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Lead Quantities in Plants, Soil, and Air near Some Major Highways in Southern California

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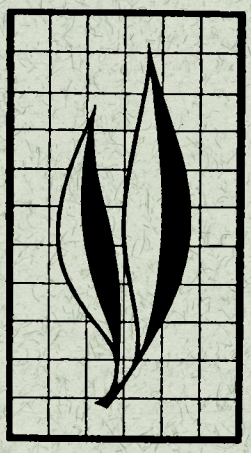

The lead contents of 27 varieties of consumer crops and plants sampled at various distances from some major highways in southern California and in local markets were carefully determined. Amounts in and on crops grown close to these highways were shown to be influenced by (a) distance from the highway, (b) extent of plant surface exposed, (c) external plant characteristics, (d) duration of plant exposure, (e) motor vehicle traffic density, and (f) direction of prevailing winds. In soils and suspended air particulates, concentrations of lead were influenced by distance from highway and direction of prevailing winds. All results demonstrated that lead accumulations in and on plants next to these highways in southern California were caused principally by aerial deposition and not by—at least to any great extent—absorption by the plant from lead-contaminated soil.

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INTRODUCTION

AMONG THE PROBLEMS in the overall environmental contamination complex is that caused by lead (Pb). While investigations proceed on how Pb affects plant and animal life (Anon., 1969; Goldsmith and Hexter, 1967; Kehoe, 1964; Haley, 1966; and Patterson, 1965), the necessary information on Pb deposition itself continues to stockpile. The authors of this report seek to provide more of this basic information.

Many sources of atmospheric contamination by Pb have been noted, but the most widespread source is acknowledged to be emissions from motor vehicles powered by leaded gasolines (American Chemical Society, 1969). The California coastal area is subject to frequent, unusually low thermal inversions, which means that the upper air flow is not available for removal of Pb contaminants. Conditions such as these, which are characteristic of southern California coastal areas, could influence the Pb content of plants and soils; and adverse levels of Pb on an area-wide scale might be expected.

For the present study, the Pb contents of 27 varieties of consumer crops and plants growing near some major southern California highways were ascertained. Amounts of Pb were also recorded for surface and subsurface soils and in suspended air particulates at or near the locations where plant samples were obtained.

Pb values of four consumer crops—cauliflower, tomatoes, cabbage, and oranges—along with lead concentrations in their associated soils and ambient air, were reported earlier by Schuck and Locke (1970). Values expressed on a fresh-weight basis by these authors are given, in certain cases, in the present report on an oven dry-weight basis. Results of the Schuck and Locke study are included with our findings in order to present a more comprehensive resume of the interaction between Pb particulates from motor vehicle exhausts and the Pb contents of consumer crops and soils in southern California.

LITERATURE REVIEW

Published results of several studies show Pb accumulation by crop plants near highways varies with motor vehicle traffic densities and generally decreases with distance from heavily traveled roads. Also, the amount of Pb accumulated by such plants varies considerably and may be attributable to meteorological elements. The question then arises: How do geographical localities affect Pb deposition and accumulation by plants?

[1] Submitted for publication August 17, 1970.

Cannon and Bowles (1962) reported that the ash of pasture grass adjacent to major intersections near Denver, Colorado, contained 3,000 μg Pb/gm, but at a location 153 meters downwind, only a little more than 50 μg/gm were found. In Canandaigua, (upstate) New York, and Washington County, (western) Maryland, the same authors reported that the ash of homegrown vegetables, within 8 meters of a road, averaged 80 to 115 μg Pb/gm, but 153 meters away they contained an average of only 20 μg/gm. In Germany, Kloke and Riebartsch (1964) found 16 μg Pb/gm (oven dry weight) in roadside grass near a highway with traffic density of 32,000 cars per 12 hours. In England, Warren and Delavault (1962) found that the first-year stems of trees grown in proximity to heavy traffic (in London) contained more Pb than specimens somewhat removed from heavily traveled areas (Sussex). Specimens of ash, oak, and hazel near London contained 14, 20, 52 μg Pb/gm, respectively; while only 2.0, 0.8, and 2.0 μg/gm, respectively, were present in such trees in the outlying area of Essex.[2] Specimens of lime, yew, willow, and birch also showed an increase of Pb in metropolitan areas. Warren and Delavault (1962) also analyzed eleven crop plants located 275 meters from a well-traveled highway in British Columbia, Canada. The average value for all crops was found to be less than 10 μg Pb/gm. In Germany, Leh (1966) reported values of 5.2 and 20.5 μg Pb/gm, respectively, on rye kernel and chaff, at distances of within 5 meters from an expressway; the values diminished to 4.8 and 11.8 μg/gm, respectively, at distances greater than 92 meters. Under similar circumstances, potato tops decreased from 40 to 21 μg Pb/gm, but little change in Pb content of tubers was noted.

Dedolph *et al.* (1970) reported grass susceptible to atmospheric Pb, but not to Pb in rainwater. Radishes were not affected by either source of Pb. Everett, Day, and Reynolds (1967) reported 86 μg Pb/gm in privet leaves along well-traveled highways in England compared with 45 μg/gm in privet leaves along less-traveled highways. Dunn and Bloxam (1933) found that horizontal wind flow affected atmospheric dust. Lead content of grass on the leeward side of the highway was much higher than on the windward side. Ter Haar (1970) studied the Pb content of the edible portions of tomatoes, potatoes, wheat, carrots, leaf lettuce, cabbage, and oats adjacent to U. S. Highway 24 near Detroit, Michigan, where traffic density was 29,000 vehicles per day. No significant effect of Pb concentration was noted on the edible portion of crops grown at distances ranging from 9 to 159 meters from this heavily-traveled highway. The nonedible portions of the crop plants (corn and soybean husks, oat, wheat, and rice chaffs) showed a two- to three-fold increase in lead concentration due to atmospheric Pb. Motto *et al.* (1970) reported an increase in Pb content of five crops—carrots, corn, lettuce, potatoes, and tomatoes—with increasing traffic volume, and a decrease with increasing distance from a highway in northeastern New Jersey where traffic volume ranges from 12,800 to 54,700 vehicles per 24 hours. Distances from the highway, at which tests were made, were 9, 31, and 76 meters. Most of the Pb accumulation was limited to a narrow zone within 31 meters of the highway.

[2] These and all subsequent values for Pb concentrations are expressed on the basis of oven dry-weight of vegetation.

MATERIALS AND METHODS

Plant samples

A number of plant species were collected at various distances from major highways in southern California—mostly from the Irvine Ranch in Orange County south of Tustin (see area 2, fig. 1). The Irvine Ranch had several advantages for the study. It includes some 6,000 acres of orchards and 17,000 acres of row crops in an area where the average daily traffic (ADT) approaches 75,000 motor vehicles. Plant samples also were obtained south of San Bernardino, southwest of Riverside, and southeast of Los Angeles (see areas 1, 3, and 4; fig. 1). Figure 2 shows area 2 of figure 1 expanded, specific sampling sites, and many of the crops sampled. Precise locations, and other pertinent data, are presented under Results and Discussion.

The following plant species were collected adjacent to highways: oranges, lemons, tomatoes, carrots, parsnips, sugar beets, corn, lima beans, red peppers, wheat, alfalfa, strawberries, romaine lettuce, cauliflower, cabbage, and freeway landscape vegetation.

Various parts of several plant species were analyzed. Part of each fresh plant tissue sample was carefully washed, and the remainder was left unwashed. In most cases, the fresh tissues were dried for approximately three days in a forced-draft oven at 70°C. The Pb content of the dried plant samples was determined by the procedure recommended by the U. S. Public Health Service (Keenan *et al.*, 1963). Briefly, the plant material was digested in a mixture of nitric, perchloric, and sulfuric acids followed by colorimetric determination of Pb as the dithizone complex.

Air samples

Four portable samplers were used to collect air particulates. A sampler consisted of a carbon vane vacuum pump, dry test meter, pressure gauge, and a 5-cm filter holder mounted 55 cm above the ground. The samplers were operated from a 9.2-meter mobile laboratory to which local power was supplied. Its automatic instruments measured wind speed, wind direction, and ambient temperature. Particulate samples were collected at various distances from the pavement edge on 5-cm Gelman filters with 0.8-micron pore size. Airflow rates varied between 0.03 and 0.06 m^3/min., and sampling periods, between 1 and 11 hours.

The filters were digested in hot acids and the Pb content determined by the dithizone method.

Market survey

Lead content was ascertained from the following fresh and frozen foods purchased from local markets: celery, collards, artichokes, spinach, romaine lettuce, carrots, potatoes, strawberries, beans, and broccoli. Canned stewed tomatoes were also analyzed.

Soil samples

Soil samples were collected from some of the fields from which the plant samples were obtained, and the amount of Pb soluble in 10 per cent nitric acid was determined. Approximately 1 gm of soil was placed in a test tube and 10 ml of 10 per cent HNO_3 (by volume) were added to the test tube. The tube was allowed to set for a minimum of three days with periodic agitation. Two milliliters of the clear supernatant were digested and analyzed colorimetrically for Pb.

Greenhouse studies

Two greenhouse studies were conducted. In one, alfalfa plants were grown on soils that were irrigated weekly with water containing 10 μg Pb

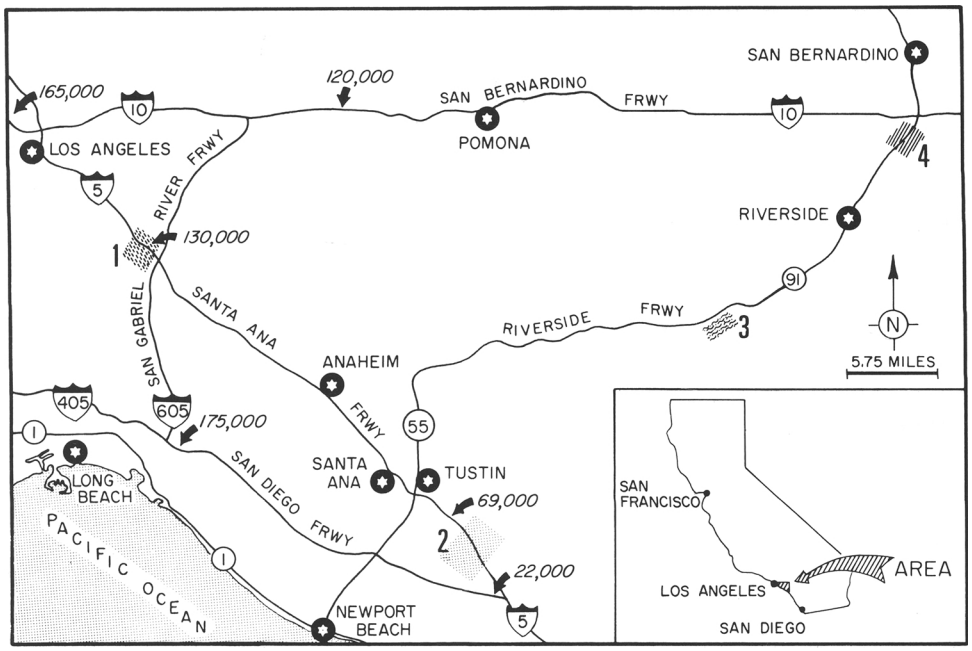

Fig. 1. Areas in southern California where motor vehicle traffic (ADT for 1968 indicated by numbers near solid arrows) affected crops sampled for lead deposition. Area 1, freeway landscape vegetation; area 2, Irvine Ranch where most of the testing occurred; area 3, lettuce; and area 4, alfalfa and air samples.

as lead nitrate. In the second, strawberry plants were grown on soils that contained varying amounts of 10 per cent nitric acid soluble Pb. Details of these experiments are described under Results and Discussion.

Pb particulates in the air

Samples of suspended Pb particulates were collected at 12 different sites on the east and west sides of the Santa Ana freeway. The particulates were collected for a period of 22 days on fluorocarbon films with a total exposed area of 132.25 cm^2 and in 600-ml beakers with a base area of 58 cm^2. The films and beakers were mounted 1.5 and 3 meters above ground level on posts at various distances from the freeway. Samples were collected 15, 30, 46, 107, 168, and 229 meters from the edge of the highway.

