LEAD, CADMIUM, NICKEL AND ZINC CONCENTRATIONS IN SOIL AND VEGETATION ASSOCIATED WITH HIGHWAYS OF DIFFERENT TRAFFIC DENSITIES

by

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TABLE OF CONTENTS

Page

ABSTRACT

LIST OF TABLES

Table Page

Table Page

Appendix

LIST OF FIGURES

INTRODUCTION

As the highway network in the United States expands, the total area influenced by highways also expands. Van Dersal (1943) calculated, that of the total land area in the United States, 20,000,000 acres (8,094,000 ha) were contained in highways and their rights of way. Wooten and Anderson (1958) reported that during the period from 1945 to 1954, the area of highway development was increasing by about 78,000 acres (31,567 ha) per year. More recently, in the 1973 edition of Highway Statistics (U.S. Department of Transportation), the total mileage of highways in the United States was reported as 3,806,883 miles (6,126,300 km). Smith (1976) reported that 3.04×10^7 hectares of land associated with highways in the United States contained elevated levels of lead generated from motor vehicles.

The Highway Ecosystem

With such a large quantity of land committed to highway development, it is imperative that highway systems be regarded as ecosystems. Highways often traverse prime agricultural land, since many of the same qualities desirable for farming are also requisite for road construction. Highways also border on residential areas, and there is a growing practice of cutting roadside and median strip grass to use as livestock feed. These factors must warrant consideration, given the present knowledge of toxic substances associated with highways and motor vehicles.

Since the highway system in this country is essential to present life styles, it is necessary to consider the highway network in an ecological manner and manage it as any biological system is managed. This involves managing for the benefit of man, by considering his agricultural crops and livestock, and also managing for the benefit of wildlife.

Highways and Wildlife

It has long been recognized that highways exert both positive and negative effects on wildlife populations. Many wild animals are attracted to roadside environments because of the beneficial alterations of habitat that roadsides provide. Roads are man made "edges," of known value to wildlife. Desirable grasses are often planted adjacent to roads and kept mowed, thereby increasing their nutritional value. Small mammals, such as rabbits and meadow voles, nest and feed along roads, as do dozens of species of song birds. In addition, raptors take advantage of the abundance and visibility of prey along road edges.

Miller and Powell (1942) determined that 75 percent of all highway areas were providing food and cover for wildlife, and that on an estimated 75 percent of these lands, it was economically feasible to improve wildlife habitat. Yet, in view of the hazards associated with highways, such as contamination by toxic substances, destruction of nests, and direct highway mortality, it has been suggested that wildlife habitat along roadsides be discouraged. Actual management policies must involve an individual evaluation of each highway, assessing the beneficial and detrimental effects. Management of highway ecosystems must relate total traffic volume and daily fluctuations in highway use to daily and seasonal patterns of roadside wildlife activity.

Roadside Contamination by Lead, Cadmium, Nickel, and Zinc

This project is specifically concerned with the extent of roadside contamination by lead, cadmium, nickel, and zinc. Earlier studies have confirmed that lead levels adjacent to roads are proportional to traffic density and inversely proportional to distance from the highway. However, the same type of information is lacking for the other three elements.

The first objective of this study was to determine the levels of these elements in soil and vegetation along highways of different traffic densities, at increasing distances from the road. The second objective was to determine the extent to which the above elements are transported from soil to vegetation.

Thirdly, it was important to determine whether there is plant species variability with respect to the concentration of lead, cadmium, nickel, and zinc. Research with cultivated crops has indicated that certain plant species, such as tomato, are more prone to take up heavy metals than others, such as wheat (Pettersson 1976). Information is still needed on the absorption of these elements by roadside vegetation. With this knowledge, there would be a basis for deciding which species might be suitable either as wildlife food crops, or as sinks to absorb vehicular emissions.

The final objective was to determine whether there is seasonal variation in plant and soil contamination along roadways. Knowledge of this might enable wildlife biologists to assess which times of the year are most critical to roadside biota.

REVIEW OF THE LITERATURE

Natural Occurrence of Lead, Cadmium, Nickel, and Zinc

Lead

Several investigators have reported values for naturally occurring lead levels. Treville (1964) reviewed the literature on the natural occurrence of lead. He cited Goldschmidt (1954) and Vinogradov (1954) as estimating the average lead content of the earth's crust at 16 μg/g. Basic rocks contain about 8 μg/g and acid rocks, about 16 μg/g lead. Patterson (1965) estimated the natural lead concentration of air at 0.0005 $\mu g/m^3$. This natural atmospheric lead is attributed to the erosion of lead containing soils.

Warren and Delavault (1962) presented data on the natural lead content of cereals and vegetables. Wheat heads contained 1.0 to 2.0 μg/g, oat heads 0.3 to 2.0 μg/g, and barley heads 0.5 to 20.0 μg/g. Cabbage ranged from 0.5 to 3.0 μg/g lead, beets from 1.0 to 6.0 μg/g, and lettuce from 1.0 to 9.0 μg/g. Other information on the natural lead content of food crops can be found in Monier-Williams (1938), Bagchi et al. (1940), and Kehoe et al. (1940).

Cadmium

It is not known precisely what level of cadmium in soil represents contamination. Analyses of purportedly uncontaminated soils indicated that normal levels of cadmium are less than one μg/g, and average 0.4 μg/g (Fleischer 1974). According to Allaway (1968), the concentration of cadmium in nonpolluted soils ranges from 0.01 to 7.0 μg/g.

Nickel

"Normal" levels of soil nickel vary with the type of soil. Mitchell (1945) reported that soils derived from basic igneous rocks or argillaceous sediments can have from 50 to 500 μg/g nickel, but in most other soils (i.e., from sandstones, limestones, and acid igneous rocks), normal nickel concentrations should be less than 50 μg/g. Vanselow (1966) reviewed the literature on natural soil levels of nickel throughout the world. He reported that European soils range from 5 to 40 μg/g nickel, Spanish soils from 5 to 230 μg/g, Russian soils from 10 to 500 μg/g, and American soils from 1 to 100 μg/g.

Zinc

Chapman (1966) reported that levels of 25 to 150 μg/g soil zinc are normally found in uncontaminated areas. No other information is available on natural levels of zinc in soil or vegetation.

Sources of Lead, Cadmium, Nickel, and Zinc From Motor Vehicles

Lead

The major uses of lead are in the manufacture of metal products, pigments, chemicals, storage batteries, and gasoline additives (Goyer and Chisholm 1972). In 1969, these gasoline additives accounted for 20 percent of the lead consumed in the United States. As reported by Goyer and Chisholm (1972), the most important source of lead contamination in ambient air was automobile exhaust, with urban atmospheric concentrations averaging 1 to 3 $\mu g/m^3$, and reaching as high as 40 $\mu g/m^3$ near traffic.

Lead is emitted in automobile exhaust in the form of mixed lead halides, and represents less than one third of the total particulates in automobile exhaust (Ter Haar et al. 1972). Lead alkyls are originally added to gasoline to serve as antiknock agents. These organic lead compounds are converted to oxides during the combustion process, and then transformed to halides by "scavengers." The scavengers are added to fuel to remove lead deposits from metallic engine parts. Because of these chemical transformations, only 10 percent of the exhaust lead is emitted in the more toxic organic state (Goyer and Chisholm 1972). The lead halides consist of predominantly $PbBrCl$, $2PbBrCl\text{-}NH_4Cl$, and $2Pb\text{-}PbBrCl$, the first one being the most abundant (Springer 1973).

The particulate nature of these lead halides governs the kinetics of lead dispersal from highways. Presently, not enough is known about particulate behavior to accurately predict rates of dispersal and fallout, especially under variable weather conditions. However, larger particulates can be expected to drift shorter distances and be deposited closer to their site of release than smaller ones.

Hirschler and Gilbert (1964) reported lead particles from automobiles ranging from 0.01 μ to several millimeters in diameter. It was concluded that 50 to 75 percent of lead exhausted under city driving conditions is associated with particles less than 5 μ in diameter. Habibi (1973) reported that 25 percent of lead emitted from motor vehicles is associated with particles less than 1 μ in size, and 57 percent is associated with particles greater than 9 μ in diameter. Daines et al. (1970) reported that 65 percent of the lead in air between 30 and 1750 ft (9.14 and 609 m) from a highway consists of particles under 2 μ, and 85 percent under 4 μ. This indicates that lead particles greater than 4 μ in diameter settle out fairly rapidly.

The size distribution of lead particulates varies with driving conditions and the age of the motor vehicle. Ter Haar et al. (1972) observed that exhausted lead particles become larger as car mileage accumulates and as driving conditions become more severe (i.e., at higher speeds and greater loads).

The same factors affecting lead particulate size also influence the rate of lead emission from motor vehicles. Lead emission rates increase with higher speeds, greater loads, and mileage accumulation of the vehicle (Habibi 1973). More particulates are released during acceleration and deceleration than constant speed driving, and cold cycle operation emits 2 to 8 times more particulates than hot engine operation (Ter Haar et al. 1972).

Cadmium

Cadmium is a widespread environmental contaminant generated from a number of man related practices. Cadmium is geochemically similar to zinc, and therefore any industry involved with zinc smelting releases cadmium as a by-product. Cadmium may also be present as an impurity in phosphate fertilizers, and is used as a fungicide, as well as a helminth suppressant for cattle (Lagerwerff and Specht, 1970a).

There are three sources of cadmium from motor vehicles: lubricating oil, diesel oil, and tire tread wear. Cadmium is generally introduced as an impurity in the antioxidant zinc dithiophosphate, a component of lubricating oil. This source of cadmium is of minor concern, since lubricating oils are burned to a major degree only in two cycle engines. Lagerwerff and Specht (1970a) analyzed three brands of lubricating oil and found from 0.20 to 0.26 μg/g cadmium. Diesel oil contained 0.07 to 0.11 μg/g cadmium. Tires are customarily vulcanized with zinc oxide and zinc diethyl or dimethyl carbamate. Because of the relationship between cadmium and zinc, tires have been found to contain 20 to 90 μg/g cadmium. This may be an important source of cadmium near roadways since Marchesani et al. (1970) estimated the daily deposition of tire tread wear in the United States at 830 tons.

Nickel

Of the four metals being studied, nickel appears to present the least danger to roadside ecosystems. It is generally toxic at only abnormally high levels, higher than are likely to be found along highways. Before the advent of massive highway networks, there were only four significant sources of nickel contamination, viz., fungicides, pulverized serpentine, nickel plating factories, and nickel mining operations (Halstead et al. 1969). Today, nickel is added as a deposit modifying agent to some gasolines, and is generated from the abrasion of nickel containing automotive parts, such as brake linings and tires (Lagerwerff 1967, National Academy of Science 1975).

Zinc

There are two major sources of zinc emissions from motor vehicles. Zinc dithiophosphate is added as an antioxidant to lubricating oil, and zinc diethyl and dimethyl carbamate are used in tire vulcanization. Other sources of zinc contamination include sewage effluents, industrial wastes, superphosphate fertilizers, and pesticides (Lagerwerff and Specht 1970b).

There is no information on the particle size distribution of cadmium, nickel, and zinc particulates generated from motor vehicles. For this reason, the kinetics of their movement and fallout in the highway ecosystem cannot be evaluated.

Roadside Contamination By Lead, Cadmium, Nickel, and Zinc

Several studies have been conducted on the roadside gradients of lead, cadmium, nickel, and zinc in soil and vegetation. The majority of these have dealt with just lead, and most studies dealt with only one sampling period, thereby ignoring possible seasonal effects. A summary of data in the literature on roadside concentrations of these elements is presented in Tables 1 through 5.

Lagerwerff and Specht (1970a, 1970b) conducted two studies on roadside contamination by heavy metals. The first dealt with lead, cadmium, nickel, and zinc, while the second included only cadmium and zinc. Soil and vegetation were collected along highways of variable traffic density, at increasing distances from the road. For all four elements, there was a decrease in plant and soil contamination as distance from the road increased. The concentration of lead, cadmium, nickel, and zinc also decreased with increasing soil depth, indicating a limited downward movement in the soil profile (Tables 1-5). Their 1970a report emphasized that high concentrations of one element do not necessarily correspond with high concentrations of one of the others. The element concentration gradient with distance followed the order Cd > Pb > Zn > Ni.

Gish and Christensen (1973) reported on the levels of lead, cadmium, nickel, and zinc in earthworms and soil along two Maryland highways. The concentration of all four elements decreased in both soil and earthworms as traffic density decreased and as distance from the highway increased. The evidence presented indicated that lead, cadmium, nickel, and zinc will accumulate in higher organisms (Tables 1-3).

Table 1. Lead Levels in Roadside Soil

Traffic Use Vehicles/Day	Location	Soil Depth (cm)	µg/g (distance from road, m) Near	Intermediate	Far	Literature Source
17,497	Eng.	0-10	130 (1)	80 (25)	19 (50)	Davies & Holmes (1972)
503	Eng.	0-10	25 (1)	20 (25)	--	Davies & Holmes (1972)
7,000	Col.	0-15.24	400 (3)	35 (13)	25 (55)	Seeley et al. (1972)
48,000	Md.	0-5	540 (8)	202 (16)	140 (32)	Lagerwerff & Specht (1970a)
48,000	Md.	5-10	300 (8)	105 (16)	60 (32)	Lagerwerff & Specht (1970a)
48,000	Md.	10-15	98 (8)	60 (16)	38 (32)	Lagerwerff & Specht (1970a)
23,000	Oh.	0-5	150 (8)	101 (16)	55 (32)	Lagerwerff & Specht (1970a)
7,500	Mo.	0-5	242 (8)	140 (16)	61 (32)	Lagerwerff & Specht (1970a)
21,040	Va.	0-2.5	87 (6)	80 (12)	47 (18)	Goldsmith et al. (1976)
1,085	Va.	0-2.5	26 (6)	20 (12)	27 (18)	Goldsmith et al. (1976)
12,800	N.J.	0-15.24	134 (7.6)	70 (22.9)	60 (38.1)	Motto et al. (1970)
54,700	N.J.	0-15.24	169 (7.6)	171 (22.9)	98 (38.1)	Motto et al. (1970)
56,000	Md.	0-5	122 (7.6)	75 (15)	63 (30)	Chow (1970)
24,000	Md.	0-5	403 (7.6)	211 (15)	92 (30)	Chow (1970)
46,000	Md.	0-2.5	700 (3)	94 (12.2)	82 (48.8)	Gish & Christensen (1973)
25,000	Md.	0-2.5	313 (3)	54 (12.2)	35 (48.8)	Gish & Christensen (1973)

Table 2. Cadmium Levels in Roadside Soil

Traffic Use Vehicles/Day	Location	Soil Depth (cm)	µg/g (distance from road, m)			Control	Literature Source
			Near	Intermediate	Far		
48,000	Md.	0-5	0.94 (8)	0.68 (16)	0.24 (32)		Lagerwerff & Specht (1970a)
48,000	Md.	5-10	0.70 (8)	0.44 (16)	0.18 (32)		Lagerwerff & Specht (1970a)
48,000	Md.	10-15	0.30 (8)	0.18 (16)	0.12 (32)		Lagerwerff & Specht (1970a)
23,000	Oh.	0-5	1.82 (8)	1.51 (16)	1.02 (32)		Lagerwerff & Specht (1970a)
7,500	Mo.	0-5	0.90 (8)	0.77 (16)	0.68 (32)		Lagerwerff & Specht (1970a)
7,500	Mo.	5-10	0.66 (8)	0.70 (16)	0.52 (32)		Lagerwerff & Specht (1970a)
20,000	Md.	0-5	0.65 (8)	0.31 (16)	0.17 (32)		Lagerwerff & Specht (1970b)
10,600	Oh.	0-5	1.04 (8)	0.86 (16)	0.66 (32)		Lagerwerff & Specht (1970b)
46,000	Md.	0-2.5	1.59 (3)	0.68 (12.2)	0.74 (48.8)		Gish & Christensen (1973
25,000	Md.	0-2.5	0.95 (3)	0.76 (12.2)	0.70 (48.8)		Gish & Christensen (1973)
Control	Md.	0-2.5				0.66	Gish & Christensen (1973)

