1,250	125
Pb	348	810	22