The material deposited on the fluorocarbon films or in the beakers was dissolved in nitric acid, and the Pb content was determined by the dithizone procedure.

RESULTS AND DISCUSSION

Alfalfa plants and surrounding air

Alfalfa plants were collected at various distances east and west of the Riverside freeway south of San Bernardino in 1967. At the time the samples were obtained, the ADT was 37,000. Continuous wind measurement from April 1, 1967, to May 10, 1967, showed that 65 per cent of the daytime wind blew into the east field and 75 per cent of the nighttime wind blew into the west field. The Pb concentrations of air samples

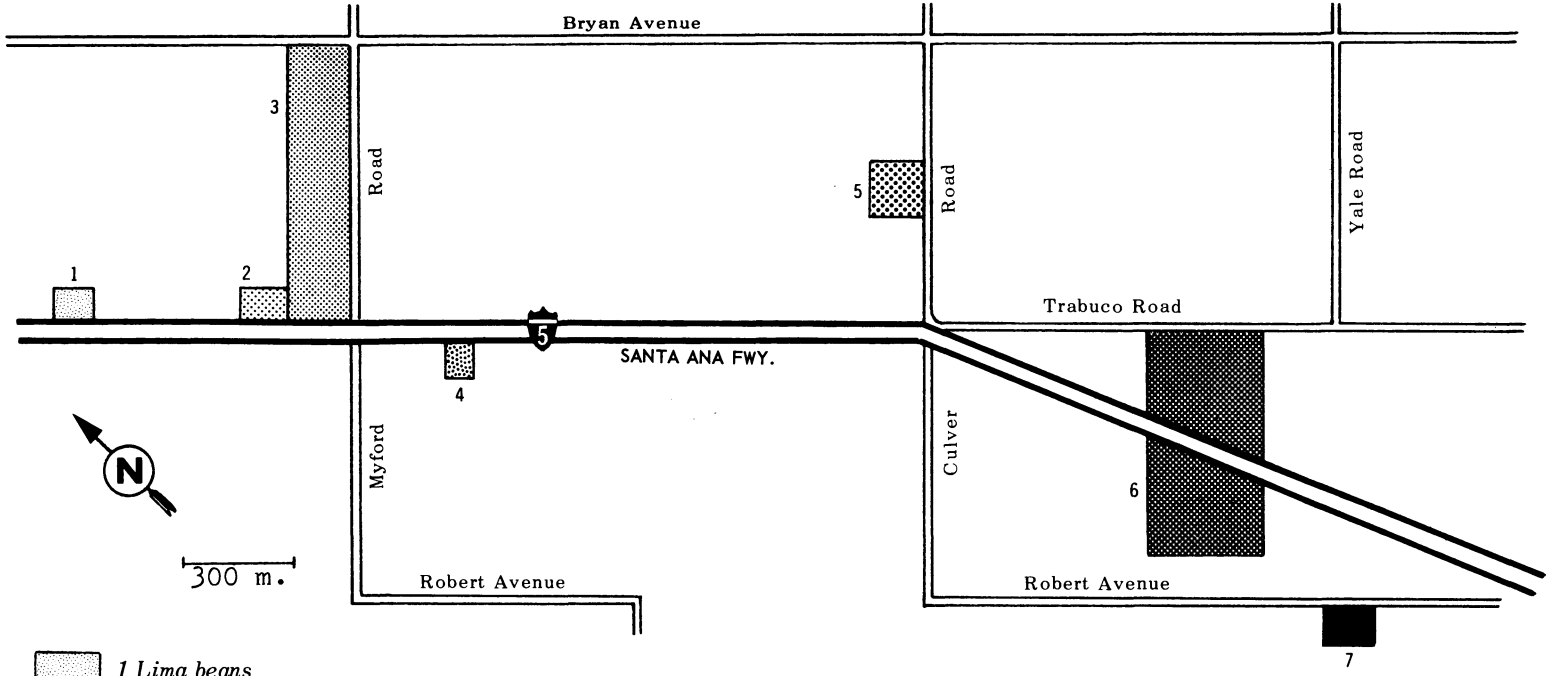

Fig. 2. Irvine Ranch. This is area 2 of figure 1 expanded to show sampling sites and crops tested for lead deposition.

TABLE 1

LEAD CONTENT OF AIR PARTICULATES EAST AND WEST OF THE RIVERSIDE FREEWAY (1967)*

Sampling period	Pb in air			Wind speed†
	8 meters west of pavement:	8 meters east of pavement:	48 meters east of pavement:	
	$\mu g/m^3$			*miles/hour*
P.M.				
12:47- 3:46	1.2	6.2	3.5	4.3
3:30- 7:00	3.1	7.9	4.2	4.7
6:39-10:26	8.2	3.4	2.5	3.1
10:18 P.M.-7:37 A.M.	4.0	3.0	2.6	2.1
A.M.				
7:19-10:13	1.5	9.9	3.0	2.4
10:04-11:58	1.4	6.3	...	3.6
11:55 A.M.-2:03 P.M.	1.0	5.2	2.0	3.5
1:53-4:11 P.M.	0.5	6.3	2.9	5.0
3:56-8:11	1.0	8.4	4.5	4.2
Mean‡	2.4_a	6.3_b	3.2_a	

* ADT = 37,000.

† Continuous measurement for April 1 to May 10 showed that 65 per cent of daytime wind blew into the east field, and 75 per cent of the nighttime wind blew into the west field.

‡ Subscript letters indicate significance at the 5 per cent level of probability. Mean values are statistically different if they do not have the same subscript after the value.

collected 8 and 48 meters east of the pavement and 8 meters west of the pavement are presented in table 1. Lead concentrations of air 8 meters from the east pavement edge, ranged betwen 3.0 and 9.9 $\mu g/m^3$ with a mean of 6.3 $\mu g/m^3$. Eight meters west of the pavement edge, the Pb concentration varied between 0.5 and 8.2 with a mean of 2.4 $\mu g/m^3$. Eight meters from the pavement, the mean Pb content of the air on the east side of the pavement was significantly greater than on the west side. Forty-eight meters east of the pavement edge, Pb concentrations ranged between 2.0 and 4.5 with a mean of 3.2 $\mu g/m^3$. The data presented in table 1 reflect the influence of prevailing winds on the Pb concentrations of air particulates. Similar results demonstrating the influence of wind direction on the Pb content of air particulates next to highways are reported by Daines, Motto, and Chilko (1970).

The Pb content of alfalfa plants, collected at distances from 18 to 80 meters from the freeway, are shown in table 2. Each sample represents the top 15 cm of 70 alfalfa plants, which were cut along a 30-meter line parallel to the freeway at the distances indicated. The washing process consisted of 1-minute agitation after submersion of the plant tops in distilled water. The data presented in table 2 show that the Pb content of the plants was significantly influenced by the direction of the prevailing winds, distance from freeway, age of the plant, and extent of washing. Since the prevailing winds were predominantly toward the east, significantly greater amounts of Pb were found in and on plants on the east side of the freeway. Dunn and Bloxam (1933) observed a similar influence of wind direction on the Pb content of grasses next to highways. Table 2 also shows a significant decrease in the Pb content of the alfalfa plants as their distance from the freeway increased. The older plants were exposed to Pb in the ambient air for longer periods of time and contained more Pb. The distilled-water washing process removed

TABLE 2

LEAD CONTENT OF ALFALFA PLANTS EAST AND WEST OF RIVERSIDE FREEWAY SOUTH OF SAN BERNARDINO (1967)*

Sampling site: relation to R'side Fwy.		Age of plant	Pb content when alfalfa is†			
Distance	Direction		Unwashed:	Washed once:	Washed twice:	Washed 3 times:
meters		*days*	*μg/gm*			
18	east	20	30.0$_a$‡	16.0$_c$	....	....
50	east	20	18.6$_b$	9.4$_d$	....	....
80	east	20	15.4$_b$	6.7$_d$	....	....
18	west	65	18.9$_e$	17.2$_e$	....	....
50	west	65	17.2$_e$	11.4$_f$	....	....
80	west	65	17.4$_e$	8.5$_g$	....	....
25	east	45	60.9$_h$	36.0$_i$	14.2$_{jk}$	19.2$_k$
25	west	24	15.8$_l$	8.2$_m$	6.7$_m$	5.9$_m$
25	east	65	34.9$_n$	14.4$_p$	12.2$_{pq}$	10.6$_q$
25	west	44	14.2$_r$	6.3$_s$	5.4$_s$	5.0$_s$

* ADT = 37,000.
† Oven dry-weight basis (70°C). Each entry is the average of the top 15 cm of 70 alfalfa plants.
‡ Within each set of data separated by the dashed lines subscript letters indicate significance at the 5 per cent leve of probability. Horizontally and vertically values are statistically different if they do not have the same subscript letter

significant amounts of Pb. The first washing removed as much as 56 per cent and, in most instances, significantly more was removed by the second and third washings. The data reveal that large amounts of Pb found their way onto plants via aerial deposition.

Table 3 shows that greater concentrations of Pb were found to be associated with the leaf than with the stem. The stem portion of the plant is shielded somewhat by the leaves. Since a substantial proportion of Pb, found in and on vegetation next to the highway, resulted from aerial deposition, this observation was anticipated. Again, washing with distilled water removed a high percentage of Pb from plant tissue.

In another experiment, several hundred alfalfa plants were collected from the field adjacent to the Riverside freeway. The leaves of these plants were subdivided into six parts, and given six different washing treatments. The leaves were then split into two parts. One part was analyzed fresh, and the second part was oven dried at 70°C for about three days and then analyzed. Lead concentrations in and on the alfalfa leaves and in the various wash solutions are presented in table 4.

TABLE 3

LEAD CONTENT OF ALFALFA PLANTS, STEMS, AND LEAVES (MEAN OF DUPLICATE SAMPLES)

Washing treatment	Pb content in alfalfa (oven dry-wt., 70°C) for		
	Entire plant:	Stems:	Leaves:
	μg/gm		
Control (unwashed)	26.2	9.2	29.0
Washed once.....	13.0	5.0	18.2
Washed twice.....	13.5	2.9	12.6
Washed three times.	8.2	2.6	12.0

About 50 per cent of the Pb was removed from the leaf tissues by washing with water; washing with dilute HNO_3 solutions removed approximately 75 per cent. Essentially, no additional Pb was removed by increasing the concentration from 1.4 to 7 per cent HNO_3

TABLE 4
LEAD CONTENT OF ALFALFA LEAVES SUBJECTED TO VARIOUS WASHING PROCEDURES

Washing treatment	Duration of washing	Condition of leaves	Pb content of		
			Wash solution:*	Leaves:	Leaves plus wash solution:
	minutes		*μg/gm*		
Control:					
(Unwashed)	0	Fresh	....	42.0	42.0
		Dried	....	49.0	49.0
Water	5	Fresh	28.0	28.0	56.0
		Dried		27.0	55.0
HNO_3					
1.4%	5	Fresh	58.0	7.0	65.0
		Dried		7.7	66.0
1.4%	20	Fresh	58.0	4.8	63.0
		Dried		4.9	63.0
3.5%	5	Fresh	46.0	7.9	54.0
		Dried		9.4	55.0
7.0%	5	Fresh	53.0	6.3	59.0
		Dried		3.1	56.0

* Amounts of Pb removed by washing fresh leaves, oven-dry-weight (70°C), washed.

when leaves were washed for five minutes. However, when leaves were washed for 20 minutes in the 1.4 per cent HNO_3 solution, Pb removed was increased by about 10 per cent. The last column in table 4 suggests that slightly more Pb was recovered from the wash solutions and washed leaves than was present initially on the unwashed leaves. This discrepancy can be explained in part by the Pb content of the wash solutions. For all practical purposes, the data show 100 per cent Pb recovery. Drying the alfalfa leaves apparently had no effect on their lead content.