Table 3. Metal and Zinc Levels in Roadside Soil

Metal	Traffic Use Vehicles/Day	Location	Soil Depth (cm)	µg/g (distance from road, m) Near	Intermediate	Far	Control	Literature Source
Nickel	48,000	Md.	0-5	7.4 (8)	4.4 (16)	2.4 (32)		Lagerwerff & Specht (1970a)
	48,000	Md.	5-10	5.6 (8)	1.6 (16)	1.2 (32)		Lagerwerff & Specht (1970a)
	48,000	Md.	10-15	1.4 (8)	0.79 (16)	0.57 (32)		Lagerwerff & Specht (1970a)
	20,000	Md.	0-5	4.7 (8)	2.4 (16)	2.2 (32)		Lagerwerff & Specht (1970a)
	46,000	Md.	0-2.5	26.3 (3)	18.4 (12.2)	12.5 (48.8)		Gish & Christensen (1973)
	25,000	Md.	0-2.5	23.9 (3)	14.3 (12.2)	14.4 (48.8)		Gish & Christensen (1973)
	Control	Md.	0-2.5				13.6	Gish & Christensen (1973)
Zinc	48,000	Md.	0-5	162.0 (8)	110.0 (16)	44.0 (32)		Lagerwerff & Specht (1970a)
	48,000	Md.	5-10	86.0 (8)	28.0 (16)	20.0 (32)		Lagerwerff & Specht (1970a)
	48,000	Md.	10-15	36.0 (8)	20.0 (16)	18.0 (32)		Lagerwerff & Specht (1970a)
	23,000	Oh.	0-5	72.0 (8)	60.0 (16)	34.0 (32)		Lagerwerff & Specht (1970a)
	7,500	Mo.	0-5	54.0 (8)	60.0 (16)	15.0 (32)		Lagerwerff & Specht (1970a)
	20,000	Md.	0-5	192.0 (8)	112.0 (16)	43.0 (32)		Lagerwerff & Specht (1970b)
	10,600	Oh.	0-5	55.5 (8)	38.0 (16)	17.4 (32)		Lagerwerff & Specht (1970b)
	46,000	Md.	0-2.5	229.1 (3)	70.8 (12.2)	72.5 (48.8)		Gish & Christensen (1973)
	25,000	Md.	0-2.5	141.1 (3)	57.6 (12.2)	48.2 (48.8)		Gish & Christensen (1973)
	Control	Md.	0-2.5				42.3	Gish & Christensen (1973)

Table 4. Lead Levels in Roadside Vegetation

Traffic Use Vehicles/Day	Location	Vegetation Type	μg/g (distance from road, m)			Literature Source
			Near	Intermediate	Far	
48,000	Md.	Grass	51.3 (8)	30 (16)	18.5 (32)	Lagerwerff & Specht (1970a)
23,000	Oh.	Grass	31.3 (8)	26.0 (16)	7.6 (32)	Lagerwerff & Specht (1970a)
7,500	Mo.	Grass	21.3 (8)	12.5 (16)	7.5 (32)	Lagerwerff & Specht (1970a)
19,000	Tx.	Ass't. Veg.	74 (1)	45 (32)	5.1 (160)	Hopkinson et al. (1972)
12,800	N.J.	Grass	63 (7.6)	76 (22.9)	--	Motto et al. (1970)
54,700	N.J.	Grass	139 (7.6)	83 (22.9)	78 (38.1)	Motto et al. (1970)
21,040	Va.	Crown Vetch	74.9 (6)	42.3 (12)	27.4 (18)	Goldsmith et al. (1976)
17,497	Eng.	Grass	580 (1)	500 (25)	171 (50)	Davies & Holmes (1972)
503	Eng.	Grass	175 (1)	99 (25)	--	Davies & Holmes (1972)
unidentified	Md.	Ass't. Veg.	80 (7.6)	66 (15.2)	45 (152)	Cannon & Bowles (1962)
56,000	Md.	Grass	48 (7.6)	41 (15)	24 (30)	Chow (1970
24,000	Md.	Grass	60 (7.6)	56 (15)	40 (30)	Chow (1970)

Table 5. Cadmium, Nickel, and Zinc Levels in Roadside Grass

Metal	Traffic Use Vehicles/Day	Location	μg/g (distance from road, m) Near	Intermediate	Far	Literature Source
Cadmium	48,000	Md.	0.75 (8)	0.63 (16)	0.48 (32)	Lagerwerff & Specht (1970a)
	23,000	Oh.	0.74 (8)	0.49 (16)	0.26 (32)	Lagerwerff & Specht (1970a)
	20,000	Md.	0.95 (8)	0.73 (16)	0.50 (32)	Lagerwerff & Specht (1970a)
	7,500	Mo.	0.49 (8)	0.37 (16)	0.25 (32)	Lagerwerff & Specht (1970a)
	20,000	Md.	1.25 (8)	0.75 (16)	0.25 (32)	Lagerwerff & Specht (1970b)
	10,600	Oh.	0.63 (8)	0.38 (16)	0.25 (32)	Lagerwerff & Specht (1970b)
Nickel	48,000	Md.	3.80 (8)	2.50 (16)	1.30 (32)	Lagerwerff & Specht (1970a)
	20,000	Md.	5.00 (8)	3.80 (16)	2.80 (32)	Lagerwerff & Specht (1970a)
Zinc	48,000	Md.	40.00 (8)	34.50 (16)	30.30 (32)	Lagerwerff & Specht (1970a)
	23,000	Oh.	85.00 (8)	72.40 (16)	67.10 (32)	Lagerwerff & Specht (1970a)
	20,000	Md.	32.00 (8)	28.50 (16)	27.30 (32)	Lagerwerff & Specht (1970a)
	7,500	Mo.	36.30 (8)	32.80 (16)	29.00 (32)	Lagerwerff & Specht (1970a)
	20,000	Md.	64.50 (8)	50.00 (16)	41.20 (32)	Lagerwerff & Specht (1970b)
	10,600	Oh.	92.40 (8)	82.70 (16)	72.50 (32)	Lagerwerff & Specht (1970b)

Chow (1970) conducted a study of the lead levels in roadside grass and soil. It was concluded that lead residues increase with increasing traffic density, and that the wind is important in distributing the lead particulates. Lead accumulated in surface soils, and was two to twelve times higher in grass than in the soil in which the grass was growing (Tables 1, 4). Chow also studied lead isotopes and found that roadside lead associated with vegetation was of the same isotopic nature as gasoline additives. The isotopic composition of the lead present in grass was more similar to the surface soil lead, some of which presumably resulted from contamination, than the lead of deeper soil levels. This indicates that either the grass is absorbing most of its lead from the surface soil, or a large percentage of the lead associated with the grass was due to direct surface deposition of lead particulates.

Motto et al. (1970), Schuck and Locke (1970), and Seeley et al. (1972) have also reported on decreasing lead concentrations in soil and vegetation as distance from the highway increased and as soil depth increased (Tables 1, 4). Motto et al. (1970) also observed a direct relationship between traffic density and the lead content of roadside soil and grass. In all of these reports it was concluded that lead levels will reach a nearly constant level at a certain distance from the road. Schuck and Locke (1970) conservatively estimated that due to the dilution of lead particulates in air with increasing distance from the road, most exhaust lead will be detected within a few hundred feet of the highway. Seeley et al. (1972) estimated this distance to be 50 to 60 ft (15.25 to 18.3 m) from a highway serving 7,000 vehicles per day. Motto et al. (1970) concluded that the major effect of traffic on roadside lead levels is restricted to a band within 100 ft (30.5 m) of the road.

Cannon and Bowles (1962), Davies and Holmes (1972), Goldsmith et al. (1976), and Hopkinson et al. (1976) conducted similar studies of roadside lead concentrations and recorded similar results. Lead levels decreased with decreased traffic volume, increased soil depth, and increasing distance from the road (Tables 1, 4).

Creason et al. (1971) reported on roadside gradients in atmospheric concentrations of lead, cadmium, and zinc. Atmospheric lead levels were greater at 25 ft (7.62 m) from the road than at 100 ft (30.48 m). There was no pattern to atmospheric cadmium or zinc concentrations that indicated the highway as a source of contamination.

Daines et al. (1970) and Schuck and Locke (1970) conducted studies on atmospheric lead gradients along highways. Daines et al. (1970) reported that there was a relationship between the concentration of lead in the air and traffic volume, proximity to the highway, engine acceleration vs. constant speed, and wind direction. Schuck and Locke (1970) observed an inverse relationship between atmospheric lead concentrations and distance from the highway.

Several researchers have concentrated on the levels of heavy metals in roadside trees. Barnes (1976) reported on the lead and zinc content of tree rings and bark. The concentration of lead and zinc in bark decreased with increasing distance from the road and with height above the ground. There was no apparent relationship between sample site or ring age and airborne levels of lead or zinc.

Ward et al. (1974) sampled bark, leaves, and cores from trees growing along a highway in New Zealand. Bark facing the road had lead levels of 1080 μg/g, compared to 750 μg/g on the opposite side of the tree. There was an increase in the bark lead content up to a height of one to two m from the ground. Thereafter, it decreased with increasing height of the tree (the authors explained that exhaust is characteristically emitted from the vehicle at about 0.25 m from the ground, and due to turbulence, rises to strike the tree bark at about 2m). Lead in the outer bark was significantly greater than lead in the inner bark--810 μg/g outer vs. 130 μg/g inner. Examination of tree rings showed an increased lead content from the year 1923, the year leaded gasoline was introduced in New Zealand.

Keller (1970, 1971) was also concerned with roadside trees, and studied lead levels in conifers growing near Swiss highways. It was contended that one year old pine needles should have a natural lead content of 2 to 3 μg/g. Actual lead levels were substantially higher than this in roadside pine, and the lead content increased with the age of the needles. This study recommended conifers for use as air filters along highways. Heichel and Hankin (1976) also investigated roadside coniferous windbreaks, and reported that they act as sinks for vehicular emissions, serving to decrease dispersion from the roads.

Kinard et al. (1976) were concerned with the effects of more complex traffic patterns on lead accumulation. An area of four square city blocks was mapped, and sampling points were chosen within the square area. There was a decline in soil lead with increasing distance from the periphery, and an accumulation near the center due to a presumed synergistic buildup.

Surface Contamination of Plants by Lead, Cadmium, Nickel, and Zinc

There are three major avenues for contamination of plants by lead, cadmium, nickel, and zinc. The elements may be absorbed through the plant roots and translocated, deposited on the plant surface, or undergo the little studied process of foliar absorption. Motto et al. (1970) determined that washing removed about half of the lead from grass growing near a road. As distance from the road increased, a lower percentage of the lead was removable by washing, indicating that there was surface contamination of plants with a lead containing material associated with the highway. The report by Suchodoller (1967) confirmed this hypothesis. It was demonstrated that 50 percent of plant lead was removable by a water wash when heavy contamination was evident. If the plants were only lightly contaminated with lead, very small percentages were removable by a water wash.

Garber (1970) found that between 30 and 50 percent of the lead associated with plants could be washed off; Schuck and Locke (1970) and Davies and Holmes (1972) also quoted a figure of 50 percent as the amount of plant lead present as surface contamination. Goodman and Roberts (1971) demonstrated that washing grass contaminated with cadmium removed as much as 45 percent of the element.

The surface structure of a plant determines to a large extent its degree of surface contamination by atmospheric particulates. Page and Ganje (1970) emphasized this relationship, and reported that plants with rough or hairy leaves and stems were found to collect more lead than those with smooth surfaces. Wedding et al. (1977) observed that the deposition rate of lead aerosols on pubescent leaves of sunflowers was nearly seven times that of the nonpubescent leaves of tulip poplar. Kloke and Leh (1969), Quinche et al. (1969), and Fidora (1972) have all reported similar findings.

The growth form of a plant also determines its degree of surface contamination. Plants with large aerial portions are more subject to contamination by airborne particulates. Suchodoller (1967) observed that cereal leaves contained 147 μg/g lead, whereas the spikes had 48 μg/g, and stems 20 μg/g. Motto et al. (1970) observed that corn tassels had very high lead levels relative to the rest of the plant.

Absorption of Lead, Cadmium, Nickel, and Zinc By Plants

Root Uptake

The absorption of lead, cadmium, nickel, and zinc by the roots of plants is highly dependent on the soil chemistry of the growth medium. Soil factors that cause a binding of these metals to soil components greatly reduce their uptake by plants. Soil factors of importance in determining element availability are cation exchange capacity (CEC), organic matter, other soil ions, chelating agents, and soil pH.

The above variables account for the often nonlinear relationship between soil concentrations of lead, cadmium, nickel, and zinc and the corresponding concentrations of these elements in vegetation growing on the soil. Marten and Hammond (1966) demonstrated that an eightfold increase in total soil lead failed to increase the lead content of bromegrass growing on it. Keaton (1937) added 2784 μg/g lead as lead nitrate to soils. After three days, only 17 μg/g was still in soluble form. Brown et al. (1962) reported that about 35 percent of zinc applied to soil was found in plants growing on the soil.

Cation exchange capacity.

The cation exchange capacity (CEC) of soil determines its ability to bind ions from the soil solution. Soils with a high organic matter or clay content have characteristically high CEC's, and would therefore be expected to reduce the availability of elements for plant absorption. Koeppe (1977) reported that the uptake and translocation of cadmium into plant shoots from a loamy sand soil was 48 μg/g dry weight of shoot tissue, whereas uptake from a silty clay loam soil with a higher CEC was 8.4 μg/g dry weight. Plant uptake of lead was also inversely proportional to the CEC of the soil medium.

Haghiri (1974) grew oats on soils of varying cation exchange capacities. As the CEC increased, the cadmium concentration in the oats decreased. John (1971) observed that cadmium absorption by soils was enhanced by an increased CEC.

Jurinak and Thorne (1955) reported that zinc applied as $ZnCl_2$ to silty clay loam leached to a depth of 3 cm. Barrows et al. (1960) applied $ZnSO_4$ to the surface of lakeland fine sand and observed leaching down to 46 cm. Singh (1974) concluded that soil columns will retain zinc in amounts equivalent to one half to one third of their cation exchange capacity.

Organic matter.

Several investigators have concentrated on the effect of soil organic matter on the availability of lead, cadmium, nickel, and zinc to plants. Gish and Christensen (1973) observed that soil organic matter was significantly correlated ($P < 0.05$) with the concentration of these elements in the soil. This suggests a high retention of lead, cadmium, nickel, and zinc by organic matter. Koeppe (1977) noted an inverse relationship between soil organic matter and the uptake of lead and cadmium by plants. John (1971) and Haghiri (1974) observed that an increase in soil organic colloids reduced the amount of cadmium that was available for absorption by oat plants. This inverse relationship between soil organic matter content and plant uptake was also reported for nickel (Halstead et al. 1969) and zinc (Hodgson et al. 1965).

Chelating agents.

The presence of chelating agents in the soil also influences the absorption of lead, cadmium, nickel, and zinc by plants. Isermann (1977) suggested a method to reduce lead uptake by plants. It was demonstrated that splashing or washing plant roots with solutions of chelates (CaEDTA and Napolyphosphate) was an effective way to reduce lead uptake, since chelated lead cannot be readily absorbed due to its charge and larger size.

John (1971) and Haghiri (1974) observed that the addition of chelating agents to soil reduced the amount of cadmium available for plant uptake. Travnikova (1963) found that the addition of various fertilizers to soil resulted in a decreased absorption of nickel by plants, presumably because more nickel ions became complexed with ions in the fertilizer. Crooke (1954), DeKock (1956), and DeKock and Mitchell (1957) have all confirmed that chelation of soil nickel reduces its availability for plant uptake.

Zinc absorption by plants is also dependent on the presence of other ions in the soil. Schmid et al. (1965) reported that much less radioactive zinc was absorbed by hydroponically grown plants if calcium was also present in the growing solution. Copper severely inhibited zinc absorption, and manganese was slightly inhibitory. It has been observed that zinc becomes strongly adsorbed to silicate mineral surfaces (Elgabaly and Jenny 1943).

Recently, research has been conducted stressing the influence of these elements on each other. Haghiri (1974) found that the addition of from 5 to 50 μg/g zinc to soil significantly raised the cadmium concentration of soybean shoots. Lagerwerff and Biersdorf (1971) also noted that zinc increased the cadmium content in radish leaves. Turner (1973) observed a variable effect of cadmium treatment on zinc accumulation in plants. At fairly low cadmium concentrations, zinc uptake was increased for beetroot, lettuce, radish, and tomato, and decreased for carrot and swiss chard. Miller et al. (1977) observed a tendency for soil lead to increase both plant cadmium and total cadmium uptake by corn shoots.