Alfalfa plants irrigated with waters containing soluble Pb were examined in a greenhouse and field-pot study (table 5). Soil from the alfalfa field, adjacent to the Riverside freeway, was collected and placed in 28 pots, each containing approximately 10 kg of soil. Eight pots were placed in a greenhouse equipped with activated charcoal filters (Barnaby-Cheney Co. Model 7FM),

TABLE 5
LEAD CONTENTS IN POTTED ALFALFA PLANTS GROWN IN GREENHOUSE AND FIELD—AND TREATED WITH 1,219 μg Pb IN IRRIGATION WATER

Potted plant in:	Pb content in alfalfa (entire plant) *
	μg/gm
Greenhouse:	
Control	1.1
Treated	1.5
Field (distance from pavement edge):	
22 meters	23.0
52 "	27.0
82 "	36.0
112 "	27.0

* Oven dry-weight basis (70°C).

and the remaining 20 pots were placed at various distances from the field sampling site adjacent to the Riverside freeway (area 4, fig. 1). The pots were planted to alfalfa and irrigated weekly with identical amounts of a solution containing approximately 10 μg Pb as Pb nitrate. The plants were grown for

TABLE 6
LEAD CONTENT OF AIR PARTICULATES ADJACENT TO THE SANTA ANA FREEWAY NEAR IRVINE, CALIFORNIA (1968)*

Sampling period	Pb in air per the following distance from pavement edge (meters):					
	11	61	91	152	182	277
	$\mu g/m^3$					
Mar. 18						
A.M.						
5:40- 6:36	1.13		1.00		1.06	...
6:30- 7:36	1.20		1.08		0.83	...
7:29- 9:05	3.20		1.97		1.55	1.29
8:28-11:03	4.23		1.09		0.65	0.33
10:55 A.M.-1:07 P.M.	3.05		1.08		0.57	...
P.M.						
1:12- 3:08	3.89		1.95		1.22	...
3:01- 5:15	6.11		2.76		1.77	...
5:06- 7:11	3.76		1.61		0.93	...
7:03- 9:13	0.92		0.05		0.02	...
9:05-11:05	0.37		0.56		0.34	...
Mean†	2.79$_a$		1.32$_b$		0.89$_b$	
Mar. 19						
P.M.						
12:57- 3:06	3.61	2.00		1.30		
3:00- 5:14	4.98	2.94		1.15		
5:05- 7:13	5.39	3.55		2.55		
7:07- 9:09	1.22	0.65		0.72		
9:03-11:05	1.03	1.00		0.71		
Mean†	3.25$_a$	2.03$_b$		1.33$_b$		

* ADT = 58,000.
† Within the dashed lines mean values are statistically different at the 5 per cent level of probability if they do not have the same subscript after the value.

42 days. The differences between Pb content of plants grown in control soils and Pb-treated soils were not statistically significant (table 5). Some Pb may have become fixed by the soil in a less soluble form. Keaton (1937) recovered only 17 μg Pb/gm soluble Pb from a soil to which he added 2,748 μg Pb/gm as Pb nitrate. The data also show that plants grown in the greenhouse and subjected to essentially Pb-free air contained only 1 to 2 μg Pb/gm alfalfa, whereas those grown next to the highway contained 23 to 36.

Amounts of Pb for alfalfa plants grown in the filtered-air greenhouse were considerably less than those for washed alfalfa plants grown next to the highway; these latter plants contained between 8.2 and 13.5 μg Pb/gm (table 3) compared to 1.1 μg/gm for plants grown in the greenhouse. Since both studies were conducted on the same soil, the results suggest that the procedure used to wash the alfalfa plants was not completely effective in removing surface deposits of Pb particulates from the plant tissues, or that Pb was absorbed through the aerial portion of the plant.

Cauliflower plants—their surrounding air and soil

Cauliflower plants, air particulates, and soil samples were collected from a field located on the Irvine Ranch, 15 meters from the Santa Ana freeway and parallel to it for a distance of 340 meters. The field extended 362 meters from the freeway edge. At the time of sampling, the ADT was 58,000.

TABLE 7

WIND SPEED AND DIRECTION DURING AIR SAMPLING IN CAULIFLOWER FIELD (1968)*

Sampling period	Wind speed		Relative wind direction†	
	Near highway:	300 meters from highway:	Near highway:	300 meters from highway:
	mi./hour			
Mar. 28				
A.M.				
5:40– 6:36	4.2	4.8	10	9
6:30– 7:36	1.8	5.4	8	8
7:29– 9:05	3.9	6.1	11	11
8:28–11:03	5.0	5.2	2	1
10:55 A.M.–1:07 P.M.	5.5	5.2	3	3
P.M.				
1:12– 3:08	11.9	9.3	3	3
3:01– 5:15	9.9	9.0	2	2
5:06– 7:11	6.7	5.8	1	1
7:03– 9:13	3.2	3.2	11	10
9:05–11:05	3.0	3.0	9	9
Mar. 19				
P.M.				
12:57– 3:06	11.6	9.8	4	3
3:00– 5:14	13.9	11.2	3	3
5:05– 7:13	6.4	4.8	2	1
7:07– 9:09	4.7	3.9	11	10
9:03–11:05	3.0	3.0	10	10

* ADT = 58,000.

† Highway heading set at 12 o'clock; actual heading NW (310°). Wind movement was from the highway toward the field during the day and toward the highway during the late evening and early morning hours.

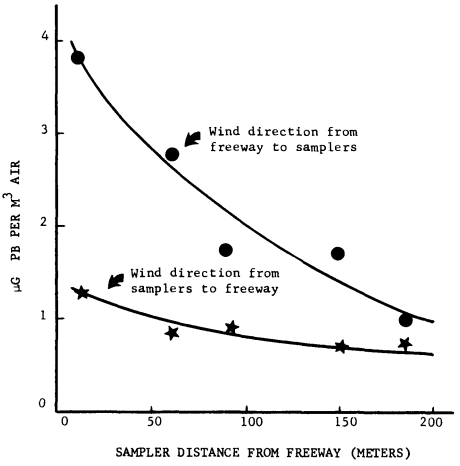

Fig. 3. Average ambient lead concentrations in a field plot on the Irvine Ranch as influenced by sampler distance and wind direction from the Santa Ana freeway.

Air samples at various distances from the highway were collected in the field plot for two days (table 6). Lead concentrations correlated significantly with their distances from the freeway. Mean ambient Pb values decreased as much as 67 per cent at distances up to 182 meters from the freeway. Lead in air particulates was generally higher during daylight hours. Similar trends were observed by others (Colucci, Begeman, and Kumler, 1969; Daines, Motto, and Chilko, 1970; Motto *et al.*, 1970; Ter Haar, 1970). Concentrations in the atmosphere vary and are most probably influenced by traffic volume, meteorological conditions, and vehicle exhaust rate. Hirschler *et al.* (1957) reported that high exhaust gas velocity results in a disproportionately high emission rate of Pb.

The associated wind variables during the test period are shown in table 7. Wind movement was from the highway to the test field during the daylight hours and from the field toward the

TABLE 8
LEAD CONTENT OF CAULIFLOWER PLANTS COLLECTED ADJACENT TO THE SANTA ANA FREEWAY NEAR IRVINE, CALIFORNIA (1968)*

Distance from freeway	Pb content† in cauliflower:	
	Top half of flower	Interior base of flower
meters	*μg/gm*	
15	0.33_a	0.03_c
77	0.11_b	0.09_{bc}
138	0.04_b	0.03_{bc}
198	0.02_b	0.07_{bc}
258	B.D.‡	B.D.
320	B.D.	B.D.
362	B.D.	B.D.

* ADT = 58,000.
† Subscript letters indicate significance at the 5 per cent level of probability. Horizontally and vertically, values are statistically different if they do not have the same subscript letter.
‡ B.D. = below detectability by methods used, or < 0.02 μg Pb/gm fresh weight.

highway during the late evening and early morning hours. By separating the air samples according to wind direction in relation to highway heading, average curves representative of the ambient Pb levels were obtained under conditions in which the wind direction was from the highway toward the field, as well as away from the field toward the highway. The two average curves representing these conditions during the two-day period are shown in figure 3. If the two-day period is considered typical, the field was continually exposed—at about 60 meters from the highway—to an air mass containing about 1.8 μg Pb/m³ of air.

On the second day of the air-sampling period, air particulate samples were collected according to particle size ranges. About 67 per cent were less than 0.5 μ in diameter. About 10 per cent were greater than 15.0 μ; 7 per cent were in the range from 5.0 to 15.0 μ; 11 per cent, from 1.5 to 5.0 μ; and 5.5 per cent, from 0.5 to 1.5 μ. Studies by Robinson and Ludwig (1967) in the Los Angeles area show that the average mass mean equivalent particle diameter is 0.25 μ. Daines, Motto and Chilko (1970) reported that over 65 per cent of the Pb in the air from 9 to 550 meters from a well-traveled highway consisted of particles under 2 μ, with over 85 per cent consisting of particles under 4 μ. The particle size and distribution we observed indicates that about 35 per cent would be expected to settle out rapidly.

Cauliflower plants were collected at distances of from 15 to 362 meters from the pavement edge. Two portions of the flower part of the plant "head," consisting of the top half and the interior base of the flower ("core"), were analyzed for Pb. The results are presented in table 8.

From seed to harvest requires about three months for the cauliflower plant. The flower begins to develop about 45 days after planting. During the last 14 days of growth, the outer leaves were tied over the flower. Hence, the edible flower was directly exposed to the ambient air for about one month. The results (table 8) show that Pb content of the flower portion was slight. At 15 meters from the highway the top half of the flower contained 0.33 μg Pb/gm fresh flower, which was significantly more than was found for the interior portion of the flower. Decrease of Pb in the top half of the flower from 0.33 μg Pb/gm at 15 meters to 0.02 μg Pb/gm at 198 meters from the freeway was significant, but no significant difference was found between 77 meters and 198 meters from the freeway. Ambient Pb deposition was most prevalent up to a distance of 15 meters from the freeway. No significant decrease in Pb content of the interior base of the flower was found as a function of distance from freeway. Beyond 198 meters from the highway, no Pb was detected in the cauliflower by the methods employed—which were sensitive to 0.01 μg Pb/gm fresh weight of flower. The low levels of Pb, variation of the Pb

TABLE 9

LEAD CONTENT OF SURFACE SOIL (0 TO 7.5 CM DEEP) AT VARIOUS SITES ADJACENT TO THE SANTA ANA FREEWAY NEAR IRVINE, CALIFORNIA (1968)*

Distance from freeway	Pb content in soil†
meters	*μg/gm*
15	118_a
77	81_b
138	85_b
198	74_b
258	85_b
320	75_b
362	85_b

* ADT = 58,000.
† Mean of six samples. Oven dry weight (110°C for 24 hours). Subscript letters indicate significance at the 5 per cent level of probability. Values are statistically different if they do not have the same subscript after the value.

TABLE 10

LEAD CONTENT OF STRAWBERRY FRUIT AND LEAVES ONE-HALF MILE SOUTH OF SANTA ANA FREEWAY NEAR TUSTIN, CALIFORNIA (1968)*

Distance from Robert Ave.	Pb content in strawberry plants:†		
	Leaves unwashed	Berries	
		Unwashed	Washed
meters	*μg/gm*	*μg/gm*	
4.6	5.8_a	0.31	0.23_a
51.0	7.7_a	....	0.09_c
97.0	5.8_a	....	0.18_c
142.0	6.9_a	....	0.13_c
189.0	5.3_a	....	....

* ADT = 48,000.
† Mean of six samples each. Oven-dry-weight basis (70°C). Subscript letters indicate significance at the 5 per cent level of probability. Values are statistically different if they do not have the same subscript letter.

content with distance, and the Pb content of the exterior portion of the flower —compared with the interior portion of the flower—all suggest that the Pb was deposited *on* rather than *absorbed by* the crop. Amounts observed in the flower were extremely low when compared with many other crops in similar locations and directly exposed to the atmosphere. Warren and Delavault (1962) found cauliflower leaves and hearts to contain 2.0 and 0.9 μg Pb/gm (expressed on an oven-dry-weight basis). Assuming a water content of 80 per cent, our values are approximately the same as those reported by Warren and Delavault (1962). Contamination of cauliflower by Pb particulates, generated on heavily traveled highways, does not appear to be critical.

Lead contents of surface soil samples (to a depth of 7.5 cm) collected in the cauliflower field at various distances from the edge of the pavement are shown in table 9. The values reported represent the amount of Pb solubilized from the soil by a 10 per cent HNO_3 solution. Lead in soil (118 μg/gm) at 15 meters from the highway was about 50 per cent greater than the Pb in soil collected at distances equal to and greater than 77 meters. This significant difference is probably due to deposition from automotive exhaust Pb particulates. Similar Pb accumulations in soils adjacent to highways are reported by others (Singer and Hanson, 1969; Colucci, Begeman, and Kumler, 1969; Motto *et al.*, 1970; Ter Haar, 1970). Compared with other soils in southern California (Page and Ganje, 1970) Pb in soil from the cauliflower field was abnormally high. Soils from fields in other areas commonly ranged between 5 and 10 μg/gm, whereas Pb in the cauliflower field was about 80 μg/gm.

Some years ago, Pb arsenate sprays were commonly used to control insect pests. Possibly, the abnormally high Pb content in this soil was due to Pb arsenate spray residues. It is noteworthy that even though Pb content of the soil was high, cauliflower plants grown on the soil contained very low amounts. It is reasonable to conclude, therefore, that the Pb in this soil was not absorbed by the cauliflower plants to any significant extent.

TABLE 11

LEAD CONTENT OF SOIL FROM STRAWBERRY FIELD ADJACENT TO ROBERT AVENUE (1968)*

Distance from Robert Ave.	Pb in soil† at depth (cm) of:	
	0–15	50–65
meters	*μg/gm*	
4.6	8.2_a	1.1_c
51.0	5.2_{ab}	2.2_c
97.0	5.2_{ab}	1.0_c
142.0	2.5_b	1.9_c
189.0	4.1_b	1.7_c

* ADT = 48,000.
† Mean of six samples. Oven-dry-weight basis (110°C). Subscript letters indicate significance at the 5 per cent level of probability. Values are statistically different if they do not have the same subscript letter.

Strawberries and their soil

Strawberry plants were sampled from a section of a field one-half mile south and upwind of the Santa Ana freeway, where ADT is 48,000 (see fig. 2). Immediately north of the field is Robert Avenue, with an ADT of 1,000. Samples of berries, which have an exposure time of 4 to 6 weeks (bloom to harvest), and their leaves, which remain on the plant all season, were collected. The leaves were analyzed fresh, and the berries were analyzed both fresh and after drying at 70°C for three days. The outsides of some berries were removed and the interior part analyzed separately.

Table 10 shows that no consistent trend in Pb content occurred in strawberry leaves or strawberries taken at distances from Robert Avenue ranging from 4.6 to 189 meters. This was expected, since traffic was not heavy. In general, the Pb content of the berries, an average of 0.16 μg/gm, and leaves, an average of 6.3 μg/gm, was quite low compared with that of other vegetation immediately adjacent to heavily traveled roads.

Lead content of the whole berry, as well as the interior portion, averaged for all sampling sites, was 0.39 and 0.36 μg/gm respectively, which indicates that traffic had no influence on Pb content.

TABLE 12

LEAD CONTENT IN STRAWBERRIES GROWN IN THE GREENHOUSE ON SOILS OF VARYING LEAD CONTENT

Soil source	Pb in soil	Pb in berries (dry weight)
	μg/gm	
Near Robert Ave.	8.0	0.07 N.S.*
Standard greenhouse mix	14.0	0.16 N.S.
Irvine Ranch	59.0	0.08 N.S.

* N.S. = no significance.

Lead amounts in soil sampled near the locations where plant samples were obtained are given in table 11. The amount in the surface soil 4.6 meters from the road was about 3 μg/gm greater than the amount found 51 meters from the road. Beyond 4.6 meters from the road no differences were noted. The surface-soil samples contained two to three times more than the subsurface samples. This effect is commonly observed (Mitchell and Reith, 1966; Page and Ganje, 1970) and is attributed to plant cycling and low solubility of Pb in soils (Motto *et al.*, 1970). The HNO_3-soluble Pb found in the soil from this field was in the range common to many other soils in southern California.

Strawberry plants were also grown in the greenhouse on three types of soils which contained from 8 to 59 μg/gm HNO_3 soluble lead. One plant per pot was used, and care was taken in the irrigation procedure to prevent splashing of soil onto the plant. A nutrient solution was applied weekly with the irrigation water. The results (table 12) show very small amounts of Pb in the berries from plants grown on all three soils. Slightly more Pb was found in berries from the field near Robert Avenue (table 10) than was found in

TABLE 13

LEAD CONTENT IN CABBAGE LEAVES AND SOIL SAMPLED ONE MILE NORTH AND DOWNWIND OF THE SANTA ANA FREEWAY (1968)*

Distance from:		Pb content† for			
		Outer cabbage leaves (fresh-weight):		Soil (oven dry weight, 110°C) to depth (cm) of:	
Browning Rd.	Irvine St.	Unwashed	Washed	0-15	50-65
meters			*μg/gm*		
4.6	7.6	1.14_a	0.51_c	67.0	1.6
65.0	7.6	0.21_{bc}	0.29_{bc}	67.0	2.0
126.0	7.6	B.D.	0.34_{bc}	17.0	1.1
187.0	7.6	B.D.	0.27_{bc}	17.0	1.6
Mean				40.0_d	1.6
4.6	38.0	B.D.	....	11.0	1.1
65.0	38.0	B.D.	....	1.4	1.6
126.0	38.0	0.08_b	....	2.9	1.1
187.0	38.0	0.11_b	....	7.5	0.7
Mean				5.7_e	1.1
4.6	68.0	0.04_b	....	9.7	1.2
65.0	68.0	0.40_c	....	0.7	1.2
126.0	68.0	B.D.	....	....	1.1
187.0	68.0	B.D.	....	1.4	1.0
Mean				3.9_e	1.1

* ADT = 70,000.
† Subscript letters indicate significance at the 5 per cent level of probability. Horizontally and vertically, values are statistically different if they do not have the same subscript letters. B.D. = below detectability.

berries grown in the greenhouse. But in both cases the Pb contents were very low when compared with those of many other types of vegetation collected next to highways (Leh, 1966; Motto *et al.*, 1970; and Ter Haar, 1970).

Cabbages and their soil

Plant and soil samples were collected from a small section of a cabbage field 1 mile north and downwind of the Santa Ana freeway. ADT at this point on the freeway in 1968 was 70,000. Adjacent to the field on the west is Browning Road with an ADT of 4,000; on the north is Irvine Street with an ADT of 5,000.

The cabbage plants grew within 7.6 meters of the edge of Irvine Street and 4.6 meters from the edge of Browning Road. Plant samples were taken every 61 meters for a distance of 187 meters parallel to Irvine Street, and every 30 meters back from Irvine Street for a distance of 68 meters. Two heads of cabbage were taken from those sampling sites next to Irvine Street; one head was taken from each of the other sites. The outer leaves of the head were removed and analyzed, unwashed; and from these same heads a wedge of the interior cabbage was analyzed, unwashed. Table 13 shows that very little Pb was found on the outer leaves of the cabbage. Warren and Delavault (1962) noted between 0.5 and 3.0 μg Pb/gm (dry weight basis) in and on cabbage leaves grown on many soils in Great Britain. Ter Haar (1970) reported values from 4.0 to 8.9 μg/gm (dry weight basis) in and on cabbage leaves from plants grown adjacent to

TABLE 14

LEAD CONTENT OF TOMATOES AND SOIL AT VARIOUS DISTANCES FROM SANTA ANA FREEWAY (1968)*

Distance from the freeway	Pb content† (mean of six samples) for tomatoes on:								Pb content for soil in tomato field to depth (cm) of:	
	July 12		July 24		July 31		Aug. 16		0–7.5	50–65
	Unwashed	Washed	Unwashed	Washed	Unwashed	Washed	Unwashed	Washed		
meters	*μg/gm*									
15	0.75_a	0.13_b	1.10_c	0.16_b	0.89_{ac}	0.12_b	4.15_d	0.57_{ah}	118_i	1.3_k
76	0.20_b	B.D.	0.12_b	B.D.	0.23_b	0.18_b	0.67_e	0.18_b	85_j	1.0_k
137	B.D.	B.D.	B.D.	B.D.	0.05_b	B.D.	0.45_{ef}	0.11_b	75_b	1.2_k
197	0.10_b	B.D.	....	B.D.	....	B.D.	0.25_{bfg}	B.D.	85_b	B.D.
258	0.09_b	B.D.	....	B.D.	....	B.D.	0.16_{bfg}	B.D.	74_b	B.D.
320	0.07_b	B.D.	....	B.D.	....	B.D.	B.D.	B.D.	85_b	B.D.
364	0.15_b	B.D.	....	B.D.	....	B.D.	0.22_{bfg}	B.D.	81_b	B.D.

* ADT = 70,000.

† Subscript letters indicate significance at the 5 per cent level of probability. Horizontally and vertically values are statistically different if they do not have the same subscript letters. B.D. = below detectability, or <0.05 μg Pb/gm (dry weight basis) for tomatoes and 1.0 μg Pb/gm for soil.

a highly traveled road near Detroit, Michigan. Assuming that cabbage leaves are about 80 per cent water, our values (table 13) fall in the range reported by others. Lead levels for the interior portion of the cabbage were below the limit of detectability which, by the method employed, is less than 0.01 μg/gm (fresh weight). The samples collected near the intersection of Irvine Street and Browning Road showed some influence of local traffic on Pb content of cabbage.

The amounts of Pb soluble in 10 per cent HNO_3 for soils collected where the cabbage plants were sampled are shown in table 13. Lead content in the surface soils collected along Irvine Street was greater than that in such soils from other locations in the test field. Surface-soil samples taken at the intersection of Irvine Street and Browning Road contained considerably more Pb than did surface soils from other locations in the field. These two observations suggest some influence of local traffic, perhaps vehicular acceleration-deceleration, on the Pb content of soil next to the roads.

Tomatoes and their soil

Tomatoes were collected in 1968 and 1969 from fields on the Irvine Ranch. In 1968, the tomatoes were collected on four different dates during the growing season from sampling sites identical to those used previously for cauliflower plants. The field was located 15 meters east of the Santa Ana freeway, parallel to the freeway for a distance of 340 meters, and extending 364 meters from the freeway edge (see fig. 2). In 1968, the ADT was 70,000.

The data in table 14 demonstrate the influence of washing, exposure time, and distance from the highway on amounts of Pb found in and on tomatoes. Significantly greater amounts were found on unwashed samples closest to the highway and exposed for the longest period of time. About 90 per cent of the Pb was removed by washing. Beyond 76 meters from the highway, washed samples were quite low. Apparently, most of the Pb is deposited on the tomato and, because of its smooth surface, is rather easily removed by washing. Possibly, the larger

TABLE 15

VERTICAL DISTRIBUTION OF LEAD IN THE SOIL FROM THE TOMATO FIELD 76 METERS FROM THE SANTA ANA FREEWAY (1968)*

Depth of soil sampled	Pb content of soil†
cm	*μg/gm*
0–7.5	76
7.5–15	84
15–25	79
25–40	83
40–50	22
50–65	B.D.‡
>65	B.D.
7.5–20	73
20–35	52
35–45	41
45–52	31
>52	B.D.

* ADT = 70,000.
† Oven-dry-weight basis, 110°C.
‡ B.D. = below detectability, or less than 1 μg Pb/gm.