Phosphates.

A particular emphasis has been placed on the relationship between soil phosphorus concentrations and the plant uptake of other elements in the soil. This is an important aspect since phosphorus is the second most critical element required for proper plant growth (Brady 1974).

MacLean et al. (1969) reported that the amount of lead taken up by plants was reduced when phosphate was added to the soil. Reuther et al. (1952) and Boawn et al. (1954) reported that the addition of phosphate to the growth medium had no effect on zinc uptake by plants.

A variable effect on nickel absorption was observed when phosphates were added to the growth medium. Crooke and Inkson (1955) and Halstead et al. (1969) reported that the addition of phosphate ions to soil increased the extractable nickel by oats. Pratt et al. (1964) added phosphate to solutions of $NiCl_2$ and noted a decreased solubility of nickel, and Nicholas and Thomas (1954) observed no effect of phosphate addition on nickel uptake by tomatoes. These reports may vary due to differential pH levels used in the experiments, since phosphate availability is altered by pH.

Soil pH.

Soil pH regulates the solubility of lead, cadmium, nickel, and zinc in the soil. As the pH of the soil decreases, the concentration of hydrogen ions increases. These ions generally have a high tenacity for soil binding sites, thereby causing the release of other ions into the soil solution, where they are available for plant uptake. Lagerwerff (1971) demonstrated that at a soil pH of 5.9, there was a large proportion of soluble lead and cadmium in soil, and a significant amount of lead and cadmium present in plant shoots. At a soil pH of 7.2, the solubility of the soil lead and cadmium, as well as the metal content of the plants, was reduced. MacLean et al.

(1969) noted an inverse relationship between soil pH and the lead content of oats and alfalfa. Similar results for lead have been reported by Cox and Rains (1972), Goyer and Chisholm (1972), and Arvik and Zimdahl (1974a).

Masuda and Sato (1962) generalized that a pH below 5.6 favors nickel absorption by plants. Hunter and Vergnano (1952) observed a 70 percent reduction in nickel uptake by sugar beets when the pH rose from 4.8 to 6.3.

Lagerwerff (1971) reported that as the pH of a soil with 10.1 μg/g zinc was raised from 5.9 to 7.2, the zinc content of radish tops growing on the soil was decreased from 47.8 μg/g to 40 μg/g. Chapman (1966) cites evidence of excess zinc in plants growing on acid peats.

Metabolic vs. nonmetabolic uptake.

The plant absorption of certain elements has been shown to vary with temperature and oxygen level of the growth medium. A temperature or oxygen dependent uptake of an element indicates that the mechanism of absorption may be metabolically controlled. Arvik and Zimdahl (1974a) exposed excised roots to a solution of $PbNO_3$ in the presence of 2,4 dinitrophenol (DNP) and sodium azide, two metabolic inhibitors. Lead uptake was not diminished by either the metabolic inhibitors or reduced temperature. It was concluded that lead uptake may not require energy expenditure by the plant.

Schmid et al. (1965) experimented with zinc in order to determine whether its uptake was an active, metabolic transport or nonmetabolic, nonselective exchange absorption. By decreasing the temperature from 30 C to 4.5 C, zinc absorption was reduced by 80 percent. Inhibition of zinc uptake under anaerobic conditions was observed, but only became severe after 15 to 30 minutes. The addition of 5 x 10^{-4} M DNP inhibited zinc absorption in a short experiment, but after 30 minutes, zinc uptake was still substantial, at 43 percent of the control rate.

Joseph et al. (1971) reported that azide and amytal, two metabolic inhibitors, had no inhibitory effect on zinc uptake. It was concluded that absorption and passive diffusion is the primary mechanism involved in zinc uptake by plants.

Haghiri (1974) observed that an increase in soil temperature from 15.5 to 21.1 C increased the cadmium in soybean shoots from 5.16 μg/g to 7.23 μg/g. Cutler and Rains (1974) grew barley in solution under anaerobic conditions, and with DNP added to the solution. Both the DNP and the lack of oxygen inhibited cadmium uptake by plants. These results, combined with Haghiri's observations on the effects of temperature, indicate that cadmium uptake is regulated by a metabolic process.

Foliar Absorption

Arvik and Zimdahl (1974b) investigated the possibilities of foliar uptake of lead. They determined that the cuticles of leaves and fruits are very effective barriers, allowing only minute amounts of lead to enter the plant.

Foliar uptake of nickel has been reported by Andersen (1960). Wheat leaves were immersed in a solution of 2.46 μg/g nickel. After four hours, the leaves contained 19.9 μg/g nickel, indicating a rapid rate of nickel absorption.

Haghiri (1973) investigated absorption of radiocadmium into the leaves of soybean plants. It was observed that foliar-applied ^{115m}Cd was readily transported within the plant, but that root uptake of the isotope was 16 times more efficient.

Foliar Release

Recent evidence has indicated that certain heavy metals are released from plants through the leaf stomata. Beauford and Barber (1975, 1977) grew pea plants in liquid culture containing equivalent concentrations of ^{65}Zn and ^{210}Pb. The amount of ^{65}Zn released from leaves was twice the amount of ^{210}Pb. It was concluded that the degree of metal release from the leaves was dependent on the metal content of the leaves, illumination, humidity, and general health of the plant.

Plant Species Variability in the Uptake of Lead, Cadmium, Nickel, and Zinc

The influence of surface structure and growth form of a plant on surface contamination by heavy metals was previously discussed. There is also species variability in the rate of absorption of heavy metals, a variability that may dictate whether a plant contains harmless or hazardous concentrations of potentially toxic substances.

Paluch and Karweta (1968) observed that among plants growing near a metallurgical industry, white clover had the greatest ability to accumulate lead. John (1977) exposed nine varieties of lettuce to a hydroponic solution of lead. Growth of the plants was dependent on the lead concentration of the medium, as well as varietal differences. It was concluded that lead translocation from plant roots to tops may be genetically controlled.

Boawn and Rasmussen (1971) demonstrated a species specific uptake of zinc from soil. At 100 μg/g soil zinc, 380 μg/g zinc was present in sorghum tops and 66 μg/g in field beans. With a soil zinc concentration of 500 μg/g, there was 1,029 μg/g zinc present in sorghum tops, compared to 257 μg/g in field beans.

Masuda and Sato (1961) reported marked variation in the nickel content of several crops grown on the same soil. Makarova and Aivazyan (1968) observed that the nickel content of cultivated crops was generally less than that of weeds grown in the same field.

John (1973) grew eight food crops on cadmium contaminated soil and observed substantial differences in their rate of cadmium absorption. Little and Martin (1972) found cadmium levels near a smelting plant of 50 μg/g in grass (Lolium perenne), 148 μg/g in moss (Eurhychium praelongum), 90 μg/g in lichen (Parmelia), and 40 μg/g in washed elm leaves. This reflects species variety as well as the tendency for perennials such as moss and lichens, to accumulate higher levels of cadmium than annual species of plants.

Relative Rates of Uptake and Translocation of Lead, Cadmium, Nickel, and Zinc by Plants

Very few studies have been conducted on all four elements (Pb, Cd, Ni, Zn) to determine their relative ease of uptake and translocation by plants. Evidence indicates that lead is easily immobilized in soil and therefore is subject to a very low rate of uptake by plants (Marten and Hammond 1966, Lagerwerff and Specht 1970a, Koeppe 1977). Malone et al. (1974) noted that a large percentage of lead associated with plants may not actually be incorporated into the plant, but is bound on the outside of roots as crystalline or amorphous deposits. It is safe to assume that under similar environmental conditions, lead has the lowest rate of uptake of the four elements being investigated in this project. There is conflicting evidence concerning the mobility of lead within plants. Pettersson (1976) determined that lead and nickel were more mobile than cadmium or zinc. However, Broyer et al. (1972) and Root et al. (1975) indicated that cadmium was more easily translocated than lead.

Based on work by Haghiri (1974), Pettersson (1976), and Koeppe (1977), it appears that of the four elements, cadmium is the most easily absorbed by plants. However, Pettersson (1976) emphasized that cadmium tends to remain in the roots and therefore has a limited mobility within the plant after absorption.

Zinc has a strong ability to form stable, complex ions, and most soil zinc is present in combined form, either in organic complexes or in various minerals (Sauchelli, 1969). Yet Ni^{++} is reported to have a stronger chelating ability than Zn^{++}. Thus, it is difficult to assess which of the two metals exhibits the greatest degree of absorption by plants. Takijima and Katsumi (1973) observed that cadmium increased steadily in rice for an entire growing season, zinc increased slightly, and lead decreased. Pettersson (1976) later determined that cadmium uptake was more extensive than nickel uptake. Zinc is considered a very mobile element within plants, as observed by Lagerwerff (1971), who determined that foliar applied zinc was more mobile in plants than either lead or cadmium. The mobility of nickel has not been evaluated with respect to the other three metals.

It can be hypothesized from the available data that plant uptake of the four elements under similar environmental conditions is of the order: $Cd^{++} > Ni^{++} \approx Zn^{++} > Pb^{++}$. No generalized statement can be made for the relative rates of translocation of the four elements.

Seasonal Variation in Ambient Levels of Lead, Cadmium, Nickel, and Zinc

Atmospheric concentrations of various pollutants have been observed to vary according to immediate weather conditions, as well as season of the year. Daines et al. (1970) reported that atmospheric lead levels near roadways exhibited an annual peak in September, October, and November. It was explained that this is the time of year when atmospheric turbulence is at a minimum. This is also the time of year when engine operation is the least efficient. These results were compared with those of Cholak et al. (1961) who reported the highest atmospheric lead levels in the colder months of the year.

These findings in themselves account for an increased level of lead deposition on the surface of soil and plants during the fall and winter months. However, Rains (1971) demonstrated that the lead incorporated into plants, and not just surface levels, also show an increase in the winter. This is attributed to a 10 to 20 percent decrease in dry matter that occurs as plants mature.

Guha and Mitchell (1966) observed that the nickel content of certain deciduous trees (*Platanus*, *Aesculus*, *Fagus*) exhibited a decrease early in the growing season (period of dry matter increase), followed by a steady rise until senescence (period of dry matter decrease), when there was a decrease.

Toxic Effects of Lead, Cadmium, Nickel, and Zinc on Plants

The reaction of plants to toxic levels of the four elements is similar, although the symptoms are elicited by varying levels of contamination. Typical mainfestations of toxicity are leaf tip and interveinal necrosis, growth and yield reduction, tissue discoloration and malformation, chlorosis, root damage, and loss of turgor pressure (Table 6).

Hassett et al. (1976) observed that corn seedling radicle elongation was decreased at 250 μg/g soil lead. A concentration of 10^{-1} M lead caused visible damage to bean plants, and was characterized by a loss of turgor pressure and reduced growth (Suchodoller 1967).

Boawn and Rasmussen (1971) found that soil zinc levels of 100 μg/g reduced growth in most vegetable species tested, although there was no apparent tissue necrosis or malformation. Mortvedt and Giordano (1975) recorded decreased yields when corn was grown on soil contaminated with 240 μg/g zinc (pH 5.5). Ohki (1975) observed that zinc toxicities were induced in plants placed in nutrient solutions at 2 μg/ml.

Plants are sensitive to low levels of nickel contamination. Chlorosis in buckwheat was observed at 0.5 μg/g nickel in soil, and 2 μg/g nickel in soil was highly toxic to bean and barley plants (Vanselow 1966). The growth of paprika (<u>Capsicum</u> <u>frutescens</u> L.) was enhanced by the foliar application of nickel at a concentration less than one μg/g. At greater than one μg/g, nickel was toxic to the same plants (Pais et al. 1970). Oats sprayed with a 5 μg/g solution of nickel exhibited reduced growth (Hunter and Vergnano 1953). Oat plants grown on nickel contaminated soil experienced markedly

Table 6. Summary of Studies Reporting Toxic Effects of Lead, Cadmium, Nickel, and Zinc on Plants

Symptom	Zinc		Nickel		Cadmium		Lead	
Reduced Growth	Bensen	(1966)	Vanselow	(1966)	Haghiri	(1973)	Suchodoller	(1967)
	Warteresiewicz	(1968)	Pais et al.	(1970)	Turner	(1973)	Carlson & Bazzazz	(1977)
	Boawn & Rasmussen	(1971)	Roth et al.	(1971)	Root et al.	(1975)	Miller et al.	(1977)
	Milbocker	(1974)	Traynor & Knezek	(1973)	Carlson & Bazzazz	(1977)		
	Singh	(1974)	Cunningham et al.	(1975)	Lamoreaux & Chaney	(1977)		
	Cunningham et al.	(1975)	National Academy of Science	(1975)	Miller et al.	(1977		
	Hortvedt & Giordano	(1975)						
	Ohki	(1975)						
Root Damage			Vergnano & Hunter	(1953)	Lagerwerff & Biersdorf	(1971	Bonnett	(1922)
					Turner	(1973)	Rasmussen & Henry	(1963)
					Pettersson	(1976)		
Chlorosis	Chapman	(1966)	Wolff	(1913)	Haghiri	(1973)		
	Warteresiewicz	(1968)	Larz	(1942)	Root et al.	(1975)		
	Milbocker	(1974)	Vergnano & Hunter	(1953)				
	Ohki	(1975)	Roth et al.	(1971)				
			National Academy of Science	(1975)				
Necrosis	Warteresiewicz	(1968)	Hewitt	(1948)				
	Milbocker	(1974)	Hunter & Vergnano	(1953)				
	Ohki	(1975)	Crooke	(1954)				
Wilting	Boawn & Rasmussen	(1971)	Bazzazz et al.	(1974a)	Lamoreaux & Chaney	(1977)		
Inhibition of Photosynthesis			Bazzazz et al.	(1974a)	Bazzazz & Govindjee	(1974)	Hampp	(1973)
					Bazzazz et al.	(1974a)	Bazzazz et al.	(1974a)
					Bazzazz et al.	(1974b)	Rolfe & Bazzazz	(1975)
					Carlson & Bazzazz	(1977)	Wooley & Lewin	(1976)
							Carlson & Bazzazz	(1977)

Table 6 (Continued)

Symptom	Zinc	Nickel	Cadmium	Lead
Inhibition of Transpiration		Bazzazz et al. (1974a)	Bazzazz et al. (1974a)	Rasmussen & Henry (1963)
			Carlson & Bazzazz (1977)	Hampp (1973)
				Bazzazz et al. (1974a)
				Carlson & Bazzazz (1977)
Inhibition of Seed Germination		Neithammer (1930)		Dilling (1926)
		Kusaka et al. (1971)		
Inhibition of Enzyme Function		DeKock (1956)	Vallee & Ulmer (1972)	Holl & Hampp (1975)
		Agarwala & Kumar (1962)		
		Lapa et al. (1963		

lower yields, with 60 μg/g nickel detected in the oat grain and 28 μg/g in the oat straw (National Academy of Science 1975).

Haghiri (1973) applied a 2.5 μg/g cadmium solution to the leaves of soybean and wheat plants. Dry matter production was reduced in both species, and soybean leaves suffered from necrosis. Root et al. (1975) noted a growth reduction and leaf chlorosis in hydroponically grown corn exposed to cadmium levels of 1 to 40 mg/l of growth solution.

Other authors have investigated the alteration of physiological mechanisms in plants by heavy metals. Bazzazz et al. (1974a) tested the effects of high lead, cadmium, and nickel concentrations on stomatal closure of sunflowers. Concentrations of these elements as low as 10 μM decreased the degree of stomatal opening, and therefore inhibited transpiration and photosynthesis. It was determined that the plants were far more tolerant to high lead concentrations than equivalent concentrations of cadmium or nickel. Plants were the most sensitive to nickel contamination. There have been other reports of reduced photosynthesis and transpiration caused by exposure of plants to lead (Bonnett 1922, Rasmussen and Henry 1963, Hampp 1973), and cadmium (Bazzazz et al. 1974b, Bazzazz and Govindjee 1974).