TABLE 16

LEAD CONTENT OF RIPE TOMATOES EAST OF THE SANTA ANA FREEWAY (1969)*

Distance from freeway	Pb content of tomatoes (oven dry weight, 70°C):†	
	Unwashed	Washed
meters	*μg/gm*	
23	6.02_a	1.55_c
183	0.95_b	0.31_d
343	0.62_b	0.33_d
503	0.65_b	0.17_d
663	0.81_b	0.22_d
823	0.59_b	0.22_{bd}

* ADT = 70,000.
† Mean of six samples collected parallel to the freeway. Subscript letters indicate significance at the 5 per cent level of probability. Horizontally and vertically, values are statistically different if they do not have the same subscript letter.

amounts on mature tomatoes are related to extent of exposure, as well as duration of exposure. The younger tomatoes are shielded by the leaves to a greater degree than the older tomatoes. When the fruit is mature, the canopy effect of the leaves is reduced, exposing more of the fruit to the ambient air. In general, the data show little contamination, most of which is readily removed by washing.

Motto *et al.* (1970) reported from 3.4 to 6.8 μg Pb/gm for peeled tomatoes (tomato pulp) grown on soils within 78 meters of a highly traveled road in New Jersey. If it is assumed that Pb from washed tomato fruits should correspond to that in peeled tomatoes, the results presented in table 14 are somewhat lower than those reported by Motto *et al.* (1970). The maximum amount of Pb observed in our studies for washed tomato fruit was 0.57 μg Pb/gm. Our results suggest that tomato fruits absorb only relatively small amounts from the soil, whereas those presented by Motto *et al.* (1970) indicate that a substantial percentage of the total may have reached the fruit via the plant absorption process. No data are available to evaluate the influence of varying soil properties on Pb absorption by plants.

Ter Haar (1970) found from 1.2 to 1.6 μg Pb/gm in and on tomato fruits collected from plants grown close to a heavily traveled road near Detroit, Michigan. These values are about the same as those observed by us for mature tomatoes (see table 14; Aug. 16, washed samples).

In the tomato field, the surface-soil samples (0 to 7.5 cm) contained significantly more Pb than the subsurface samples (50 to 65 cm), (see table 14). Surface soil collected 15 meters from the highway contained about 35 μg/gm more than soil collected 76 meters from the highway; beyond 76 meters, distance from the highway had no significant influence on the amount of Pb found. Lead concentration in surface soil was somewhat greater than that commonly observed in California soils generally. Some years previous to the sampling, the field was a walnut grove, and Pb arsenate had been commonly used to control pests on walnuts. This

TABLE 17

LEAD CONTENT OF ORANGE PEELS AND PULP FROM TREES ON EAST AND WEST SIDES OF THE SANTA ANA FREEWAY AND ON UNWASHED PEELS FROM EAST AND WEST SIDES OF THE TREES (1968)*

Item	Pb content at the following distances (meters) from the freeway:†									Mean‡
	23-30	30-60	60-90	90-120	120-150	150-180	180-210	210-240	240-270	
	μg/gm									
East side of freeway:										
Peels										
Unwashed	16.0	7.6	6.8	5.2	5.7	4.5	3.3	5.0	7.4	7.6$_a$
East side of tree	16.4	8.2	6.1	4.7	6.0	4.5	3.2	5.4	7.5	6.9$_a$
West side of tree	15.7	7.0	7.6	5.7	5.4	4.6	3.5	4.8	7.5	6.9$_a$
Water-rinsed	5.1	2.9	2.5	2.3	2.0	1.5	1.5	2.4	2.3	2.5$_b$
Detergent-scrubbed, acid-water rinsed	2.5	0.84	1.1	...	...	...	...	...	...	...
Pulp**	0.39	0.23	0.19	0.25	0.14	0.17	0.19	0.17	0.06	0.20$_c$
West side of freeway:										
Peels										
Unwashed	7.8	4.4	4.7	3.7	2.7	2.3	2.4	2.7	2.8	3.7$_d$
East side of tree	10.5	5.5	5.3	4.1	2.6	2.2	3.0	3.0	2.7	4.3$_d$
West side of tree	5.1	3.3	4.2	3.4	2.8	2.4	1.8	2.5	3.0	3.2$_{bd}$
Water-rinsed	4.5	2.3	2.4	2.3	1.7	1.3	1.0	1.7	1.5	2.1$_b$
Detergent-scrubbed, acid-water rinsed	1.2	0.64	0.66	...	...	...	...	...	...	...
Pulp	0.44	0.39	0.24	0.29	0.35	0.51	0.24	0.26	0.13	0.32$_c$

* The oranges were mature and on the tree about 16 months.
† The freeway bisected the grove at an angle. Results represent the mean Pb content (oven dry weight, 70°C) of fruit collected from trees located with the range of distance from the freeway, as indicated.
‡ Subscript letters indicate significance at the 5 per cent level of probability. Values are statistically different if they do not have the same subscript letter.
** Oranges were peeled and pulp rinsed by immersing it in distilled water.

was reflected in the fairly uniform vertical distribution of Pb to about 40 cm, which is about equal to the depth of normal tillage operations (table 15). Tillage would mix the Pb accumulated on the surface of the soil to the tillage depth.

During the summer of 1969, a second set of tomato samples were collected from a field on the north side of Myford Road between the Santa Ana freeway and Bryan Avenue (see fig. 2). Samples were collected 23 meters from the edge of the Santa Ana freeway and parallel to it every 30 meters for a distance of 180 meters and east of the freeway every 160 meters for a distance of 823 meters. Tomatoes were analyzed for Pb both before and after being washed. The values (table 16) are slightly greater than those observed the previous year for ripe tomatoes (table 14). At 23 meters from the freeway, unwashed tomatoes showed six times more Pb than was observed at distances greater than 183 meters. About 70 per cent Pb was removed by washing.

Oranges and their soil

Valencia oranges from the Irvine Ranch were collected from a grove which was bisected by the Santa Ana freeway, resulting in sections on the east and west sides of the freeway (see fig. 2). About 60 per cent of the time, the direction of the wind was from the freeway to the eastern section of the grove.

With the freeway as a reference point, comparable sample locations were selected on both sides. Oranges were also sampled from the east and west sides of the trees. The peels were divided into three subsamples, and both peel and pulp were analyzed. The first sample analyzed was not washed; the

TABLE 18

LEAD CONTENT OF LEMON LEAVES, PEELS, AND PULP EAST OF THE SANTA ANA FREEWAY, NORTH OF CULVER ROAD (1969)*

Distance† from:		Pb content in lemons (oven dry weight, 70°C) for:				
		Leaves‡		Peels‡		Pulp
Freeway	Culver Rd.	Unwashed	Washed	Unwashed	Washed	Unwashed
meters		*μg/gm*				
320	3	4.1	2.5	5.2	2.0	0.03
358	3	5.8	3.3	3.6	1.8	0.20
396	3	9.1	5.9	5.0	3.2	0.14
434	3	17.4	9.9	4.8	3.2	0.49
472	3	16.2	2.5	2.5	2.1	0.20
320	41	4.1	7.2	3.3	1.5	0.02
358	41	8.8	0.9	3.5	2.1	0.06
396	41	15.0	4.1	3.3	1.3	0.15
434	41	9.5	2.8	3.3	1.5	0.08
472	41	11.5	2.8	3.9	2.2	0.26
320	79	7.2	1.1	3.0	2.4	0.08
358	79	7.9	2.7	3.5	2.1	0.28
396	79	5.1	3.6	5.4	1.7	0.17
434	79	9.4	2.5	2.2	1.4	0.06
472	79	10.4	1.1	2.9	1.4	0.24
320	117	20.7	2.2	2.6	2.1	0.12
358	117	16.6	2.3	2.6	1.7	0.25
396	117	16.4	1.1	2.8	2.8	0.08
434	117	11.5	0.3	3.2	1.6	0.23
472	117	15.1	5.6	2.7	2.0	0.10
320	155	24.7	6.4	2.1	1.4	0.03
358	155	8.9	2.4	2.3	1.5	0.10
396	155	14.6	1.7	3.5	2.1	0.18
434	155	7.7	2.2	2.7	2.2	0.14
472	155	13.4	4.9	3.8	1.1	0.21

* ADT = 69,000.
† Effect of distance on Pb content of leaves and peels is not significant.
‡ Pb contents of washed leaves and peels are significantly different from the unwashed at the 5 per cent level of probability for all distances from the freeway.

second was rinsed with water; the third was scrubbed with detergent, rinsed with 10 per cent HNO_3, then rinsed again with water. Table 17 shows significantly larger amounts of Pb on the unwashed peels of oranges collected on the east side of the freeway than on the west, probably because the prevailing winds move more often from the freeway to the east. Much more Pb was found in and on the unwashed peels from oranges sampled closest to the freeway. Beyond 90 meters from the freeway, the peels showed more or less uniform amounts of Pb. Rinsing with water removed from 50 to 70 per cent Pb from those peels containing about 5 μg/gm; scrubbing with detergent, followed by acid and water rinsing, removed 85 to 90 per cent from the unwashed peels. The results indicate that although the fruit near the highway accumulated rather large amounts, most of it could be removed by careful washing.

Orange pulp showed rather small amounts of Pb when compared with the peel (table 17) and about the same amounts from both the east and west sides of the freeway. In general, orange pulp sampled at locations 23 to 30 meters from the freeway contained slightly more Pb than that sampled beyond 30 meters.

Peel samples from the east and west sides of the tree were analyzed without washing of any kind. Although table 17 shows that greater concentrations of

TABLE 19
LEAD CONTENT OF CORN, WEST OF THE SANTA ANA FREEWAY (1969)*

Distance from freeway	Pb content in corn† (oven dry weight, 70°C) for:						
	Silk		Leaves		Husks		Kernel
	Unwashed	Washed	Unwashed	Washed	Unwashed	Washed	Unwashed
meters	*μg/gm*						
23	32.0_a	38.0_a	24.0_c	16.0_d	2.0_f	0.9_f	0.14_h
53	17.0_b	17.0_b	15.0_d	7.0_e	0.7_g	1.4_{fg}	0.15_h
84	15.0_b	20.0_b	14.0_d	6.0_e	2.0_f	1.0_f	0.25_i
114	16.0_b	13.0_b	14.0_d	5.0_e	0.6_g	1.0_{fg}	0.08_h

* ADT = 70,000.
† Mean of four samples. For each tissue reported, subscript letters indicate significance at the 5 per cent level of probability. Horizontally and vertically, values are statistically different if they do not have the same subscript letter.

Pb were associated with peels from oranges on the east side of the freeway, the side of the tree from which the samples were taken had no significant effect.

Lead in surface soil (to 7.5 cm depth) from the east side of the freeway varied from a high of 29 μg/gm near the roadbed to a low of 6 μg/gm 75 meters from the roadbed. Between 50 and 65 cm deep, contents ranged from 0.1 to 1.33 μg Pb/gm; amounts on the west side were similar.

Lemons

Lemon leaves and fruit were collected during July, 1969, from a grove 320 meters east of the Santa Ana freeway and just north of Culver Road (see fig. 2). The ADT along the Santa Ana freeway near the site was 69,000; along Culver Road, it was 5,500. Lemon leaves were analyzed both before and after being washed with water. Lemon fruit were peeled, and peels and pulp were analyzed separately. The peels and pulp were immersed again and again in distilled water for 5 minutes.

Table 18 shows that Pb found in and on the washed and unwashed leaves was variable and bore no relation to distance from traffic—probably because it was difficult, even for experienced horticulturists, to identify lemon leaves of the same age. The leaves sampled could have varied in age from a few to 18 months. In general, the data shows that mild washing removed 50 per cent or more Pb.

Three meters from Culver Road, the mean Pb content of the peels was 4.2 μg/gm, whereas at 117 and 155 meters from Culver Road, it was reduced to about 2.8 μg/gm. Mild washing of the lemon peel removed from 30 to 60 per cent Pb. Lead in the pulp of lemons was low. Again, most of the Pb found was deposited on the crop; little appeared to be absorbed from the soil.

Corn

Mature corn samples were collected in July, 1969, from a field on the west side of the Santa Ana freeway near Myford Road (see fig. 2). The ADT in 1968 was 70,000; prevailing winds were from the west.

Samples were collected from four rows of corn parallel to the freeway. The first row of corn was 23 meters from the pavement edge; additional samples were collected to the west from rows 30 meters apart. Four samples were collected in each row. The leaves, silk, and husk of the corn plant were analyzed for Pb before and after being washed. The kernel was analyzed without prior washing. The results are shown in table 19.

Corn silk, leaves, and husks collected 23 meters from the freeway contained

TABLE 20
LEAD CONTENT OF LIMA BEANS, EAST OF THE SANTA ANA FREEWAY (1969)*

Distance from freeway	Pb content† for lima beans (oven dry weight, 70°C) for:				
	Leaves		Pods		Beans
	Unwashed	Washed	Unwashed	Washed	Unwashed
meters	*μg/gm*				
23	99.0$_a$	72.0$_d$	5.0$_g$	4.0$_j$	0.40$_l$
53	83.0$_b$	64.0$_e$	4.0$_h$	2.0$_k$	0.20$_l$
84	35.0$_c$	15.0$_f$	3.0$_i$	2.0$_k$	0.10$_l$

* ADT = 70,000.
† Mean of four samples. For each tissue reported, subscript letters indicate significance at the 5 per cent level of probability. Horizontally and vertically, values are statistically different if they do not have the same subscript letter.

about twice as much Pb as the tissues collected 53 meters from the freeway. Amounts were reasonably uniform at locations from 53 to 114 meters from the freeway.

Washing had no influence on the Pb content of the silk. The silk is fine-textured and, as a consequence, mild washing procedures are ineffective. Washing with distilled water removed about 50 per cent of the Pb from the leaves. Husks contained considerably less Pb than did silk and leaves. Kernels had small amounts of lead when compared with the other tissues; of course, they are not exposed to the ambient air and atmospheric contamination. The Pb observed in the kernel results from plant uptake from the soil and perhaps from unavoidable contamination during handling. The relationships between Pb contents in corn-plant parts and distances from the highway are similar to those found by Motto *et al.* (1970) in New Jersey and Ter Haar (1970) in Michigan, but Pb levels in corn from New Jersey are much higher than those in southern California corn. Age of the plant at the time of sampling, meteorological conditions, and extent of absorption from soil may have contributed to these differences.

Lima beans

Twelve samples of lima bean plants were collected from a field due east of the Santa Ana freeway in August, 1969 (see fig. 2). The ADT in 1968 was 70,000. Samples were collected from rows parallel to the freeway and 30 meters apart; the first row was about 20 meters from the pavement edge.

Lima bean leaves and pods were analyzed separately before and after being washed with distilled water (table 20). Beans inside the pod were also analyzed. Significant decrease in Pb content of beans, leaves, and pods occurred with increased distance from the freeway, with a relatively high content on leaves from plants collected within 53 meters of the pavement edge. At 84 meters from the pavement, Pb in the unwashed leaves was 35 μg/gm compared with 83 and 99 μg/gm at 53 and 23 meters, respectively, from the pavement. About 30 per cent of the Pb was removed by washing leaves sampled within 53 meters of the pavement. Pods contained about 80 per cent less Pb than the leaves; washing the pods removed from 30 to 50 per cent. Although the leaves and pods were both exposed to the ambient air, their Pb contents varied considerably. These differences probably can be explained in terms of the duration of exposure, texture of the tissues and canopy effect. Pods appear late in the life cycle of the bean plant and are exposed for a shorter period of time. They are also shielded

TABLE 21

LEAD CONTENT OF RED PEPPERS, WEST OF THE SAN DIEGO FREEWAY (1969)*

Distance from freeway	Pb content for red peppers† (oven dry weight, 70°C):	
	Unwashed	Washed
meters	*μg/gm*	
20	2.3_a	0.6_d
50	1.9_b	0.4_d
80	1.0_c	0.6_d

* ADT = 70,000.
† Mean of five samples. Subscript letters indicate significance at the 5 per cent level of probability. Horizontally and vertically, values are statistically different if they do not have the same subscript letter.

TABLE 22

LEAD CONTENT OF SUGAR BEETS, EAST OF THE SANTA ANA FREEWAY (1969)*

Distance from freeway	Pb content for sugar beets† (oven dry-weight, 70°C) for:			
	Leaves		Roots	
	Unwashed	Washed	Unwashed	Washed
meters	*μg/gm*			
23	106_a	36_d	2.3_f	0.2_h
53	60_b	41_{bde}	0.2_g	0.1_{gh}
114	44_c	23_{ce}	0.4_g	...

* ADT = 70,000.
† Mean of six samples. Subscript letters indicate significance at the 5 per cent level of probability. Horizontally and vertically, values are statistically different if they do not have the same subscript after the value.

by the leaves from surface exposure. Finally, Pb particulates of the size present in the atmosphere would be expected to adhere more readily to the rough surface of leaves than to the relatively smooth surface of pods.

Unwashed beans, removed from the pod, showed very small amounts of Pb. Although not statistically significant, Pb in beans collected 23 meters from the highway was somewhat greater than that in beans obtained 53 and 84 meters from the highway.

Red peppers

In September, 1969, red peppers were collected from a field west of the San Diego freeway near Valencia Avenue. The ADT near the sampling site was 22,000. Peppers from five plants were collected from rows parallel to the freeway and 30 meters apart. The first row was 20 meters from the pavement edge. Peppers were analyzed before and after being washed with distilled water (table 21). They accumulated between 1 and 2.3 μg Pb/gm. Distance from the highway had a small but statistically significant effect, and washing with water significantly reduced Pb content to about 0.5 μg/gm. When compared with other crops tested, Pb content for the peppers was quite low—probably due to duration of exposure and the very smooth surface of peppers, which does not retain exhaust particulates.

Sugar beets

Eighteen samples each of sugar beet and sugar beet leaves were collected from a field on the east side of the Santa Ana freeway in August, 1969 (see fig. 2). Samples were collected from rows parallel to the freeway and about 30 meters apart; first row was 23 meters from the pavement edge. The individual beet root was split into two parts; one part was analyzed after being washed with water and the other part was analyzed unwashed (table 22). The washing procedure consisted of scrubbing with detergent followed by water rinsing. The leaves were also split into two parts; one part was analyzed without being washed, and the second part was repeatedly immersed in distilled water for a 5-minute period. All samples were dried in a forced draft oven for four days.

Sugar beet leaves close to the freeway accumulated rather large amounts of Pb. The leaves were exposed to the ambient air for about eight months. Their surface area is large and rough,

with most of it exposed directly to the air; these conditions probably accounted for excessive Pb accumulations. At 23 meters from the highway, Pb in beet leaves was about 100 μg/gm. Hammond and Aronson (1964) reported that horses and cattle suffered from Pb poisoning when fed a diet consisting almost exclusively of forage containing 150 to 300 μg Pb/gm. This suggests possible hazards to large animals when forages grown close to major highways are used as the principal source of feed.

Lead was significantly higher for beet leaves close to the freeway and dropped off markedly as the distance from the freeway increased from 23 to 114 meters. Washing the leaf surfaces removed about 30 to 60 per cent Pb. Lead levels found in and on sugar beet leaves in our study were considerably higher than those observed by others. Leh (1966) in Germany found 29 μg Pb/gm in and on sugar beet leaves within 5 meters of a highway. Warren and Delavault (1962) in Great Britain report a range of from 2 to 10 μg Pb/gm in beet tops.

Lead content of the beet root was low; in unwashed beets it ranged between 0.2 and 2.3 μg/gm. Washing reduced the concentration to about 0.1 μg/gm.

Carrots and parsnips

Twelve carrot roots were sampled from a field on the University of California's South Coast Field Station—about one-half mile from the Santa Ana freeway. Lead found in carefully washed samples ranged between a high of 0.10 μg/gm and a low of 0.01 μg/gm with a mean of 0.03 μg/gm, all expressed on an oven dry-weight basis. These values are somewhat lower than those observed for carrot roots by others. Warren and Delavault (1962) report a range from 2 to 4 μg/gm for 10 samples collected from fields in British Columbia and Great Britain. Ter Haar (1970) found about 1.5 μg/gm for carrot roots grown next to a heavily traveled highway near Detroit, Michigan. Distances ranging from 9 to 160 meters from the highway had no effect on Pb in carrot roots. Motto *et al.* (1970) in New Jersey reported carrot roots grown next to highways contained 3.8 to 10 μg Pb/gm. Since it is difficult to remove all traces of soil from root crops, variations observed in the Pb content of carrots may be attributable to soil residues. Of course, differences in the amounts absorbed from the soil by the plant may also vary. Unfortunately, no data are available to evaluate the influence of soil properties on the amounts of Pb absorbed by crops.

Parsnips were collected from a field north of the San Diego freeway near Tustin at 23 and 84 meters from the pavement edge. The freeway near the sampling site carried about 70,000 motor vehicles per day. Average Pb content of parsnips, sampled 23 meters from the freeway, then carefully washed, was 0.77 μg/gm with a range from 0.08 to 1.4 μg/gm. Mean Pb content of parsnips sampled 84 meters from the highway, then washed, was 0.53 μg/gm with a range from 0.34 to 0.75 μg/gm.

Apparently, neither carrots nor parsnips will accumulate substantial amounts of Pb when grown on soils similar to those in the fields tested.

Wheat

Wheat samples were collected in June, 1969, from a field at distances of 177 and 354 meters east of the San Diego freeway. The field was bounded on the south by Harbor Boulevard, and the samples were collected at distances from 8 to 188 meters from this

TABLE 23

LEAD CONTENT OF WHEAT COLLECTED EAST OF THE SAN DIEGO FREEWAY (1969)*

Distance from Harbor Blvd.:†	Pb content of wheat (oven dry weight, 70°C):	
	Unwashed	Washed‡
meters	*μg/gm*	
177 meters from San Diego Fwy.:		
8	30.0	5.6
38	61.0	11.0
68	6.7	10.0
98	25.0	13.0
128	23.0	31.0
158	41.0	9.4
188	33.0	26.0
354 meters from San Diego Fwy.:		
8	30.0	16.0
38	12.0	8.6
68	14.0	9.8
98	14.0	14.0
128	13.0	3.1
158	29.0	16.0
188	17.0	0.8

* ADT = 34,000.
† Effect of distance on the lead content of the wheat is not significant.
‡ Effect of washing is significant at the 5 per cent level of probability.

boulevard. The ADT on the San Diego freeway at the Harbor Boulevard interchange was 34,000.

The bearded spike of the mature wheat plant was analyzed both before and after frequent immersion in distilled water for a 5-minute period. No consistent trends of Pb contents were noted in relation to distance from the freeway or from Harbor Boulevard (table 23). In most instances, washing removed some Pb from the wheat spike, but amounts were highly variable. On the unwashed bearded spike, the range was 6.7 to 61 μg/gm. No attempt was made in this study to separate the grain from the spike. Since the bearded spike, including the grain, contained a significant amount of Pb, it would be of value to determine amounts in the grain. Ter Haar (1970) found about 0.2 μg Pb/gm in wheat grain.

TABLE 24

LEAD CONTENT OF ROMAINE LETTUCE ADJACENT TO MAGNOLIA AVENUE (1969)*

Distance from:		Pb content of romaine lettuce† (oven dry weight, 70°C):	
Riverside Fwy.	Magnolia Ave.	Unwashed	Washed
meters		*μg/gm*	
540	15	1.82	0.93
510	34	1.16	1.22
480	74	2.69	1.16
450	103	0.88	1.42
420	133	2.03	1.37
390	162	1.68	0.88
360	192	1.69	0.96
Mean		1.70 N.S.‡	1.13 N.S.

* ADT = 33,500.
† Mean of three samples.
‡ N.S. = not significant.

The random nature of the results obtained for wheat are probably due to sampling errors and the character of the plant. That is, direct exposure to the ambient air was variable with individual plants. This appeared to be particularly true in the case of lodged plants.

Romaine lettuce

Mature romaine lettuce was collected from a field near Home Gardens, California, between Magnolia Avenue and the Riverside freeway (see area 3, fig. 1). The ADT on the Riverside freeway near the field sampled was 33,500 motor vehicles in 1968.