There is evidence that lead, cadmium, and nickel interfere with enzyme function in plants. Lead has been observed to inhibit enzyme activity by blocking sulfhydryl groups of proteins (Holl and Hampp 1975). Cadmium has a known tendency to replace zinc in certain enzymes, thereby impairing their catalytic activity.

It has been suggested that cadmium, nickel, and zinc toxicity resemble iron deficiency. Root et al. (1975) determined that as the cadmium concentration of plants increased, their iron content also increased. It was hypothesized that increased cadmium levels cause a decrease in zinc uptake, which subsequently causes an increased iron uptake. This is in conflict with evidence by Ambler et al. (1970) demonstrating that at toxic zinc levels, iron uptake by plants was inhibited. Milbocker (1974) tested the hypothesis of a zinc induced iron deficiency by adding iron to plants that were exhibiting symptoms of zinc toxicity. The addition of iron enhanced the growth and leaf color of the zinc contaminated plants.

Crooke et al. (1954) and Halstead et al. (1969) proposed that nickel does not interfere with iron uptake, but does affect its metabolism within the plant. This explains the nickel induced chlorosis as an inability of the plant to metabolize iron.

Hassett et al. (1976) and Miller et al. (1977) investigated the interactive effects of cadmium and lead. Hassett et al. (1976) observed a synergism between the two metals, and reported that the depression of corn seedling radicle elongation was greater with both elements than the combined effects of either element acting alone.

MATERIALS AND METHODS

Sampling Areas

Four areas adjacent to highways were selected on the basis of traffic density, slope of the terrain, and vegetative cover (Figure 1). An attempt was made to locate roadside areas that were flat and open, with a variety of vegetation types. The highways and corresponding traffic densities in 1975 (Commonwealth of Va. Dept. of Highways 1975) were as follows:

Area A: Interstate Rte. 95 -- 92,400 vehicles per day
Area B: US Rte. 460 -- 24,095 vehicles per day
Area C: Va. Rte. 114 -- 7,510 vehicles per day
Area D: Va. Rte. 42 -- 525 vehicles per day

Two control areas were also selected, with the requirements that they be situated at least 500 m from a road and were a combination of open and wooded terrain.

Site A was located along Interstate Rte. 95, between Edsall Road and Interstate Rte. 495. This portion of Rte. 95 has recently been redesignated Interatate Rte. 395 (Figure 2). There was a 30 degree downward slope that extended from the highway edge to a concrete drainage ditch approximately 10 m distant. Otherwise, the land at this site was flat, open, and relatively poorly drained. The predominant type of vegetation was _Lespedeza_ spp., although _Solidago_ spp. and _Festuca_ spp. were commonly found within 24 m of the highway. Portions of the area

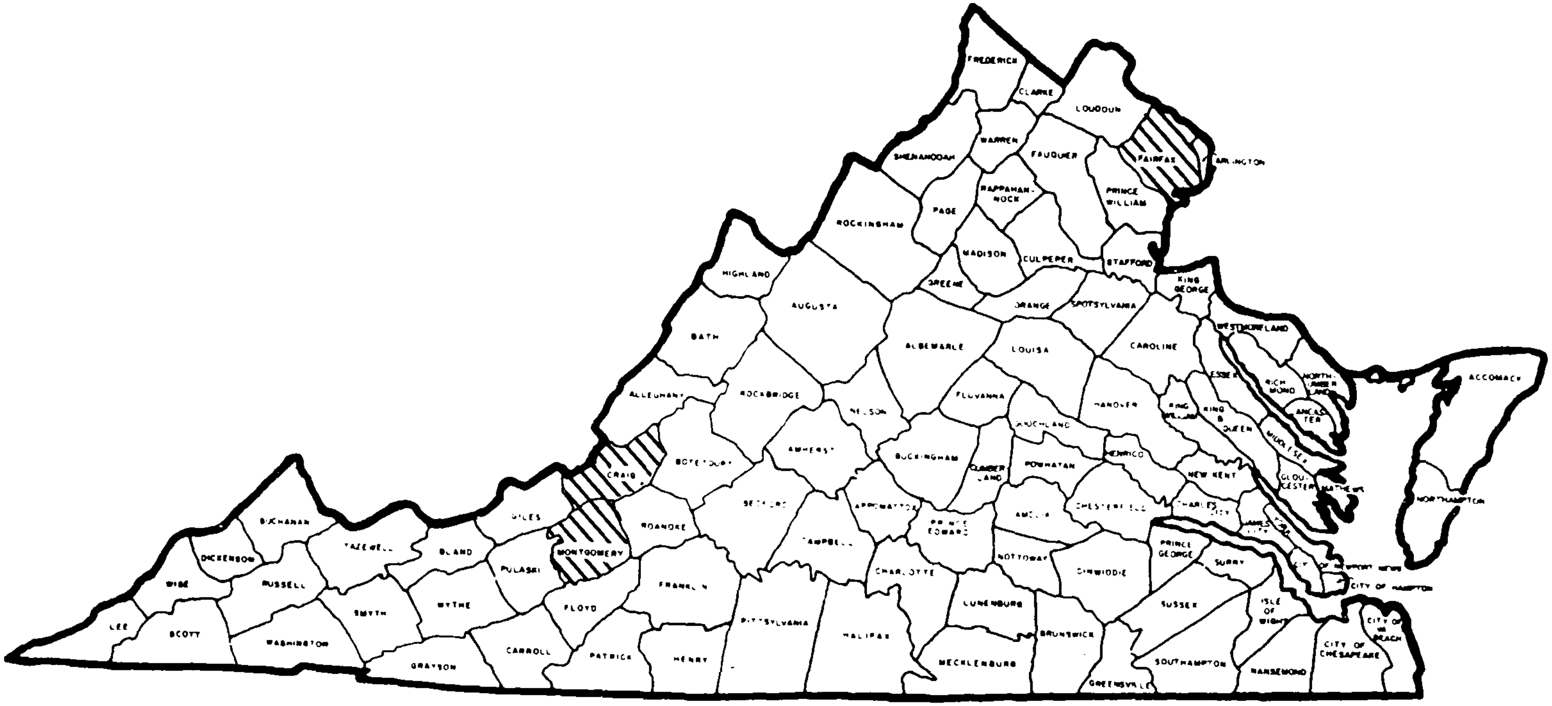

Fig. 1. Counties in which study areas were located.

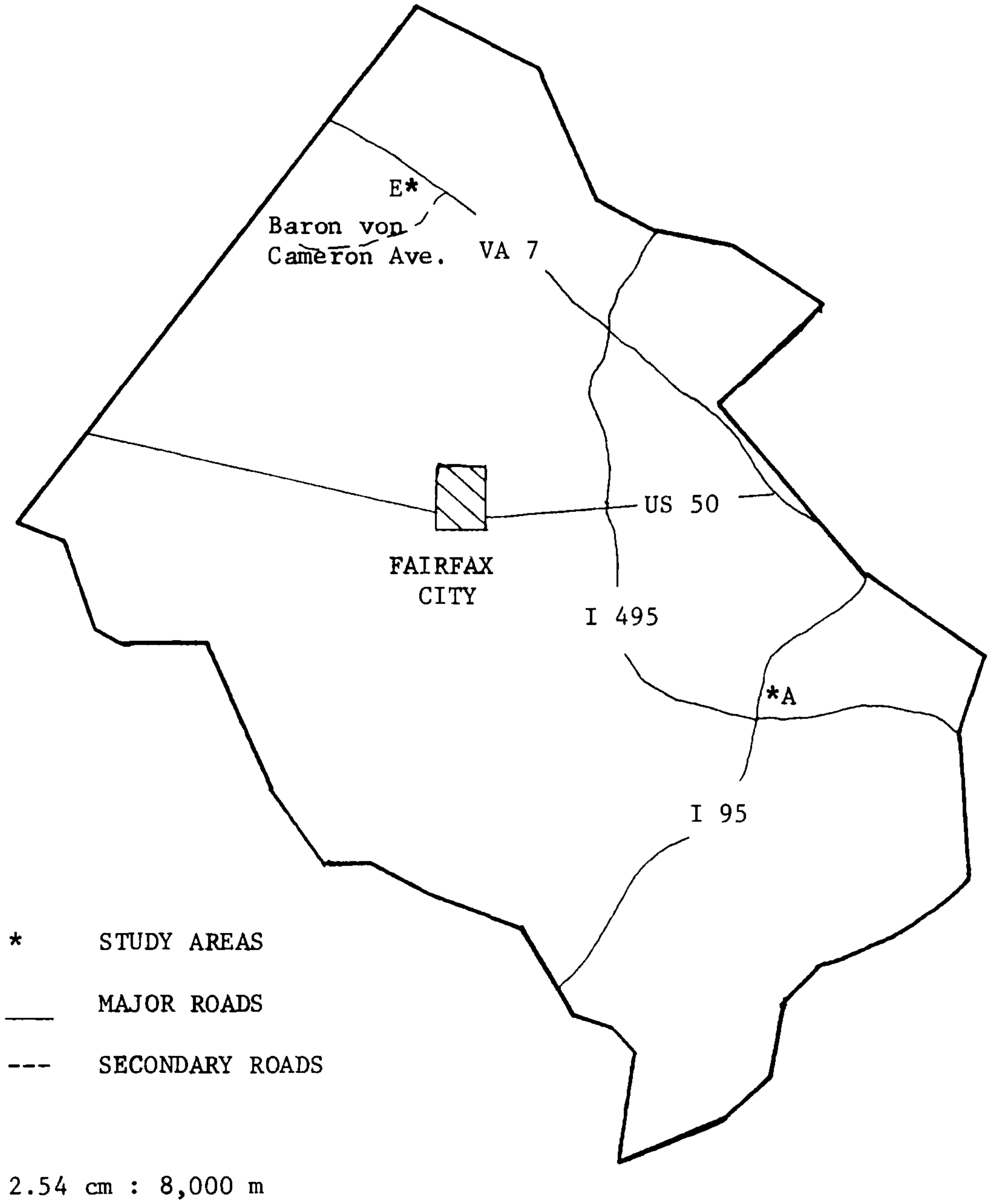

Fig. 2. Sampling Locations in Fairfax County, Virginia.

were previously quarried for gravel; at the time of this report the land was being parcelled out for commercial development.

Site B was located along US Rte. 460, between Blacksburg and Christiansburg, Virginia (Figure 3). It was situated within 50 m of the intersection of US Rte. 460 and Va. Rte. 114, an intersection that was controlled by a traffic signal. There was a 45 degree incline that sloped away from the pavement edge, ending 12 m from the road. The remainder of the land at this site was flat and open, with scattered trees and shrubs. The predominant type of vegetation was *Festuca* spp., especially beyond 12 m from the road, where there had been recent mowing. Other common plant species included *Coronilla varia*, *Daucus carota*, and *Asclepias syriaca*.

Site C was situated on Va. Rte. 114, between US Rte. 460 and Radford, Virginia. It was approximately one km from Site B (Figure 3). This site had flat, open terrain, and was grazed periodically by horses. The predominant type of vegetation was *Festuca* spp.; *Daucus carota*, *Chicorium intybus*, and *Lonicera japonica* were also common.

Site D was located along Va. Rte. 42, between Newport and Newcastle. The precise location of the sampling site had to be changed after the first two sampling periods, but traffic density was essentially similar between the two areas. The land at the initially chosen site (Figure 3) was flat and open, and was previously used for forage crop production. A two m high mound ran parallel to and approximately 36 m from the highway. The predominant type of vegetation was *Festuca* spp.; *Daucus carota* and *Chicorium intybus* were fairly common.

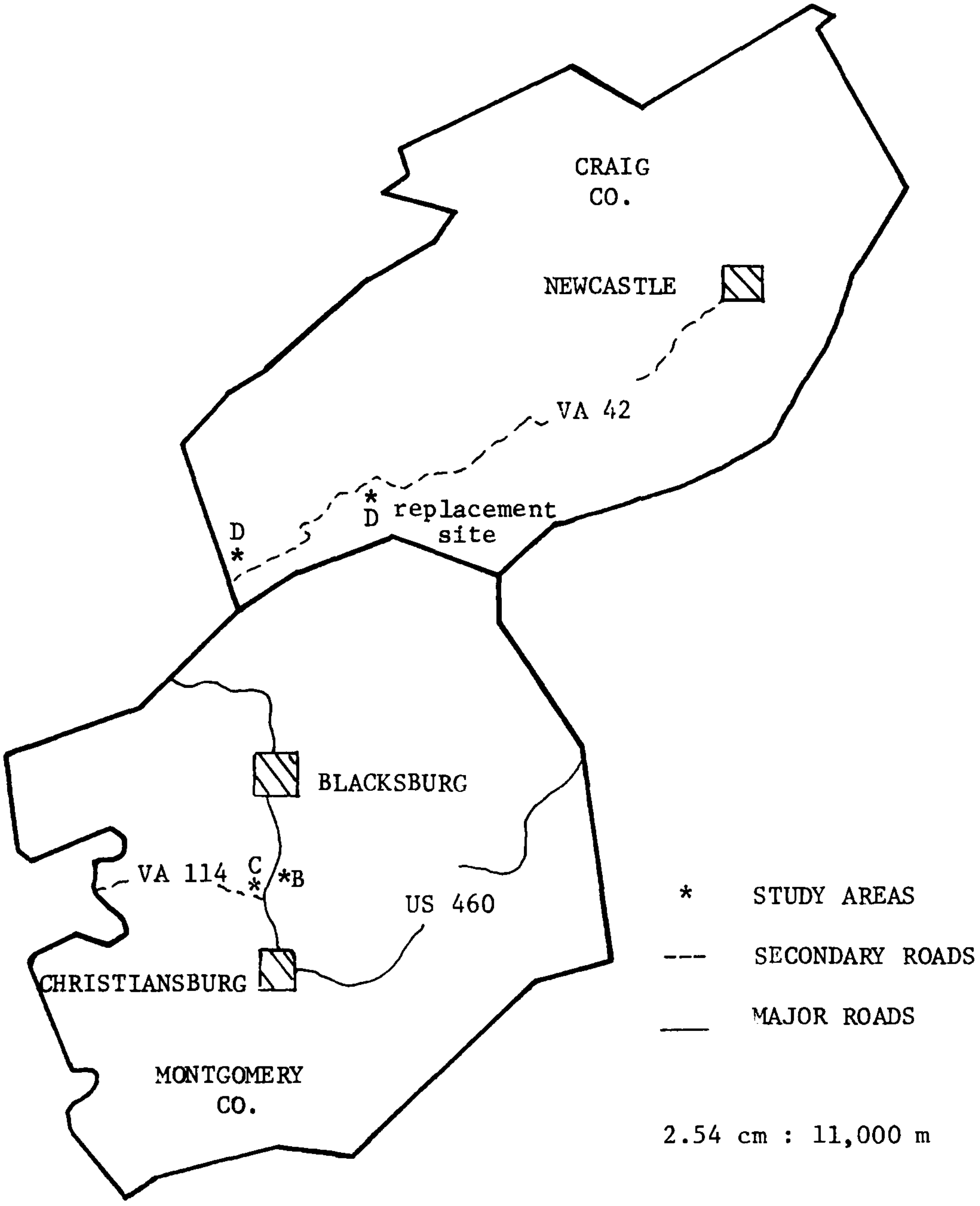

Fig. 3. Sampling Locations in Montgomery and Craig Counties, Virginia.

The replacement site chosen along Rte. 42 (Figure 3) had the greatest variety of vegetation of all highway sites. *Festuca* spp. was very common, as well as *Daucus carota*, *Solidago* spp., and *Chicorium intybus*. The land sloped upward away from the road at generally less than a 15 degree angle. The area was previously grazed, but had been unused for several years prior to this study.

The Fairfax County Control Area (Site E) was located in Baron von Cameron Park in Reston, Virginia (Figure 2). It was approximately 40 km from the sampling site along Interstate Rte. 95. This was a moderate use recreational area, and no motor vehicles were permitted within 500 m of where the sampling was conducted. The predominant types of vegetation were *Solidago* spp., *Lonicera japonica*, and *Festuca* spp.

The Montgomery County Control Area (Site F) was located along the Boundary Woodlot, owned by Virginia Polytechnic Institute and State University (Figure 3). The land was grazed by cattle, and the predominant type of vegetation was *Festuca* spp., although *Asclepias syriaca*, *Daucus carota* and *Solanum carolinense* were also common.