The outer three leaves of the plant were removed and analyzed both before and after the usual washing procedure. Lead contents in the unwashed leaves varied between about 1.0 and 3.0 μg/gm (table 24). Lead content of the lettuce leaves was not related to distances of sampling sites from either the freeway or Magnolia Avenue. Apparently, the minimum distance from the Riverside freeway was too great, and the traffic

TABLE 25
LEAD CONTENT OF LANDSCAPE VEGETATION ALONG THE SANTA ANA FREEWAY (1969)*

Freeway location	Vegetation	Pb content for landscape vegetation (oven dry-weight, 70°C) :			
		West side of freeway		East side of freeway	
		Unwashed	Washed	Unwashed	Washed
		μg/gm			
Lakewood Blvd.:					
On-ramp	ice plant	20	21	..	..
Off-ramp	ice plant	..	..	22	18
Midway between:					
Lakewood Blvd.	ice plant	10	10	45	20
Florence Ave.	carob leaves	24	8	28	21
	bottle brush leaves	22	10	..	..
	eucalyptus leaves	..	..	80	34
Florence Ave.:					
On-ramp	ice plant	..	..	36	22
Off-ramp	ice plant	32	23	..	..

* ADT = 130,000.

density along Magnolia Avenue was too low to affect Pb content. Washing the romaine lettuce leaves removed about 35 per cent Pb.

When compared with other leafy vegetables which were collected at distances less than about 100 meters from highly traveled highways, Pb amounts found in and on the lettuce leaves at the locations sampled were quite low. Motto *et al.* (1970) and Ter Haar (1970) report 12 to 56 and 4.8 to 6.5 μg Pb/gm, respectively, in and on lettuce leaves collected close to highways. Warren and Delavault (1962) observed a range of from 1 to 11 μg/gm for random samples collected in British Columbia and Great Britain.

Landscape vegetation

The amount of particulate matter, its size, and distribution on freeways is influenced by other conditions, as well as number of vehicles. Traffic commonly accelerates near freeway on-ramps and commonly decelerates near the off-ramps. Between on- and off-ramps, traffic usually proceeds at a more or less constant speed. With this in mind, landscape vegetation was collected along a one-mile stretch of the Santa Ana freeway between Lakewood Boulevard and Florence Avenue (see area 1, fig. 1). The prevailing winds in the area were from the west, and the freeway runs north and south. The ADT in 1968 was 130,000.

Ice plant was collected along the Lakewood Boulevard southbound on-ramp and along the Florence Avenue southbound off-ramp one mile south of Lakewood Boulevard. Halfway between the ramps on the west side of the freeway, ice plant, carob tree leaves, and bottle brush leaves were collected. Similarly, ice plant was sampled along the northbound Florence Avenue on-ramp and along the northbound Lakewood Boulevard off-ramp. Midway between these two ramps on the east side of the freeway, samples consisting of ice plant, carob tree leaves, and eucalyptus tree leaves were collected. Lead was determined on samples both before and after they were washed with distilled water (table 25).

No essential difference occurred in Pb content for samples collected along on- and off-ramps at both Lakewood Boulevard and Florence Avenue. Along

the east side of the freeway midway between the on- and off-ramps, Pb content of the ice plant was somewhat greater than that observed along each of the ramps—probably due to the greater density of traffic along the freeway as compared with the ramps. But on the west side of the freeway between the on- and off-ramps, amounts were less than that observed along the ramps. Unwashed ice plant contained between 10 and 45 μg Pb/gm; unwashed carob leaves, 24 to 28 μg/gm; unwashed bottle brush leaves, 22 μg/gm; and unwashed eucalyptus leaves, 80 μg/gm. In general Pb in and on vegetation on the east side of the freeway was greater than that on the west side of the freeway—probably due to prevailing winds. Washing the vegetation with distilled water removed some Pb from all of the types sampled.

Lead amounts observed on and in the landscape vegetation, when compared with that observed for leafy consumer crops that were sampled in areas of lesser traffic density and at greater distances from the pavement edges, were not as great as was anticipated. Landscape vegetation is irrigated with sprinklers, and this, in addition to rainfall, could wash off considerable amounts of Pb from plant surfaces. Also, the nature of the absorbing surface influences the amount of lead that is deposited on it.

Market survey

A number of fresh and frozen foods, and one canned food—tomatoes, were purchased from local markets and analyzed as received and, where appropriate, after being washed. Washing consisted of frequent immersions in distilled water for a 5-minute period. Results expressed on a fresh-weight basis, are presented in table 26.

Leafy crops, such as collards, spinach, and the outer leaves of romaine lettuce contained more Pb than the other crops analyzed. Removing the outer surface of root crops (carrots and potatoes) reduced their Pb content. Broccoli flower contained more Pb than the broccoli stalk. Washing reduced Pb content of all the foods examined. These observations suggest that part of the Pb found for foods obtained in markets was present as a surface deposit. However, when compared to similar vegetables collected along roadsides, Pb in vegetables collected from the markets was quite low. All foods contain at least traces of Pb. Amounts found in and on green vegetables grown in rural areas vary quite widely and range between traces and a few micrograms per

TABLE 26
LEAD CONTENT OF VARIOUS FRESH AND FROZEN FOODS PURCHASED FROM LOCAL MARKETS

Type of food	Pb content in purchased foods:*	
	As received	Water-washed
	μg/gm	
Fresh foods:		
Celery	0.02	B.D.
Collards	0.50	0.25
Spinach	0.25	0.10
Romaine lettuce		
outer leaves	0.18	0.10
inner leaves	0.01	B.D.
Artichokes		
outer leaves	0.04	0.04
inner leaves	B.D.	B.D.
Broccoli		
flower	0.30	0.19
stalk	0.04	0.04
Carrots		
peels	0.06	0.05
inner portion	B.D.	B.D.
Potatoes		
peels	0.11	0.02
inner portion	0.02	0.02
Peas		
pods with peas	0.02	B.D.
pods	0.02	B.D.
Frozen foods:		
Beans	B.D.	....
Peas	B.D.	....
Carrots	B.D.	....
Spinach	0.07	....
Strawberries	0.02	....
Potatoes	0.01	....

* B.D. = below the limit of detectability or less than 0.01 μg Pb/gm.

TABLE 27
LEAD CONTENT OF CANNED STEWED TOMATOES

Brand	Pb content in canned tomatoes* analyzed on:			
	Sept. 18, '68	Jan. 14, '69	June 18, '69	Mean
	μg/gm			
A	0.13	0.26	0.22	0.20
B	0.22	0.20	0.25	0.22
C	0.10	0.62	0.20	0.31
D	0.45	0.75	0.39	0.53

* Mean of two different samples on each date.

gram vegetable material. Natural levels are not precisely known, but Warren and Delavault (1962) and Lewis (1966) have estimated normal values (i.e., Pb content of foods not subjected to excessive soil or atmospheric contamination) of 0.2 to 0.5 μg/gm on a fresh-weight basis. The values reported in table 26 fall into the range considered normal. Consequently, the market vegetables collected in this study are not considered to represent a significant source of Pb contamination.

Except for spinach, the amount of Pb found in frozen foods is either very low or below the limits of detectability.

The Pb content of four brands of canned stewed tomatoes was determined. A sufficient number of cans of each brand were obtained so that determinations could be made on three successive dates. The data obtained, expressed in micrograms Pb per gram of contents, are shown in table 26. Lead as a contaminant from the container could enter food. The purpose of analyzing the canned tomatoes on three successive dates was to determine if there was any noticeable trend in Pb content as a function of storage time. Table 27 shows that no consistent trend occurred in relation to aging. The mean Pb content of the four brands analyzed ranged from 0.20 to 0.53 μg/gm of contents. The range for brands A, B, C, and D was 0.12 to 0.37, 0.15 to 0.28, 0.08 to 0.75, and 0.37 to 0.81 μg Pb/gm contents, respectively.

TABLE 28
LEAD DEPOSITION ON FLUOROCARBON FILMS AT VARIOUS DISTANCES FROM THE SANTA ANA FREEWAY (1969)*

Distance from freeway	Height above soil surface	Pb collected on film:†			
		East side of freeway‡		West side of freeway‡	
		Per film	Per cm²	Per film	Per cm²
meters		*μg*			
15	1.5	68.71	0.519	42.75	0.323
15	3.0	78.62	0.594	43.45	0.328
30	1.5	54.51	0.412	23.22	0.176
30	3.0	51.61	0.390	19.13	0.145
46	1.5	72.27	0.545	15.26	0.138
46	3.0	45.85	0.354	18.27	0.174
107	1.5	37.13	0.280	14.38	0.109
107	3.0	30.69	0.232	12.59	0.095
168	1.5	15.94	0.118	12.40	0.094
168	3.0	18.17	0.137	12.59	0.095
229	1.5	14.21	0.108	11.86	0.089
229	3.0	14.42	0.109	11.34	0.086

* ADT = 70,000.
† Films, each with 132.25 cm² collecting surface, were fixed on the tops of posts and exposed for 22 days.
‡ The lead deposited on the films on the east side of the freeway is significantly different from the west side at the 5 per cent level of probability.

TABLE 29

LEAD DEPOSITION IN 600-ml BEAKERS AT VARIOUS DISTANCES FROM THE SANTA ANA FREEWAY (1969)*

Distance from freeway	Height above soil surface	Pb collected in beaker on:†			
		East side of freeway‡		West side of freeway‡	
		Per beaker	Per cm²	Per beaker	Per cm²
meters		*μg*			
15	1.5	370.96	6.40	168.85	2.92
15	3.0	206.09	3.57	111.16	1.91
30	1.5	155.35	2.65	54.51	0.94
30	3.0	122.89	2.12	42.27	0.73
46	1.5	86.92	1.50	48.98	0.84
46	3.0	64.03	1.11	30.69	0.54
107	1.5	10.00	0.17	48.98	0.84
107	3.0	35.02	0.60	28.87	0.50
168	1.5	28.44	0.49	60.07	1.04
168	3.0	25.16	0.43	23.29	0.40
229	1.5	24.74	0.43	48.98	0.84
229	3.0	29.53	0.51	22.54	0.39

* ADT = 70,000.
† Beakers were fixed on the tops of posts and exposed for 22 days.
‡ The lead collected in the beakers on the east side of the freeway is significantly different from the west side at the 5 per cent level of probability.

Deposition of lead in beakers on fluorocarbon films and on oranges

Twelve posts were set in the ground along the Santa Ana freeway between Myford and Culver roads (see fig. 2); some of the tops of posts were 1.5 meters and some were 3 meters above the soil surface. Fluorocarbon films and 600-ml beakers were fixed horizontally at the top of each post to serve as collecting surfaces. The fluorocarbon film collecting surface had an area of 132.25 cm². The base area of the 600-ml beakers was 58 cm². The posts were placed on the east and the west sides of the freeway at 15, 30, 46, 107, 168, and 229 meters distance from the pavement edge. After 22 days, the films and beakers were removed from the posts. The particulates deposited on the films and in the beakers were dissolved in 10 per cent HNO_3, and Pb contents were determined for the HNO_3 extract colorimetrically.

No difference occurred between the amount of Pb deposited on the fluorocarbon films at 1.5 and 3.0 meters height above the soil surface (see table 28). Considerably more Pb was deposited on the films placed close to the freeway. Amounts of Pb found on the films 15 meters from the highway were about four times greater than those found 229 meters from the highway. Also, significantly more Pb deposits were on the films placed on the east side of the freeway, which received the prevailing winds.

Lead particulate deposits in the 600-ml beakers expressed in terms of total amounts collected and in terms of amount deposited per square centimeter of base surface are shown in table 29. Considerably more Pb was collected in the beakers than on the fluorocarbon films (compare tables 28 and 29). Although the film had a good collecting surface, once some coverage was attained, particulates were being deposited on particulates. It is reasonable to suspect that part of the top layer would be subsequently removed, particularly at times when the wind velocity was high. In contrast, materials deposited

TABLE 30

LEAD DEPOSITION ON PEELS FROM ORANGES GROWING NEAR THE SANTA ANA FREEWAY (1969)*

Distance from freeway†	Pb/cm² peels:‡			
	East side of freeway		West side of freeway	
	East side of tree	West side of tree	Eastside of tree	Westside of tree
meters	*μg*			
23- 30	0.78	0.97	0.65	0.32
30- 60	0.47	0.42	0.37	0.24
60- 90	0.37	0.48	0.33	0.26
90-120	0.38	0.34	0.23	0.19
120-150	0.32	0.32	0.17	0.17
150-180	0.25	0.24	0.11	0.12
180-210	0.21	0.21	0.18	0.12
210-240	0.29	0.29	0.18	0.16
240-270	0.33	0.31	0.17	0.18

* ADT = 70,000.
† Range of distance shown because the freeway bisected the orange grove at an angle.
‡ Each value reported is the mean of four fruit samples.