Sampling Procedures

Sampling for soil and vegetation was conducted along transect lines that were parallel to the edge of the highway. The edge was denoted by the marginal white line and not the edge of the pavement. Lines were established at 3, 6, 12, 24, and 48 m from the marginal white line. At the two highest density highways, a 3 m sample was not collected because the shoulder of the road extended into the 3 m zone. Four collections were conducted, at 90 day intervals, throughout the period of one year. Sampling periods were in August and September of 1976 (sampling period 1), November and December of 1976 (sampling period 2), February and March of 1977 (sampling period 3) and June and July of 1977 (sampling period 4).

Vegetation Sampling

An attempt was made to collect samples of grass, broad leaved plants, evergreen, and deciduous flora at each sampling line. When possible, common species were selected between sampling lines, as well as between areas and sampling periods. Five samples of each species at each line were collected when sufficient plant material was available.

Each transect line was paced, and one to several plants of the selected species were collected and labeled. Five samples of plant material were collected along each transect. All vegetation, except trees and shrubs, were cut close to the ground, with all parts, except roots, being taken. On trees and shrubs, twigs were cut from the most recent growth increments. Sampling for each seasonal period was conducted within a three to four week interval.

Soil Sampling

Soil was collected along each line using a standard soil sample tool, to a depth of 2.5 cm. Five 2.5 cm soil cores were taken from within a meter's radius and placed in a soil box. Five boxes were collected in this manner at each sampling line.

Laboratory Analysis

Vegetation

All vegetation samples were dried in a forced air oven at 80 C for at least 24 hours. The contents of each bag were then ground, using an intermediate size Wiley Mill with a 20 mesh screen. Ground material was placed into labeled shell vials and kept in the drying oven at 80 C until it was weighed. Two vials were filled from each sample's contents when possible. Ground samples were weighed into porcelain Coors crucibles in approximately two gram aliquots, and exact weights were recorded. The weighed samples were then ashed in a muffle furnace at 400 C for eight hours, followed by a digestion with an acid mixture for at least five hours. The acid mixture was 50 percent concentrated nitric acid and 50 percent concentrated hydrochloric acid.

Digested samples were centrifuged, and the liquid in each test tube was raised to a ten ml volume with deionized water. The samples were then thoroughly agitated and recentrifuged. The supernatant was decanted into another test tube. This supernatant was tested for lead, cadmium, nickel, and zinc using an Instrumentation Laboratories Model 351 Atomic Absorption Spectrophotometer.

Soil

Soil was dried at 80 C for at least 24 hours. It was then ground and sieved. Ground soil was weighed into test tubes in approximately two gram aliquots; an acid mixture was added to the soil samples that was 50 percent concentrated nitric acid and 50 percent concentrated hydrochloric acid. The test tubes containing the soil and acid mixture were placed in a hot water bath at 70 C for two hours to allow complete digestion of the soil organic matter. Digested samples were then tested for lead, cadmium, nickel, and zinc using atomic absorption spectrophotometry.

Statistical Analysis

The soil and vegetation data were analyzed by a Three Way Unbalanced Analysis of Variance. This procedure was designed to detect significant differences in the concentration of lead, cadmium, nickel, and zinc between sampling areas, sampling distances, and sampling periods. A Duncan's Multiple Range Test was used to identify specific differences in the metal concentrations between sampling areas, sampling distances, and sampling periods. Due to the pooling of soil samples for the first two sampling periods, no statistical tests could be conducted on these data. All tests were conducted at a 0.05 acceptance level.

RESULTS AND DISCUSSION

Soil Lead

At all highways in this study, there was a general decrease in the concentration of soil lead as distance from the highway increased (Table 7). These declines in lead concentration were statistically significant ($P < 0.05$) at sites A and C. At Site B, in all but one sampling period, the highest soil lead levels were detected at the 12 m sampling line. The 12 m line was located at the base of a 45 degree incline that sloped away from the highway edge. Runoff from the highway therefore tended to accumulate at the bottom of this slope. At Site D, there was a general decrease in soil lead concentration with increasing distance from the road. This decrease was only statistically significant for one sampling period.

Soil lead levels were observed to be proportional to traffic density when the same sampling lines were compared among areas (Table 8). In Period 3 (Feb/Mar), the difference between areas was significant for all sampling lines compared. In Period 4 (Jun/July), at all but one distance from the highway (48 m) there were significant differences between areas. These variations in soil lead contamination among highways were consistently of the order: Site A > Site B > Site C > Site D. This indicates a strong positive relationship between soil lead and traffic density, since even the lines most distant from the highway exhibited soil lead concentrations that were dependent on traffic density.

Table 7. Comparisons Among Distances from the Highway of the Mean Lead Level (μg/g dry wt) in Soil Collected Along Highways of Different Traffic Volume.

Area	Distance from Road (m)	Sampling Periods I Aug/Sept	II Nov/Dec	III Feb/Mar	IV Jun/July	Overall Average
A. I 95	6	1483	1600	669a	480a	735a
	12	492	328	235b	258b	273b
	24	261	99	94c	170bc	140c
	48	188	57	46c	100c	81c
B. US 460	6	136	121	133b	153a	140b
	12	307	99	317a	237a	265a
	24	78	60	64b	119a	88b
	48	34	33	33b	88a	56b
C. Va 114	3	354	261	--	--	308a
	6	93	71	47a	109a	79b
	12	22	30	30b	27b	28b
	24	18	37	17c	19b	20b
	48	18	18	13c	15b	15b
D. Va 42	3	56	42	27a	27a	31a
	6	56	29	20b	19a	23a
	12	27	28	21b	17a	21a
	24	24	--	19b	19a	19a
	48	41	--	19b	17a	20a
E. Fairfax Control	-	20	15	24	21	22
F. Montgomery Control	-	22	12	20	20	20

a,b,c: Column means followed by different letters within each area, for each sampling period are significantly different ($P < 0.05$).

Table 8. Comparisons Among Highways of the Mean Lead Levels (μg/g dry wt) in Soil at Increasing Distance from the Highway.

Distance from Road (m)	Area[1]	Sampling Periods			
		I Aug/Sept	II Nov/Dec	III Feb/Mar	IV Jun/July
3	C. Va 114	354	261	--	--
	D. Va 42	56	42	29	27
6	A. I 95	1483	1600	669a	480a[2]
	B. US 460	136	121	133b	153b
	C. Va 114	93	71	47b	109b
	D. Va 42	56	29	20b	19c
12	A. I 95	492	328	235a	258a
	B. US 460	307	99	317a	237a
	C. Va 114	22	30	30b	27b
	D. Va 42	27	28	21b	17b
24	A. I 95	261	99	99a	170a
	B. US 460	78	60	64b	119a
	C. Va 114	18	37	17c	19b
	D. Va 42	24	--	19c	19b
48	A. I 95	188	57	46a	100a
	B. US 460	34	33	33b	88a
	C. Va 114	18	18	14c	15a
	D. Va 42	41	--	19c	17a

[1] Traffic volumes (vehicles per day) for study areas are as follows:

A. I 95	92,400	B. US 460	24,095
C. Va 114	7,510	D. Va 42	525

[2] a,b,c: Column means followed by different letters for each distance and for each sampling period are significantly different ($P < 0.05$).

At the control areas, lead concentrations in soil were always less than the lead levels of soil collected at distances close to the highway. At greater distances from the highway, the lead levels approached or fell below control area levels. This is especially true for sampling areas C and D. It can be concluded that at fairly low traffic densities (< 7,500 vehicles per day), the effect of the highway on soil lead contamination does not extend much beyond the 24 m line. Along highways of greater traffic volume, larger quantities of lead are subject to dispersal, thereby exerting more of an effect on soil lead concentrations beyond the 48 m line. This conclusion is similar to those proposed by Motto et al. (1970) and Schuck and Locke (1970).

There was no seasonal variation in lead contamination of roadside soil that was consistent for all sampling sites. Soil lead levels at Site A were higher in sampling Periods 1 and 2 than 3 or 4. This may be due to traffic conditions or weather factors.

The lead concentrations of roadside soil observed in this report (Table 7) are generally lower than those reported in the literature (Chow 1970, Lagerwerff and Specht 1970a, Seeley et al. 1972). However, they are higher than the values reported by Goldsmith (1976). This is particularly relevant because Goldsmith sampled along three of the same highways used in this project (B, C, and D). Values here may be higher than Goldsmith's because of greater traffic volumes at the sites, variation in site location along the highway, variation in sampling technique, or an additional accumulation of lead that occurred in the interval since Goldsmith's report.

The data in this report correspond with reports in the literature that indicate a positive relationship between soil lead levels and traffic density and a negative relationship between soil lead levels and distance from the highway.

Lead in Vegetation

There were significant declines in the concentration of lead in vegetation with increasing distance from the road at Sites A and B (Table 9). At Sites C and D, the declines were significant for some seasons, but not when the lead levels for all seasons were averaged. These declines in plant lead are of the same direction and magnitude as the decreases observed with soil lead as distance from the highway increased. The major exception to this is for Site B, where vegetation from the 6 m line had the highest lead concentrations for three out of four seasons. Soil lead exhibited the highest values at the 12 m line, presumably due to runoff from an adjacent slope. It is concluded that a large percentage of the lead associated with vegetation is deposited aerially on the plant surface and not absorbed from the soil. This is in agreement with the findings of Suchodoller (1967), Garber (1970), and Motto et al. (1970), who determined that approximately 50 percent of plant lead was due to surface deposition.

Table 9. Comparisons Among Distances from the Highway of the Mean Lead Levels (μg/g dry wt) in Vegetation Collected Along Highways of Different Traffic Volume

Area	Distance from Road (m)	Sampling Periods				Overall Average
		I Aug/Sept	II Nov/Dec	III Feb/Mar	IV Jun/July	
A. I 95	6	99a	378a	614a	144a	287a
	12	90a	145b	309b	86b	167b
	24	54ab	93b	150c	29c	92c
	48	31b	194ab	154c	16c	85c
B. US 460	6	47a	124a	287a	49ab	147a
	12	31b	184a	207ab	30bc	101b
	24	29b	187a	221ab	51c	57c
	48	15c	76a	136b	18c	57c
C. Va 114	3	13ab	--	190a	9b	33a
	6	30a	66a	63b	15a	39a
	12	20ab	20b	42c	10b	17a
	24	6b	13c	27d	5bc	15a
	48	7b	16d	23d	4c	11a
D. Va 42	3	8a	23a	30a	7a	14a
	6	6a	12b	12b	4b	8a
	12	11a	12b	16b	3bc	10a
	24	3a	4b	16b	3c	8a
	48	4a	--	13b	2c	7a
E. Fairfax Control	-	8	8	15	4	10
F. Montgomery Control	-	3	10	13	4	7

a,b,c: Column means followed by different letters within each area and for each sampling period are significantly different ($P < 0.05$).

There was a significant difference between plant lead concentrations at the various roadside locations (Table 10). This is based on comparisons of common sampling lines among areas. The decrease in the lead contamination of vegetation by area was of the order: Site A > Site B > Site C > Site D. As with soil lead, vegetation collected at even the most distant sampling lines had lead concentrations that were positively related to traffic density.

The two control areas had comparable levels of lead in vegetation, indicating similar concentrations of background lead at the two areas. Plant lead concentrations at the Fairfax County Control Area (Site E) were far below the concentrations at the 48 m line of Site A. The levels of lead in vegetation at the Montgomery County Control (Site F) were substantially less than the levels at the 48 m line of Site B. At Sites C and D, the lead concentrations of vegetation taken from the 48 m line were similar or less than control area levels. This pattern reflects the greater degree of lead dispersal from highways of higher traffic densities. As with soil lead, it can be concluded that the effect of low density highways (< 7,500 vehicles per day) is restricted to a band generally less than 24 m from the highway.

Roadside lead concentrations in vegetation from Periods 1 and 4 were similar to the values reported by Chow (1970), Lagerwerff and Specht (1970a), Hopkinson et al. (1972), and Goldsmith (1976). Lead levels of vegetation collected in Periods 2 (Nov/Dec) and 3 (Feb/Mar) were in excess of most values reported in the literature. Since

Table 10. Comparisons Among Highways of the Mean Lead Levels (μg/g dry wt) in Vegetation at Increasing Distance from the Highway

Distance from Road (m)	Area[1]	Sampling Periods I Aug/Sept	 II Nov/Dec	 III Feb/Mar	 IV Jun/July
3	C. Va 114	13a[2]	--	190a	9a
	D. Va 42	8a	23	30b	7b
6	A. I 95	99a	378a	614a	144a
	B. US 460	47b	124b	283b	49b
	C. Va 114	30b	66b	63c	15c
	D. Va 42	6b	12b	12d	4c
12	A. I 95	90a	145a	309a	86a
	B. US 460	31b	184a	207b	30b
	C. Va 114	20b	20b	42c	10b
	D. Va 42	11b	12b	16c	3b
24	A. I 95	54a	93b	150b	29ab
	B. US 460	29b	187a	221a	51a
	C. Va 114	6b	13c	27c	5b
	D. Va 42	3b	4d	16c	3b
48	A. I 95	31a	194a	154a	16a
	B. US 460	15b	76a	136a	18a
	C. Va 114	7b	16a	23b	4b
	D. Va 42	4b	--	13b	2b

[1] Traffic volumes (vehicles per day) for study areas are as follows:

A. I 95	92,400	B. US 460	24,095
C. Va 114	7,510	D. Va 42	525

[2] a,b,c,d: Column means followed by different letters for each distance and for each sampling period are significantly different ($P < 0.05$).

few authors indicate the season of their plant collection, comparisons of the lead concentrations of vegetation from this report with values from the literature cannot be critically evaluated. All of these authors concluded that lead in vegetation decreases with decreasing traffic volume and increasing distance from the road.

There was a definite seasonal pattern to the lead contamination of roadside vegetation. For most sampling lines at all areas, the highest lead concentrations were detected in vegetation from sampling Period 3 (Feb/Mar). There was a consistent pattern of increasing lead contamination of vegetation from Periods 1 to 3. Period 4 vegetation had lower levels of lead than vegetation from Periods 2 or 3 (Figure 4). There are two factors contributing to this pattern of lead contamination. Surface lead accumulates as the plant ages, even with successive washings by rainfall. The vegetation from sampling Period 3 was the oldest collected, and therefore should have the greatest amount of surface contamination. Also, Rains (1971) reported that as plants ripen, there is 10 to 20 percent loss of dry matter. This concentrates lead residues within the plant. The combined effects of these two processes account for the observed peak in plant lead in the late winter. Fidora (1971) analyzed plant material growing near highways over the period of a growing season, and reported a constant lead content during the spring, followed by an increase during the summer months.

A further analysis of this seasonal trend in lead contamination of vegetation involved comparisons of the ratios of the lead

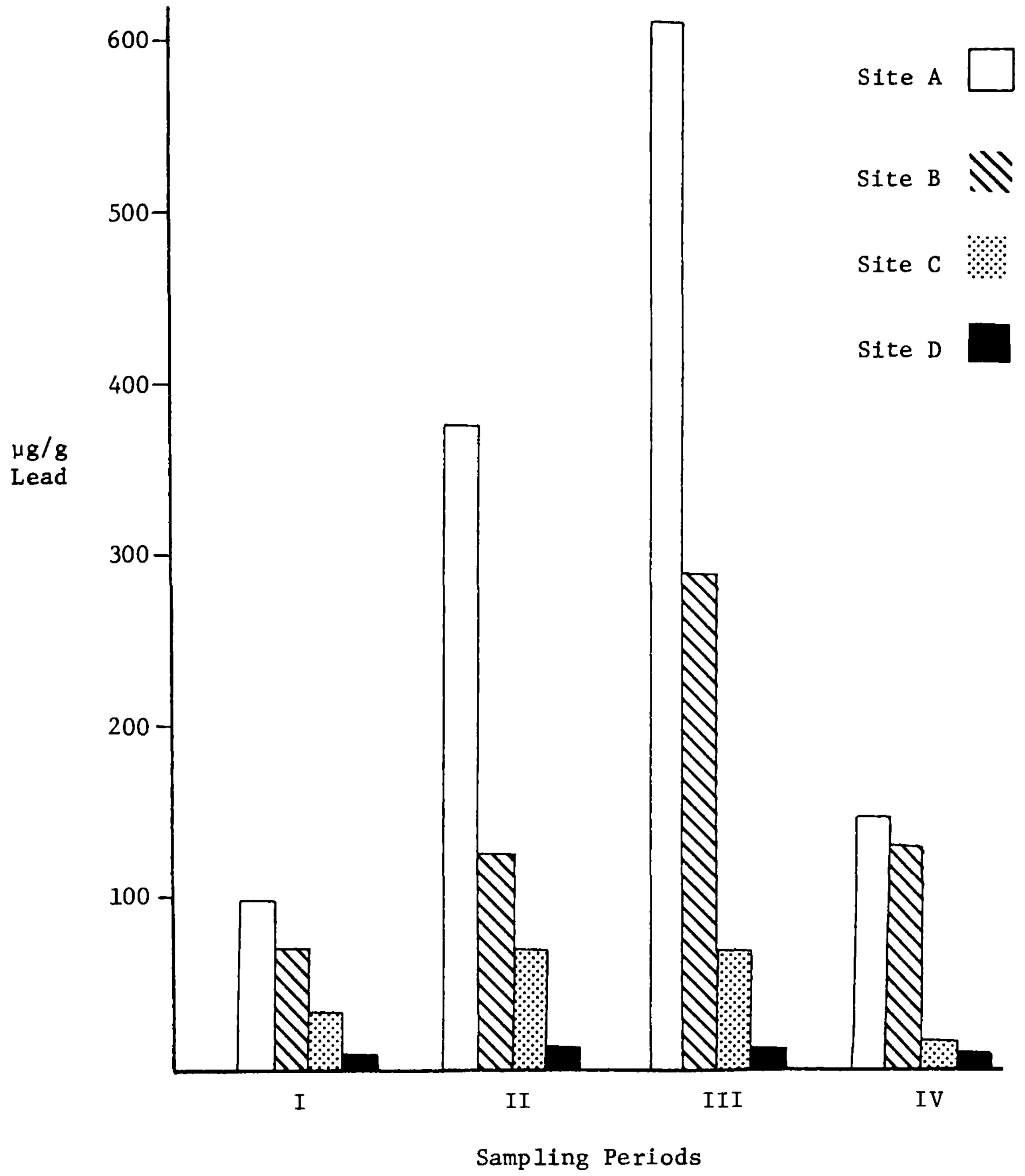

Fig. 4. Lead Levels in Vegetation Collected 6 m from Highways by Sampling Period.

concentration in vegetation to the lead concentration in soil. These ratios are the highest and are generally greater than 1 in Period 3. This provides further insight into the mechanism operating to concentrate lead in plants over a growing season.

Soil is influenced by the highway on a long term basis, beginning at the time of highway construction, whereas annual plant species are affected by the highway for less than a year. For this reason, plants can be expected to have lower lead levels than the soil at the start of their life cycle. As the growing season progresses, surface deposition alone can account for the rise in the lead content of plants. Whereas it can be expected that roadside vegetation will intercept larger quantities of atmospheric particles than soil, vegetation will also be more subject to washing by rainfall than the underlying soil. If surface contamination is regarded as the only avenue of contamination of soil and vegetation, and if both edaphic and vegetative components are assumed equally contaminated, the ratio of the lead content of plants to the lead content of soil should never exceed 1. If it does, some other process must be operating to concentrate lead in plants that is not operating to concentrate it in soil. Since the literature indicates a minimal uptake of lead by vegetation, the hypothesis proposed by Rains (1971) is the most logical explanation for the seasonal peak in the lead concentration of vegetation from Period 3.

Soil Cadmium

Soil cadmium was observed to vary inversely with distance from the highway at Sites A and D (Table 11). At Sites B and C, there was no consistent relationship between soil cadmium concentrations and sampling distance from the highway. Since the particulate nature of the cadmium, nickel, and zinc released from motor vehicles has not been characterized with respect to size or drift properties, dispersal of these elements from the highway cannot be adequately predicted. It can be logically assumed that particles from the abrasion of tires and brake linings are large and of a complex chemical nature. They may therefore be deposited on the highway surface or in the immediate roadside environment. Thus, high levels of cadmium may be detected close to the highway, but no pattern of contamination will be evident with increasing distance from the particulate source. The data in this report are in partial disagreement with that of Lagerwerff and Specht (1970a, 1970b). They reported a consistent decrease of soil cadmium with increasing distance from the road, even at highways with low traffic densities (i.e., < 7,500 vehicles per day).

There was no strong indication that cadmium contamination of roadside soil was proportional to traffic density (Table 12). The only significant relationship between soil cadmium and traffic density was in Period 4, as reflected by the soil cadmium levels at the 6 and 12 m sampling lines. The highest soil cadmium concentrations were associated with the higher traffic volumes.

Table 11. Comparisons Among Distances from the Highway of the Mean Cadmium Levels (μg/g dry wt) in Soil Collected Along Highways of Different Traffic Volume.

Area	Distance from Road (m)	Sampling Periods				Overall Average
		I Aug/Sept	II Nov/Dec	III Feb/Mar	IV Jun/July	
A. I 95	6	1.81	0.80	0.67a	0.52c	0.71a
	12	0.94	0.25	0.44b	0.44a	0.47b
	24	1.10	0.06	0.24c	0.25b	0.35b
	48	1.93	0.05	0.21c	0.23b	0.30b
B. US 460	6	2.27	0.13	0.26c	0.22a	0.40c
	12	3.15	0.11	1.29b	0.21a	0.90b
	24	1.12	0.09	0.28c	0.27a	0.33c
	48	3.64	0.10	1.62a	0.27a	1.10a
C. Va 114	3	0.54	0.09	--	--	0.32b
	6	4.19	1.46	0.77a	0.39a	0.96a
	12	1.66	1.97	0.22a	0.28a	0.51b
	24	0.54	1.60	0.23a	0.24a	0.37b
	48	1.46	1.52	0.31a	0.22a	0.47b
D. Va 42	3	1.08	0.19	1.21a	0.29a	0.73a
	6	0.64	0.03	0.86ab	0.26b	0.52b
	12	0.35	0.12	0.76bc	0.32ab	0.49b
	24	0.25	--	0.43bc	0.46a	0.43b
	48	0.22	--	0.38c	0.31ab	0.33b
E. Fairfax Control	-	2.33	0.02	0.23	0.24	0.39
F. Montgomery Control	-	0.76	0.69	0.22	0.25	0.32

a,b,c: Column means followed by different letters within each area and for each sampling period are significantly different ($P < 0.05$).

Table 12. Comparisons Among Highways of the Mean Cadmium Levels (μg/g dry wt) in Soil at Increasing Distance from the Highway.

Distance from Road (m)	Area[1]	Sampling Periods I Aug/Sept	II Nov/Dec	III Feb/Mar	IV Jun/July
3	C. Va 114	0.54	0.09	--	--
	D. Va 42	1.08	0.19	1.21	0.29
6	A. I 95	1.81	0.80	0.67a[2]	0.52a
	B. US 460	2.27	0.13	0.26a	0.22b
	C. Va 114	4.19	1.46	0.77a	0.39ab
	D. Va 42	0.64	0.03	0.86a	0.26b
12	A. I 95	0.94	0.25	0.44c	0.44a
	B. US 460	3.15	0.11	1.29a	0.21b
	C. Va 114	1.66	1.97	0.22c	0.28b
	D. Va 42	0.35	0.12	0.76b	0.32b
24	A. I 95	1.10	0.06	0.24b	0.25b
	B. US 460	1.12	0.09	0.28b	0.27b
	C. Va 114	0.54	1.60	0.23b	0.24b
	D. Va 42	0.25	--	0.43a	0.46a
48	A. I 95	1.93	0.05	0.21b	0.23a
	B. US 460	3.64	0.10	1.62a	0.27a
	C. Va 114	1.46	1.52	0.31b	0.22a
	D. Va 42	0.22	--	0.38b	0.31a

[1] Traffic volumes (vehicles per day) for study areas are as follows:

A. I 95	92,400	B. US 460	24,095
C. Va 114	7,510	D. Va 42	525

[2] a,b,c: Column means followed by different letters for each distance and for each sampling period are significantly different ($P < 0.05$).

Soil sampled at lines close to the road (3, 6, 12 m) generally had higher cadmium levels than were detected in soil at the corresponding control areas. Soil cadmium levels at the more distant sampling lines were similar to control area levels, even at Sites A and B.

The observed levels of soil cadmium were lower than most values reported in the literature. Lagerwerff and Specht (1970a) sampled along a highway with a traffic volume of 23,000 vehicles per day, and detected 1.82, 1.51, and 1,02 μg/g soil cadmium at 8, 16, and 32 m from the highway, respectively. These values are substantially higher than the ones from Site B of this report, a highway of comparable traffic density. These same authors also sampled along a highway serving 48,000 vehicles per day. Soil cadmium levels at this highway were half of the reported values for their previously mentioned site. This indicates, as does the data of this report, the lack of a direct relationship between soil cadmium and traffic density.

No seasonal pattern was indicated by the data that was consistent for all sampling sites. At Sites A and B, the highest values were observed in Period 1, and at Site C, in Periods 1 and 2. There are no reports in the literature regarding seasonal variation in the concentrations of cadmium in soil or vegetation.

Cadmium in Vegetation

The concentration of cadmium in vegetation was observed to decrease significantly with increasing distance from the road at Sites A, B, and D (Table 13). This indicates a more complete relationship between plant cadmium levels and distance from the highway than was evident from the soil cadmium data. Possibly, this is because vegetation is more effective at trapping airborne particulates than is the underlying soil. The magnitude of the cadmium concentrations in vegetation compare favorably with the values reported by Lagerwerff and Specht (1970a, 1970b). However, these authors observed a more consistent decrease in the cadmium levels of vegetation as distance from the highway increased.

Site A exhibited the highest levels of cadmium in vegetation when the values for all sampling periods were averaged, but wide fluctuations in the plant cadmium levels at the remaining areas indicated that plant cadmium concentrations are not strongly influenced by traffic density (Table 14). Since the magnitude of cadmium levels in vegetation is low, only substantial increases in traffic volume will be reflected in a corresponding increase in cadmium contamination of the roadside.

At Sites A, B, and C, the cadmium concentration of vegetation growing on the 6 m sampling line was greater than the cadmium levels in vegetation from the corresponding control areas. Otherwise,

Table 13. Comparisons Among Distances from the Highway of the Mean Cadmium Levels (μg/g dry wt) in Vegetation Collected Along Highways of Different Traffic Volume.

Area	Distance from Road (m)	Sampling Periods I Aug/Sept	 II Nov/Dec	 III Feb/Mar	 IV Jun/July	Overall Average
A. I 95	5	0.36a	1.88a	1.36a	0.88a	0.98a
	12	0.47a	0.14a	0.44b	0.42b	0.41b
	24	0.28a	0.20a	0.49b	0.40b	0.38b
	48	0.42a	0.26a	0.49b	0.22b	0.33b
B. US 460	6	0.32a	0.09ab	0.41a	0.67a	0.48a
	12	0.37a	0.21a	0.23b	0.18b	0.23b
	24	0.27a	0.08ab	0.27b	0.16b	0.21b
	48	0.22a	0.03b	0.19b	0.20b	0.19b
C. Va 114	3	0.31a	--	0.70a	0.19b	0.26b
	6	0.64a	0.14a	0.28bc	0.18b	0.28b
	12	0.32a	0.06a	0.31bc	0.26b	0.26b
	24	0.10a	0.14a	0.34b	0.27b	0.26b
	48	0.84a	1.12a	0.22c	0.73a	0.62a
D. Va 42	3	0.19a	0.06c	0.18a	0.79a	0.50a
	6	0.18a	0.06c	0.14a	0.61a	0.33b
	12	0.14a	0.44a	0.24a	0.45bc	0.33b
	24	0.16a	0.24b	0.15a	0.48bc	0.34b
	48	0.29a	--	0.18a	0.29c	0.25b
E. Fairfax Control	-	0.28	0.65	0.42	0.35	0.40
F. Montgomery Control	-	0.22	0.84	0.18	0.16	0.24

a,b,c: Column means followed by different letters within each area and for each sampling period are significantly different ($P < 0.05$).

Table 14. Comparisons Among Highways of the Mean Cadmium Levels (μg/g dry wt) in Vegetation at Increasing Distance from the Highway

Distance from Road (m)	Area[1]	Sampling Periods I Aug/Sept	 II Nov/Dec	 III Feb/Mar	 IV Jun/July
3	C. Va 114	0.31a[2]	--	0.70a	0.19b
	D. Va 42	0.19a	0.06	0.18b	0.79a
6	A. I 95	0.36b	1.88a	1.36a	0.88a
	B. US 460	0.32a	0.09a	0.40b	0.67a
	C. Va 114	0.64a	0.14a	0.28b	0.18b
	D. Va 42	0.18b	0.06a	0.15b	0.61a
12	A. I 95	0.47a	0.14a	0.44a	0.42a
	B. US 460	0.37a	0.21a	0.23b	0.18b
	C. Va 114	0.32a	0.06a	0.31ab	0.26ab
	D. Va 42	0.14a	0.44a	0.24b	0.45a
24	A. I 95	0.28a	0.20a	0.49a	0.40ab
	B. US 460	0.27a	0.08a	0.27bc	0.16c
	C. Va 114	0.10a	0.14a	0.34b	0.27bc
	D. Va 42	0.16a	0.24a	0.15c	0.48a
48	A. I 95	0.42ab	0.26a	0.39a	0.22b
	B. US 460	0.22b	0.03a	0.19b	0.20b
	C. Va 114	0.84a	1.12a	0.22b	0.73a
	D. Va 42	0.29ab	--	0.18b	0.29b

[1] Traffic volumes (vehicles per day) for study areas are as follows:

A. I 95	92,400	B. US 460	24,095
C. Va 114	7,510	D. Va 42	525

[2] a,b,c: Column means followed by different letters for each distance and for each sampling period are significantly different ($P < 0.05$).

highway vegetation did not have markedly different cadmium concentrations than control area vegetation.

There was no consistent seasonal pattern of cadmium contamination at any site, based on actual data values. The ratios of the cadmium in vegetation to the cadmium in soil were analyzed in the same manner as for lead, and a weak seasonal pattern was detected. The ratios in Periods 2 and 3 were the highest, and except for a single value, were greater than 1. This suggests a seasonal gradient of cadmium accumulation by plants in excess of the corresponding levels of cadmium in soil. Along the lower density highways, this gradient may be masked due to the low magnitude and narrow range of the data.

Soil Nickel

Soil nickel concentrations along roadsides exhibited a significant decrease with increasing distance from the highway at Sites A, B, and C (Table 15). At Site D, there was a nonsignificant, decreasing trend in soil nickel concentrations as distance from the highway increased during Periods 1 and 2, but not 3 or 4. Levels of soil nickel were of the same magnitude as those reported by Lagerwerff and Specht (1970a).

For Periods 1 and 2, soil nickel concentrations were the highest at Site B, followed in order by Sites A, C, and D (Table 16). In seasons 3 and 4, Site D had the most heavily contaminated soil,

Table 15. Comparisons Among Distances from the Highway of the Mean Nickel Levels (μg/g dry wt) in Soil Collected Along Highways of Different Traffic Volume.

Area	Distance from Road (m)	Sampling Periods I Aug/Sept	II Nov/Dec	III Feb/Mar	IV Jun/July	Overall Average
A. I 95	6	4.45	5.60	6.35a	2.51a	4.53a
	12	3.32	2.65	2.61ab	1.97a	2.41b
	24	2.37	2.02	1.53b	2.21a	1.93b
	48	2.75	2.07	1.60b	1.67a	1.76b
B. US 460	6	10.20	10.79	3.86a	3.54a	4.83a
	12	8.76	2.81	4.03a	3.04a	3.91a
	24	6.91	2.92	2.30a	2.20a	2.70b
	48	6.62	2.32	2.14a	2.00a	2.47b
C. Va 114	3	8.00	10.44	--	--	9.22a
	6	3.10	1.81	1.62a	2.73a	2.22b
	12	1.77	2.70	1.54a	1.29b	1.55b
	24	2.12	2.16	1.25b	1.77ab	1.61b
	48	1.70	2.19	1.19b	1.31b	1.37b
D. Va 42	3	2.52	3.03	4.55a	4.02a	4.03a
	6	2.40	1.72	5.19a	3.67a	4.04a
	12	1.22	1.94	5.57a	3.58a	4.07a
	24	1.79	--	5.06a	4.58a	4.54a
	48	1.65	--	3.50a	4.40a	3.74a
E. Fairfax Control	-	4.82	2.03	1.34	1.39	1.71
F. Montgomery Control	-	2.03	1.58	1.68	2.34	1.98

a,b: Column means followed by different letters within each area and for each sampling period are significantly different ($P < 0.05$).