TABLE 31

LEAD CONCENTRATIONS OF SUSPENDED AIR PARTICULATES 45 CM ABOVE GROUND COLLECTED BETWEEN MYFORD AND CULVER ROADS ALONG THE SANTA ANA FREEWAY (1969)*

Distance from freeway	Sampling date	Sampling time	Pb/m³
meters			*μg*
10	2-2-68	10:40 A.M.-3:40 P.M.	8.43
10	2-5-68	11:34 A.M.-3:01 P.M.	5.81
15	4-29-69	11:37 A.M.-1:55 P.M.	3.18
15	4-30-69	10:45 A.M.-1:55 P.M.	3.30
15	5-8-69	12:30 P.M.-3:53 P.M.	5.29
15	5-9-69	12:45 P.M.-2:55 P.M.	6.03
15	5-12-69	10:12 A.M.-2:50 P.M.	3.18
15	5-26-69	10:42 A.M.-3:20 P.M.	4.29
15	5-29-69	10:57 A.M.-2:08 P.M.	5.95

* ADT = 70,000.

in the beakers were not subject to subsequent removal.

Results again showed that more Pb was deposited in the beakers placed close to the freeway decreasing as the distance from the freeway increased. Up to 107 meters from the freeway, more was deposited in the beakers on the east side of the road; beyond 107 meters the amounts collected on both sides of the freeway were about the same. If one assumes a bulk density for soil of 1.5 gm/cm³, the data presented for Pb deposition in beakers (table 29) indicate that the amounts deposited on soil to a depth of 1 cm—15 meters from the east side of the freeway—would be about 70 μg/gm per year. At 229 meters it would amount to about 5 μg Pb/gm per year. Surface soils adjacent to streets and highways in the Los Angeles area are reported to contain as much as 8,600 μg Pb/gm (Colucci, Begeman, and Kumler, 1969). Page and Ganje (1970) observed that the surface 2.5 cm layer of soil 1 mile or more from major highways in the Los Angeles metropolitan area accumulated around 25 μg Pb/gm over the past 30 to 40 years.

Deposition on the fluorocarbon film should more closely resemble deposition on vegetation surfaces. To determine this, oranges were sampled from a grove along the Santa Ana freeway (see fig. 2) about 1 mile south of where the films and beakers were placed. Samples were collected from the east and west sides of the freeway and from the east and west sides of the tree.

Table 30 showed trends similar to those obtained for Pb deposition on fluorocarbon films and in beakers. More Pb was deposited on the oranges from trees on the east side of the freeway. Lead on fruit taken from the west and east sides of the tree was about the same. Up to about 150 meters from the freeway, amounts on the oranges decreased as the distance from the freeway increased. Beyond 150 meters from the freeway, distance had little influence on Pb deposition.

It is not possible to make a true comparison of Pb on oranges and on the

fluorocarbon films, because the surface area of the orange is constantly changing and often shielded by leaves. Also, the oranges sampled had been on the tree about 16 months, from fruit set; and fluorocarbon films were exposed only 22 days.

Air-suspended particulates were collected at about the same location as was used for the Pb deposition study on fluorocarbon films along the Santa Ana freeway between Myford and Culver roads. Samples were collected on the east side of the freeway 10 and 15 meters from the pavement edge and 45 cm above the ground surface. The results (table 31) show a range of about 3 to 8.5 μg Pb/m^3 of air. With one exception, samples collected in 1968 at 10 meters from the pavement edge contained more Pb than samples collected about 14 months later, 15 meters from the pavement edge.

SUMMARY AND CONCLUSIONS

The Pb contents of 27 varieties of consumer crops and plants sampled at various distances from some major highways in southern California and in local markets were carefully determined. Amounts in and on crops grown close to these freeways were shown to be influenced by (a) distance from the highway, (b) extent of surface exposed, (c) nature of the collecting surface, (d) duration of exposure, (e) motor vehicle traffic density, and (f) direction of prevailing winds.

Exposed tissues of plants grown very close to major highways contained more Pb than similar tissues of plants grown some distance from the highways. This effect was most apparent at distances less than about 150 meters from freeway. Beyond 150 meters the Pb in and on vegetation was no longer related to distance from the highway and appeared to be governed by regional effects as opposed to local effects. In general, the greatest accumulations of Pb on crops occurred within 50 meters from the pavement edge.

Lead in parts of plants that are not in direct contact with the atmosphere, such as root, pod, and husk crops, was not substantially influenced by proximity to highly traveled roads. Corn kernels, lima beans, carrot, parsnip, and sugar beet roots all contained comparatively small amounts of Pb which were not significantly related to distance from the highway.

Exposed tissues of plants that have flexible, rough, hairy surfaces, and were close to highways, accumulated more Pb per unit time than did exposed tissues of plants having smooth surfaces. Lead particulates, deposited from the ambient air, adhered to the rough surfaces to a greater extent and were less subject to removal by wind action.

Duration of time of exposure of plant tissues, next to highways, influenced the amount of Pb collected by the tissues. Tomatoes, picked at various stages of maturity, showed increased Pb as the season progressed.

Direction of the prevailing wind also had a significant effect on Pb content of plants close to major highways. Without exception, Pb in plants on the leeward side of the highway exceeded that in similar plants on the windward side.

Where the traffic density was less than about 5,000 motor vehicles per day, exposed tissues from annual crops close to the pavement edge showed relatively minor Pb accumulations. When highways were traversed by 35,000 motor vehicles per day and over, Pb in these crops was substantially influenced.

Careful washing of plant parts collected from vegetation near highways served to reduce Pb to levels about equal to that observed in the same type of plant parts collected some distance from the highway. Where the surface of plant parts was smooth, mild washing procedures tended to remove high percentages of Pb. In contrast, more vigorous washing was required to remove high percentages of Pb from flexible, rough, hairy surfaces.

Amounts of Pb in and on nonbiological surfaces (films and beakers) were found to decrease as the distance from the freeway increased up to a maximum of about 120 meters from the pavement edge. Beyond 120 meters, amounts were more or less uniform and reflected regional rather than local effects.

Plants grown in Pb-free air on neutral or slightly alkaline southern California soils which contained a few to about 100 μg/gm nitric acid soluble Pb, did not absorb substantial amounts from the soil. Also, alfalfa plants grown in soil and irrigated in such a way that 10 μg Pb were applied weekly did not absorb measurable amounts of the added Pb.

All of the study results demonstrated that Pb accumulations in and on plants next to highways in southern California were caused principally by aerial deposition and not by—at least to any great extent—absorption by the plant from Pb-contaminated soil.

Lead in surface soils near major highways was greater than that obtained some distance from the highway. Roadside contamination was, for the most part, restricted to distances from the highway of less than 50 meters and occurred only in the surface (0 to 7.5 cm) horizons. At depths in the profile 50 to 65 cm, Pb in soils was not related to distance from the highway.

Concentration of Pb in suspended air particulates was influenced by distance from the highway and direction of the prevailing winds; in the air, concentrations were greatest on the leeward side of the highway.

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LITERATURE CITED

AMERICAN CHEMICAL SOCIETY
1969. *In:* Cleaning our environment—the chemical basis for action. A report by the Subcommittee on Environmental Improvement, Committee on Chemistry and Public Affairs, Washington, D.C.

ANON.
1969. Lead in the air. *In* "Outlook." Environ. Sci. and Technol. 3:529.

CANNON, H. L., and J. M. BOWLES
1962. Contamination of vegetation by tetraethyl lead. Science 137:765–66.

COLUCCI, J. M., C. R. BEGEMAN, and K. KUMLER
1969. Lead concentrations in Detroit, New York, and Los Angeles air. Jour. Air Pollution Control Association 19:255–60.

DAINES, R. H., H. MOTTO, and D. M. CHILKO
1970. Atmospheric lead: its relationship to traffic volume and proximity to highways. Environ. Sci. and Technol. 4:318–22.

DEDOLPH, R., G. TER HAAR, R. HOLTZMAN, and H. LUCAS
1970. Sources of lead in perennial ryegrass and radishes. Environ. Sci. and Technol. **4**:217–23.
DUNN, J. T., and H. C. L. BLOXAM
1933. The occurrence of lead, copper, zinc and arsenic compounds in atmospheric dust and the source of these impurities. Jour. Soc. Chem. Ind., London. **52**, 189T.
EVERETT, J. C., C. L. DAY, and D. REYNOLDS
1967. Comparative survey of lead at selected sites in the British Isles in relation to air pollution. Food and Cosmetic Toxicol. **5**:29–35.
GOLDSMITH, J. R., and A. C. HEXTER
1967. Respiratory exposure to lead: epidemiological and experimental dose-response relationships. Science **158**:132–34.
HALEY, THOMAS J.
1966. Chronic lead intoxication from environmental contamination: myth or fact. Arch. Environ. Health **12**:781–85.
HAMMOND, P. B., and A. L. ARONSON
1964. Lead poisoning in cattle and horses in the vicinity of a smelter. Ann. N. Y. Acad. Sci. **III**, Art. 2, 595–611.
HIRSCHLER, D. A., L. F. GILBERT, F. W. LAMB, and L. M. NIEBYLSKY
1957. Particulate lead compounds in automobile exhaust gas. Ind. Eng. Chem. **49**:1131–42.
KEATON, C. M.
1937. The influence of lead compounds on the growth of barley. Soil Sci. **43**:401–11.
KEENAN, R. G., D. H. BYERS, B. E. SALTZMAN, and F. L. HYSLOP
1963. The "USPHS" method for determining lead in air and in biological materials. Amer. Indust. Hyg. Assoc. Jour. **24**:481–91.
KEHOE, R. A.
1964. Standards with respect to atmospheric lead. Arch. Environ. Health **8**:348–54.
KLOKE, A., and K. RIEBARTSCH
1964. The contamination of plants with lead from motor exhausts. Die Naturwissenschaften **51**:367–68.
LEH, H. O.
1966. Contamination of crop plants with lead from motor vehicle exhaust gases. Gesunde Pflanzen **18**:21–24.
LEWIS, K. H.
1966. *In* "Symposium on Environmental Lead Contamination," U. S. Publ. Health Serv. Publ. No. **1440**, U. S. Govt. Printing Office, Washington, D.C. p. 17.
MITCHELL, R. L., and J. W. S. REITH
1966. The lead content of pasture herbage. Jour. Sci. Food Agr. **17**:437–40.
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. and Technol. **4**:231–37.
PAGE, A. L., and T. J. GANJE
1970. Accumulation of lead in soils for regions of high and low motor vehicle traffic density. Environ. Sci. and Technol. **4**:140–42.
PATTERSON, C. C.
1965. Contamination and natural lead environments of man. Arch. Environ. Health **11**:344–58.
ROBINSON, E., and F. L. LUDWIG
1967. Particle size distribution of urban lead aerosols. Jour. Air Pollution Control Association **17**:664–69.
SCHUCK, E. A., and J. K. LOCKE
1970. Relationship of automotive lead particulates to certain consumer crops. Environ. Sci. and Technol. **4**:324–30.
SINGER, M. J., and L. HANSON
1969. Lead accumulation in soils near highways in the twin cities metropolitan area. Soil Sci. Soc. Amer. Proc. **33**: 152–53.
TER HAAR, G.
1970. Air as a source of lead in edible crops. Environ. Sci. and Technol. **4**:226–29.
WARREN, H. V., and R. E. DELAVAULT
1962. Lead in some food crops and trees. Jour. Sci. Food Agr. **13**:96–98.

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