Table 16. Comparisons Among Highways of the Mean Nickel Levels (μg/g dry wt) in Soil at Increasing Distance from the Highway

Distance from Road (m)	Area[1]	Sampling Periods I Aug/Sept	 II Nov/Dec	 III Feb/Mar	 IV Jun/July
3	C. Va 114	8.00	10.44	--	--
	D. Va 42	2.52	3.03	4.55	4.02
6	A. I 95	4.45	5.60	6.35a[2]	2.51a
	B. US 460	10.20	10.79	3.86a	3.54a
	C. Va 114	3.10	1.81	1.62a	2.73a
	D. Va 42	2.40	1.72	5.19a	3.67a
12	A. I 95	3.32	2.65	2.61bc	1.97b
	B. US 460	8.76	2.81	4.03ab	3.04a
	C. Va 114	1.77	2.70	1.54c	1.29b
	D. Va 42	1.22	1.94	5.57a	3.58a
24	A. I 95	2.37	2.02	1.53c	2.21b
	B. US 460	6.91	2.92	2.30b	2.20b
	C. Va 114	2.12	2.16	1.25c	1.77b
	D. Va 42	1.79	--	5.06a	4.58a
48	A. I 95	2.75	2.07	1.60bc	1.67b
	B. US 460	6.62	2.32	2.14b	2.00b
	C. Va 114	1.70	2.19	1.19c	1.31b
	D. Va 42	1.65	--	3.50a	4.40a

[1] Traffic volumes (vehicles per day) for study areas are as follows:

A. I 95	92,400	B. US 460	24,095
C. Va 114	7,510	D. Va 42	525

[2] a,b,c: Column means followed by different letters for each distance and for each sampling period are significantly different ($P < 0.05$).

followed in order by Sites B, A, and C. These data indicate that the two sampling locations chosen along VA Rte 42 had markedly different levels of soil nickel. This is attributed to variable background nickel concentrations, and not a difference in traffic volume between the two locations.

Concentrations of nickel in soil sampled at lines close to the highway were generally greater than the nickel levels at the corresponding control areas. At Site D, in Periods 3 and 4, the soil nickel concentrations at all sampling distances exceeded the control area levels by at least 50 percent.

It can be concluded that soil nickel bears only a minor relationship to traffic density, with background nickel concentrations accounting for most of the nickel present in soil. A small portion of roadside nickel is contributed by motor vehicles, thus accounting for the observed relationship between soil nickel concentrations and distance from the road.

At Sites A and B, the highest concentrations of soil nickel were detected in Period 1, and at Site C, in Period 2. A seasonal comparison cannot be made for Site D because of the different sampling locations used.

Nickel in Vegetation

There was no apparent relationship between distance from the highway and the nickel concentrations of vegetation at any site

(Table 17). This is in contrast to the observed decreasing trends for soil nickel as distance from the road increased, and may be due to the variability of plant species selected at each sampling line.

There was a decreasing pattern in nickel concentrations in vegetation as traffic density decreased (Table 18). The vegetation collected at Site A exhibited the highest nickel levels, followed in order by Sites B, C, and D. As was observed for the soil, the levels of nickel in plants at Site D were higher in Periods 3 and 4 than in Periods 1 and 2, and higher than the nickel levels of vegetation sampled at the control area (Site F). This is further indication of the varying background nickel levels between the two sampling locations on VA Rte 42.

For Sites A, B, and C, the nickel concentrations of vegetation collected from the 6 m sampling line were generally greater than the nickel levels in vegetation from the corresponding control areas.

At Sites B, C, and D, vegetation that was collected in Period 3 had the highest nickel concentrations, indicating that the nickel concentration of plants increases with age. A comparison of the ratios of the nickel concentration of vegetation to the nickel concentration of soil yielded slightly different results. These ratios were the highest for Period 3 at Sites A, B, and C.

Soil Zinc

Concentrations of zinc in roadside soil decreased with increasing distance from the highway at Sites A, B, and C, with Site A exhibiting

Table 17. Comparisons Among Distances from the Highway of the Mean Nickel Levels (μg/g dry wt) in Vegetation Collected Along Highways of Different Traffic Volume

Area	Distance from Road (m)	Sampling Periods				Overall Average
		I Aug/Sept	II Nov/Dec	III Feb/Mar	IV Jun/July	
A. I 95	6	1.92a	1.85ab	2.77a	2.87a	2.55ab
	12	3.33a	1.57b	2.86a	1.72b	2.39b
	24	2.66a	1.60ab	2.52a	2.45ab	2.44ab
	48	3.84a	3.09a	2.87a	2.74a	3.03a
B. US 460	6	0.62a	1.57a	2.64a	1.04b	1.66ab
	12	0.82a	0.74a	1.79a	1.18b	1.26b
	24	1.09a	0.95a	1.79a	1.50ab	1.48ab
	48	0.63a	1.88a	2.20a	2.00a	1.86a
C. Va 114	3	1.28a	--	3.12a	1.84a	1.99a
	6	1.50a	0.94a	1.67b	0.98b	1.28b
	12	3.85a	0.33b	1.45b	1.56ab	1.80ab
	24	0.50a	1.28a	1.61b	1.39ab	1.37ab
	48	0.64a	0.40b	1.30b	1.21ab	1.13b
D. Va 42	3	0.56a	0.76a	2.77a	1.30a	1.42a
	6	0.38a	0.66a	1.51b	1.62a	1.31a
	12	0.36a	1.22a	1.34b	0.94a	1.07a
	24	0.88a	0.92a	1.20b	1.45a	1.31a
	48	0.94a	--	1.83ab	1.18a	1.43a
E. Fairfax Control	-	2.05	1.36	1.53	2.18	1.80
F. Montgomery Control	-	0.66	0.71	1.13	1.51	1.21

a,b: Column means followed by different letters within each area and for each sampling period are significantly different ($P < 0.05$).

Table 18. Comparisons Among Highways of the Mean Nickel Levels (μg/g dry wt) in Vegetation at Increasing Distance from the Highway

Distance from Road (m)	Area[1]	Sampling Periods I Aug/Sept	II Nov/Dec	III Feb/Mar	IV Jun/July
3	C. Va 114	1.28a[2]	--	3.12a	1.84a
	D. Va 42	0.56a	0.76	2.77a	1.30a
6	A. I 95	1.92a	1.85a	2.77a	2.87a
	B. US 460	0.62 bc	1.57ab	2.72a	1.04b
	C. Va 114	1.50ab	0.94bc	1.67a	0.98b
	D. Va 42	0.38c	0.66c	1.51a	1.62b
12	A. I 95	3.33a	1.57a	2.86a	1.72a
	B. US 460	0.82a	0.74ab	1.79b	1.18bc
	C. Va 114	3.85a	0.33b	1.45b	1.56ab
	D. Va 42	0.36a	1.22ab	1.34b	0.94c
24	A. I 95	2.66a	1.60a	2.52a	2.45a
	B. US 460	1.09b	0.95a	1.79b	1.51b
	C. Va 114	0.88b	1.28a	1.61b	1.39b
	D. Va 42	0.50b	0.92a	1.20b	1.45b
48	A. I 95	3.84a	3.09a	2.87a	2.74a
	B. US 460	0.63b	1.88ab	2.20ab	2.00a
	C. Va 114	0.64b	0.40b	1.30b	1.21b
	D. Va 42	0.94ab	--	1.83ab	1.18b

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[1] Traffic volumes (vehicles per day) for study areas are as follows:

A. I 95	92,400	B. US 460	24,095
B. Va 114	7,510	D. Va 42	525

[2] a,b,c: Column means followed by different letters for each distance and for each sampling period are significantly different ($P < 0.05$).

the most pronounced decrease (Table 19). The levels of zinc in roadside soil were of the same magnitude and direction as the values reported by Lagerwerff and Specht (1970a, 1970b) and Gish and Christensen (1973).

Upon comparison of the soil zinc concentrations at the 6 m line, Site A had significantly higher levels than the other three highway sites (Table 20). At the 6 m line, Site B had comparatively higher soil zinc levels than either Sites C or D. The concentrations of zinc in roadside soil at Sites C and D were similar.

Comparison of the roadside levels of soil zinc with control area levels indicated that the influence of the highway on zinc contamination of the surrounding soil is more restricted than with lead contamination. Soil zinc levels at the 48 m line of all sites were close to the zinc levels at the corresponding control areas.

At Sites A and B, the highest soil zinc concentrations were detected in Period 3. No seasonal trends were apparent at Sites C or D.

Zinc in Vegetation

Levels of zinc in vegetation were inversely related to distance from the highway at Sites A and B (Table 21). At Sites C and D, there was no pattern to the zinc concentration of vegetation with increasing distance. The data correspond with the levels of roadside zinc contamination reported by Lagerwerff and Specht (1970a, 1970b).

Table 19. Comparisons Among Distances from the Highway of the Mean Zinc Levels (μg/g dry wt) in Soil Collected Along Highways of Different Traffic Volume

Area	Distance from Road (m)	Sampling Periods I Aug/Sept	 II Nov/Dec	 III Feb/Mar	 IV Jun/July	Overall Average
A. I 95	6	228	348	171a	78a	152a
	12	72	43	42b	49b	47b
	24	41	24	22b	34bc	29c
	48	33	23	13b	21c	19c
B. US 460	6	170	165	61a	46ab	72a
	12	100	48	84ab	70a	76a
	24	56	39	21b	28b	28b
	48	44	22	15b	31b	25b
C. Va 114	3	56	58	--	--	57a
	6	39	34	25a	36a	32ab
	12	21	28	22ab	21b	22ab
	24	18	38	12c	12b	15b
	48	14	18	15bc	14b	15b
D. Va 42	3	67	78	35ab	24a	36abc
	6	156	63	44a	33a	51a
	12	17	30	23b	21a	22c
	24	23	--	48a	56a	49ab
	48	79	--	23b	27a	30bc
E. Fairfax Control	-	27	18	12	14	15
F. Montgomery Control	-	30	14	17	16	18

a,b,c: Column means followed by different letters within each area and for each sampling period are significantly different ($P < 0.05$).

Table 20. Comparisons Among Highways of the Mean Zinc Levels (μg/g dry wt) in Soil at Increasing Distance from the Highway

Distance from Road (m)	Area[1]	Sampling Periods			
		I Aug/Sept	II Nov/Dec	III Feb/Mar	IV Jun/July
3	C. Va 114	56	48	--	--
	D. Va 42	67	78	35	36
6	A. I 95	228	348	171a[2]	78a
	B. US 460	170	165	61b	46b
	C. Va 114	39	34	25b	36b
	D. Va 42	156	63	44b	33b
12	A. I 95	72	43	42b	49a
	B. US 460	100	48	84a	70a
	C. Va 114	21	28	22b	21b
	D. Va 42	17	30	23b	21b
24	A. I 95	41	24	22b	34a
	B. US 460	56	39	21b	28a
	C. Va 114	18	38	12b	12a
	D. Va 42	23	--	48a	56a
48	A. I 95	33	23	13b	21a
	B. US 460	44	22	15b	31a
	C. Va 114	14	18	15b	14a
	D. Va 42	79	--	23a	27a

[1] Traffic volumes (vehicles per day) for study areas are as follows:

A. I 95	92,400	B. US 460	24,095
C. Va 114	7,510	D. Va 42	525

[2] a,b: Column means followed by different letters for each distance and for each sampling period are significantly different ($P < 0.05$).

Table 21. Comparisons Among Distances from the Highway of the Mean Zinc Levels (µg/g dry wt) in Vegetation Collected Along Highways of Different Traffic Volume.

Area	Distance from Road (m)	Sampling Periods				Overall Average
		I Aug/Sept	II Nov/Dec	III Feb/Mar	IV Jun/July	
A. I 95	6	113a	227a	348a	186a	219a
	12	85a	56c	101b	82b	98b
	24	74a	127b	131b	68b	86c
	48	85a	56c	67b	47b	63d
B. US 460	6	50a	51a	98a	81a	81a
	12	60a	73a	98a	54b	71b
	24	73a	85a	80ab	55b	68b
	48	53a	48a	60b	47b	52c
C. Va 114	3	82a	--	77a	50b	55b
	6	93a	49ab	69a	39b	58b
	12	110a	32ab	52a	71a	71a
	24	46a	80a	93a	49b	70a
	48	52a	23b	42a	38b	39c
D. Va 42	3	28b	55a	33ab	49a	45b
	6	81a	105a	32ab	47a	54a
	12	44ab	80a	37a	39a	39bc
	24	29ab	30a	26b	40a	34c
	48	41ab	--	22b	40a	33c
E. Fairfax Control	-	60	61	57	45	54
F. Montgomery Control	-	47	21	26	45	38

a,b,c,d: Column means followed by different letters within each area and for each sampling period are significantly different ($P < 0.05$).

In general, zinc levels in roadside vegetation were directly related to traffic density, with Site A having the highest zinc values, followed in order by Sites B, C, and D (Table 22).

Vegetation collected at the 48 m sampling line of all sites had zinc concentrations that were close to the levels of the corresponding control areas. As the traffic density decreased, the concentrations of zinc in vegetation from the 48 m line were more comparable to control area levels.

The highest concentrations of zinc in vegetation were observed in Period 3 for Sites A, B, and E. This is reflected in the actual data values, as well as the ratios of the zinc concentration in vegetation to the zinc concentration in soil.

General Discussion

Samples of grass, broad leaved plants, evergreen and deciduous flora were collected at each sampling line, when possible. However, due to the constraints imposed by differential soil types and seasonal factors, only a few species of plants were collected more than 50 percent of the time. A complete list of the species sampled can be found in Table 23. Of these plant species, fescue (*Festuca* spp.), chicory (*Chicorium intybus*) and wild carrot (*Daucus carota*) were the three most representative. Levels of lead, cadmium, nickel, and zinc in these plant species exhibited the same patterns in relation to the highway that were apparent for vegetation as a whole (Table I--appendix).

Table 22. Comparisons Among Highways of the Mean Zinc Levels (μg/g dry wt) in Vegetation at Increasing Distance from the Highway

Distance from Road (m)	Area[1]	Sampling Periods I Aug/Sept	 II Nov/Dec	 III Feb/Mar	 IV Jun/July
3	C. Va 114	82a[2]	--	77a	50a
	D. Va 42	28a	55	33b	49a
6	A. I 95	113a	227a	348a	186a
	B. US 460	50a	51c	98b	81b
	C. Va 114	93a	49d	69b	39b
	D. Va 42	81a	105b	32b	47b
12	A. I 95	85ab	56a	101a	82a
	B. US 460	60b	73a	98a	54bc
	C. Va 114	110a	32a	52b	71ab
	D. Va 42	44b	80a	37b	39c
24	A. I 95	74a	127a	131a	68a
	B. US 460	73a	85a	80b	55b
	C. Va 114	46a	80a	94ab	49bc
	D. Va 42	29a	30a	26c	40c
48	A. I 95	85a	56a	67a	47ab
	B. US 460	53b	48ab	60a	47a
	C. Va 114	52b	23b	42b	38b
	D. Va 42	41b	--	22b	40ab

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[1] Traffic volumes (vehicles per day) for study areas are as follows:

A. I 95	92,400	B. US 460	24,095
C. VA 114	7,510	D. Va 42	525

[2] a,b,c,d: Column means followed by different letters for each distance and for each sampling period are significantly different ($P < 0.05$).

Table 23. Plant species collected

Common Names	Specific Name
Albizzia	Albizzia julibrissin
American Elm	Ulmus americana
American Yew	Taxus canadensis
Apple (domestic)	Pyrus malus
Aster	Aster spp.
Bittersweet Nightshade	Solanum carolinense
Broom Sedge	Andropogon virginicus
Bull Thistle	Cirsium vulgare
Cherry (Black, Choke)	Prunus spp.
Chicory	Chicorium intybus
Common Mullein	Verbascum thapsus
Crown Vetch	Coronilla varia
Dandelion (common)	Taraxacum officinale
Fescue	Festuca spp.
Goldenrod (varieties)	Solidago spp.
Hawthorne	Crataegus
Heal All	Prunella vulgaris
Japanese Honeysuckle	Lonicera japonica
Lespedeza	Lespedeza spp.
Milkweed	Asclepias syriaca
Multiflora Rose	Rosa multiflora
Oak (White, Red, Chestnut)	Quercus spp.
Pearly Everlasting	Anaphalis margaritacea
Pine (Red, White, Virginia)	Pinus spp.
Plantain (Narrow & Broad Leaved)	Plantago spp.
Ragweed	Ambrosia artemisiifolia
Red Cedar	Juniperus virginiana
Red Clover	Trifolium pratense
Spiny Leaved Sow Thistle	Sonchus asper
Spotted Knapweed	Centaurea maculosa
White Ash	Fraxinus americana
Wild Carrot	Daucus carota
Yarrow	Achillea millefolium

It has been noted in the literature that there is great variability in the uptake of lead, cadmium, nickel, and zinc by various plant species. Plants also differ in morphological characteristics that influence surface deposition and retention of these elements. Differences among plant species, with respect to concentrations of lead, cadmium, nickel, and zinc were evident in this report, and were dependent primarily on surface structure and growth form of the plant.

Chicory (Chicorium intybus), pearly everlasting (Anaphalis margaritacea), goldenrod (Solidago spp.), ragweed (Ambrosia artemisiifolia), and common mullein (Verbascum thapsus) had generally high levels of lead, cadmium, nickel, and zinc. These plant species are characterized by either pubescent leaf and flower surfaces (mullein, everlasting) or tall aerial portions with large surface areas (goldenrod, chicory, ragweed).

Plant species with generally low concentrations of the elements were Japanese honeysuckle (Lonicera japonica), American elm (Ulmus americana), multiflora rose (Rosa spp.), red cedar (Juniperus virginiana), black cherry (Prunus serotina), American yew (Taxus canadensis), common milkweed (Asclepias syriaca), lespedeza (Lespedeza spp.), and white oak (Quercus alba). Included among these species of vegetation is a large percentage of the deciduous species that were sampled. All of the deciduous species with low levels of the elements were characterized by leaves and twigs with smooth surfaces. Also, deciduous species have stomata only on the undersides of the leaves. In addition, during two of the sampling periods (2 and 3), these species were leafless, and only twigs were collected. Lespedeza, although it has a large aerial portion, has smooth surfaced leaves that are greatly reduced in surface area during the winter months. Honeysuckle bears leaves year round, but they are nonpubescent.

Surface structure alone cannot account for the low levels of lead, cadmium, nickel, and zinc associated with milkweed, yew, or red cedar. All have rough surfaces, and the leaves of yew and cedar persist for two to three years. These and other apparent anomalies in the species information may be based on differential rates of uptake of these elements by various species of vegetation, or a differential loss of dry matter that occurs over the course of a year. Evergreen perennials, such as red cedar and American yew, may not lose dry matter over the year, and therefore may not experience the consequent concentration of elements in tissues as do annual plant species.

This report does not fully support the conclusions of Keller (1970, 1971) and Heichel and Hankin (1976) that recommended conifers for use as sinks for vehicular emissions. In general, trees are better adapted than most annual species to trap (although not necessarily retain) particles that are transported at higher than 1 m from the soil surface, and they will trap a larger total volume of particulates than low lying vegetation. However, conifers in this study were not associated with large quantities of lead, cadmium, nickel, and zinc, but were noted for their average or low levels of these elements. Thus, in comparison with such annual plant species as goldenrod and ragweed, particle retention per unit surface area is low for the conifers sampled in this report.

Of the plant species that exhibited typically high levels of these elements, goldenrod is a suitable choice for planting immediately adjacent to highways. It has exceptional particulate trapping qualities and a low utility for most wildlife species. Plant species such as lespedeza and honeysuckle are recommended as plantings at greater distances from the road. These species have characteristically low concentrations of highway generated lead, cadmium, nickel, and zinc, and are of high utility for many wildlife species.

The roadside levels of cadmium and zinc in soil and vegetation were typically within "normal" background concentrations, and below reported levels of toxicity to plants. More concern must be expressed for roadside contamination by lead and nickel. The lead concentrations of soil and vegetation exceeded accepted normal background levels along the highways of greater traffic volume, most notably at distances close to the highway. Plant lead levels at Sites A and B were frequently in excess of concentrations known to inhibit photosynthesis (Bazzazz et al. 1974a), decrease dry matter production (Koeppe 1977), and depress the elongation of corn seedling radicles (Hassett et al. 1976).

Although plant concentrations of nickel were within the uncontaminated range of 0.05 to 5.0 μg/g reported by Vanselow (1966), some levels were above those at which toxicity to plants can occur. Vanselow (1966) reported that 2 μg/g soil nickel was toxic to bean and barley plants, and a foliar application of nickel at a concentration greater than 1 μg/g was toxic to paprika (Pais et al. 1970).

The implications for toxicity to organisms higher on the food chain has been evaluated by Blair (1978) in an associated report dealing with levels of lead, cadmium, nickel, and zinc in small mammals and earthworms collected in conjunction with this report. It is likely that higher organisms will be under the most stress from airborne and dietary levels of lead, nickel, and zinc during the winter months, since the concentration of these elements in the atmospheric and vegetative components of the ecosystem have been observed to peak at this time of year.

There were contributing factors to roadside contamination by lead, cadmium, nickel, and zinc that this report was unable to give full consideration. Both plant and soil levels were affected by such weather parameters as wind speed and direction, precipitation, and soil and air temperature. Soil chemistry was of major importance in determining the extent of uptake of these elements by plants. A soil analysis revealed that soil pH was characteristically lower along roads of greater traffic density. This indicates a greater availability of lead, cadmium, nickel, and zinc for plant uptake along highways of greater traffic density. Also, the organic matter fractions of all soils tested were higher than the average of 4 percent reported by

Brady (1974), indicating a high CEC of all roadside soil environments sampled at this report (Table II--appendix).

SUMMARY AND CONCLUSIONS

It was observed that concentrations of lead, cadmium, nickel, and zinc in soil and vegetation were generally inversely proportional to distance from the highway. The declines in elemental concentration with increasing distance were significant along highways of greater traffic density, and were more pronounced when dealing with lead and zinc.

Concentrations of lead and zinc detected in roadside soil and vegetation were proportional to traffic density, but traffic density related patterns were weak or nonexistent for corresponding levels of cadmium and nickel.

No seasonal variation was apparent for these elements (Pb, Cd, Ni, Zn) in soil. However, plant levels of lead, nickel, and zinc exhibited a seasonal peak in sampling Period 3(Feb/Mar).

The concentrations of lead, cadmium, nickel, and zinc associated with plants varies with plant species, and seems to depend on surface characteristics of the plant that promote trapping and retention of atmospheric particulates. This report was unable to give sufficient emphasis to characterizing roadside plant species according to particle retaining abilities. Future roadside studies should emphasize the relationship between the levels of lead, cadmium, nickel and zinc associated with individual plant species and their value as wildlife food and cover crops.

It can be concluded that highways do have a significant effect on contamination of the highway ecosystem by lead, cadmium, nickel, and zinc. However, only along roads of high traffic volume ($<$ 7,500 vehicles per day) should this contamination be of major concern to human and wildlife populations. Along these high density highways, proper emphasis should be placed on the selection of roadside plantings to minimize the toxic effects of these pollutants while maximizing wildlife habitat.

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APPENDIX

Table I. Lead, Cadmium, Nickel, and Zinc Levels (μg/g) in Selected Plant Species

Species	Area	Distance from Road (m)	Sampling Periods															
			I (Aug/Sept)				II (Nov/Dec)				III (Feb/Mar)				IV (Jun/July)			
			Pb	Cd	Ni	Zn	Pb	Cd	Ni	Zn	Pb	Cd	Ni	Zn	Pb	Cd	Ni	Zn
FESCUE	A. I 95	6					588	0.15	1.13	33	673	0.64	3.76	438	145	0.77	3.00	127
		12					53	--	1.14	17	596	0.26	4.56	82	8	0.21	1.85	40
		24					--	--	--	--	--	--	--	--	--	--	--	--
		48					--	--	--	--	157	0.35	3.96	58	--	--	--	--
	B. US 460	6					95	0.05	1.83	25	330	0.41	4.81	77	35	0.73	1.88	37
		12					--	--	--	--	137	0.21	4.32	104	16	0.18	1.92	38
		24					--	--	--	--	372	0.32	2.17	80	19	0.11	1.45	37
		48					--	--	--	--	153	0.18	3.10	47	9	0.12	1.30	32
	C. VA 114	3					--	--	--	--	190	0.70	3.12	77	11	0.13	4.12	23
		6					16	0.08	1.08	14	74	0.26	2.26	94	7	0.16	1.29	36
		12					21	0.09	0.50	21	42	0.31	1.45	52	6	0.12	0.95	47
		24					8	--	1.19	181	33	0.32	2.05	34	--	--	--	--
		48					12	0.02	0.51	10	22	0.18	2.00	28	3	0.53	0.75	31
	D. VA 42	3					--	--	--	--	38	0.21	2.71	38	4	0.75	0.85	56
		6					--	--	--	--	16	0.15	1.86	31	2	0.53	1.03	46
		12					--	--	--	--	19	0.40	1.67	31	--	--	--	--
		24					--	--	--	--	22	0.13	0.80	19	2	0.14	1.65	29
		48					--	--	--	--	14	0.12	0.94	24	2	0.37	0.39	28
	E. Fairfax Control	-					--	--	--	--	--	--	--	--	3	0.15	1.88	39
	F. Montgomery Control	-					4	0.11	0.63	--	5	0.14	1.30	27	2	0.13	1.26	32
CHICORY	B. US 460	6	53	0.49	0.60	61	--	--	--	--	210	0.38	4.81	81	51	0.64	1.26	127
		12	23	0.37	0.63	35	--	--	--	--	--	--	--	--	13	0.24	1.61	49
		24	15	0.23	1.13	55	419	0.10	0.98	116	93	0.32	1.67	51	17	0.16	2.56	63
		48	7	0.10	0.63	44	82	0.04	1.45	49	79	0.33	1.15	57	7	0.33	1.59	53
	C. VA 114	3	--	--	--	--	--	--	--	--	--	--	--	--	3	0.44	0.85	73
		6	--	--	--	--	121	0.54	1.31	72	--	--	--	--	--	--	--	--
		12	11	0.59	2.57	256	26	--	0.01	64	--	--	--	--	4	0.44	2.01	115
		24	--	--	--	--	18	0.10	0.85	54	14	0.28	1.18	120	3	0.36	1.62	62
		48	--	--	--	--	--	--	--	--	--	--	--	--	1	0.95	1.73	47

Table I - (Continued)

Species	Area	Distance from Road (m)	I (Aug/Sept)				II (Nov/Dec)				III (Feb/Mar)				IV (Jun/July)			
			Pb	Cd	Ni	Zn	Pb	Cd	Ni	Zn	Pb	Cd	Ni	Zn	Pb	Cd	Ni	Zn
	D. VA 42	3	--	--	--	--	43	0.16	2.00	61	--	--	--	--	7	1.41	1.82	67
		6	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
		12	--	--	--	--	--	--	--	--	--	--	--	--	3	0.15	1.57	45
		24	3	0.32	1.51	29	--	--	--	--	--	--	--	--	2	0.85	2.00	51
		48	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
	E. Fairfax Control	-	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
	F. Montgomery Control	-	2	0.12	0.73	39	4	0.21	0.21	35	17	0.21	1.40	35	2	0.22	1.92	46
WILD CARROT	A. I 95	6	109	0.60	2.28	64	--	--	--	--	--	--	--	--	--	--	--	--
		12	95	0.17	3.77	53	294	0.52	4.10	73	426	0.76	2.62	88	58	0.55	1.55	49
	B. US 460	6	--	--	--	--	--	--	--	--	318	0.34	1.50	88	52	1.04	0.56	134
		12	38	0.21	0.88	43	349	0.10	0.91	84	327	0.40	1.22	106	26	0.26	0.54	68
		24	38	0.25	1.13	45	--	--	--	--	326	0.35	0.73	78	13	0.17	0.97	38
		48	9	0.10	--	--	--	--	--	--	--	--	--	--	18	0.22	1.29	68
	C. VA 114	6	19	0.70	0.70	37	--	--	--	--	58	0.54	1.62	64	--	--	--	--
		12	--	--	--	--	--	--	--	--	--	--	--	--	19	0.35	2.58	71
		24	--	--	--	--	--	--	--	--	--	--	--	--	3	0.31	1.07	44
		48	5	0.14	0.10	39	--	--	--	--	--	--	--	--	5	0.54	0.80	35
	D. VA 42	6	5	[illegible]	[illegible]	[illegible]	--	--	--	--	9	0.34	1.07	30	--	--	--	--
		12	2	0.25	0.48	90	--	--	--	--	11	0.48	0.66	29	3	0.68	0.90	45
		24	--	--	--	--	3	0.19	--	51	13	0.22	1.66	21	2	0.30	1.20	42
		48	2	0.18	1.08	34	--	--	--	--	10	0.39	0.86	21	2	0.20	1.01	59
	E. Fairfax Control	-	4	0.54	2.92	58	7	0.53	1.06	30	23	0.94	1.45	39	5	0.91	2.44	55
	F. Montgomery Control	-	3	0.31	0.77	49	32	4.22	2.16	36	25	0.36	1.02	29	2	0.24	1.07	97

Table II. Analysis of Soil Characteristics at the Various Sampling Locations

Area	Distance from Road (m)	pH	lbs/acre				Organic Matter (%)
			CaO	MgO	P_2O_5	K_2O	
A. I 95	6	5.8	2619	167	250+	120	5.0
	12	6.9	3358	179	250+	270	3.6
	24	4.8	2485	191	61	177	7.1
	48	5.1	2384	167	42	235	6.5
B. US 460	6	7.2	3358	398	75	373	2.9
	12	7.1	3358	398	48	45	6.8
	24	6.3	3223	398	37	12	7.4
	48	5.9	2451	398	31	365	6.2
C. Va 114	3	8.3	3358	398	7	169	2.5
	6	7.0	3358	398	57	349	7.4
	12	6.3	3156	398	169	97	7.4
	24	6.0	2787	398	181	75	6.5
	48	5.8	2585	398	141	86	6.8
D. Va 42	3	7.1	3358	398	167	23	7.1
	6	6.5	3290	398	128	357	4.4
	12	7.2	3358	398	104	219	4.4
	24	7.0	3358	398	150	219	4.6
	48	6.1	3223	398	250+	26	6.2
E. Fairfax Control	-	5.0	1746	251	39	208	5.6
F. Montgomery Control	-	6.0	3358	398	84	101	7.4

LEAD, CADMIUM, NICKEL, ANC ZINC CONCENTRATIONS IN SOIL AND VEGETATION ASSOCIATED WITH HIGHWAYS OF DIFFERENT TRAFFIC DENSITIES

by

Anne Lee Hiller

(ABSTRACT)

Soil and vegetation was collected along four highways of different traffic volumes, at varying distances from the road, and at two control areas. Four sampling periods were conducted throughout the course of a year from August, 1976 to June, 1977. Soil and vegetation samples were tested for concentrations of lead, cadmium, nickel, and zinc. There were general declines in the concentrations of lead, cadmium, nickel, and zinc as proximity to the highway decreased. These declines were significant ($P < 0.05$) along the highways of greater traffic density. Lead and zinc levels in roadside soil and vegetation exhibited a general decrease with decreasing traffic density. There was not a strong relationship between the levels of cadmium and nickel in soil and vegetation and traffic volume. There was a seasonal pattern to the levels of lead, nickel, and zinc in roadside vegetation, with plants from Period 3 (Feb/Mar) exhibiting the highest levels.