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LEAD IN THE SOIL ENVIRONMENT

Technical Report

Prepared by:
MONITORING AND ASSESSMENT RESEARCH CENTRE
Chelsea College, University of London

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Lead in the soil environment

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A Technical Report (1980)

Prepared by:
Monitoring and Assessment Research Centre,
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Abstract

This survey of the literature on lead in soil discusses methods of estimation of total and available lead in soils, the relationships between soil properties and the uptake of lead by plants, and the form and distribution of lead in soil profiles. Examples of the accumulation of lead in soils from various sources are presented. An appendix of 31 tables brings together the available data on lead as well as other associated trace metals in soils, providing useful reference material for exposure assessment calculations.

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1 Introduction

Soil is the major reservoir for lead in the environment and forms the initial link of the food-chain through which the metal is transferred to man. Lead arising from man's activities enters the soil from polluted atmospheric or aquatic systems or through land-based disposal of contaminated wastes.

In an excellent review, Jones and Clement (1972) pointed out a number of barriers which may restrict the movement of lead from soil via the food-chain to man. Sequentially, these barriers are:

1. soil (binding with inorganic and organic constituents)
2. plant roots (immobilization in the cell wall)
3. alimentary tracts and bones of ruminant animals.

The movement of lead from the soil to man may not necessarily be restricted by the additive effects of the three barriers; the third barrier is by-passed, for instance, by ingestion of plants directly in the human diet, rather than of animal products.

This report is a survey of the literature on lead in soils, particularly the mode of occurrence of the metal in soils, the form and distribution in soil profiles, and the availability for transfer to plants. An appendix is included of the tabulated data on lead as well as other associated trace metals of biological importance. This should provide reference material for possible use in exposure assessments.

2 Sources and forms of lead in soil

2.1 Sources

Lead in soil originates from both geochemical weathering and anthropogenic inputs. Major sources and forms of lead are illustrated in Figure 1. The other sources of lead include volcanic, meteoritic and marine aerosols, wood and tobacco smokes, lead-based paints, and refuse incineration.

In the uncontaminated environment, soils produced by weathering *in situ* reflect the composition of the underlying parent materials. A listing of average concentrations of lead and other trace metals in soils, the lithosphere and in rocks is given in Table A-1. Data on the levels of lead in some surface soils of England, Wales and Scotland are presented in

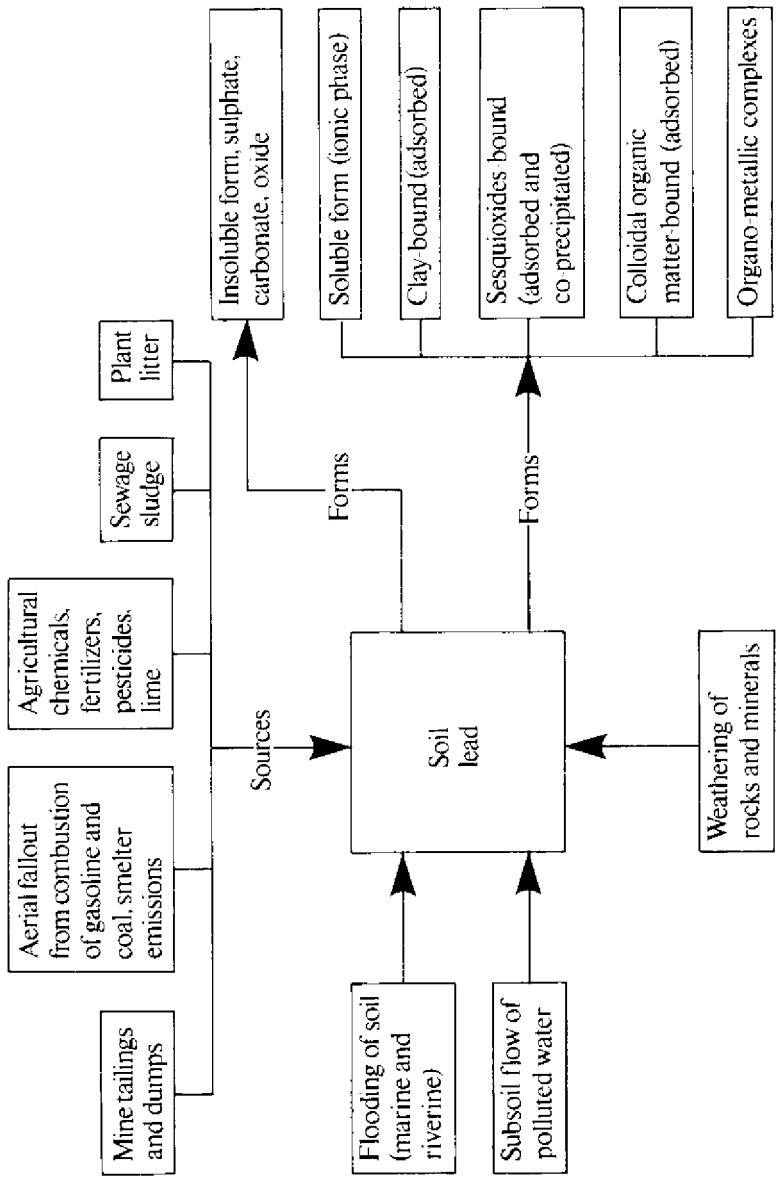


Figure 1 Sources and forms of lead in soil

Tables A-2 and A-3. Weathering processes mobilize an estimated $11,000 \text{ t y}^{-1}$ of lead through river flow and $2,100 \text{ t y}^{-1}$ from sediments, as compared with $3,600 \text{ t y}^{-1}$ released by fossil fuel combustion (Bertine and Goldberg 1971).

Atmospheric lead arises mainly from the emissions of automobile exhausts, the combustion of coal, and metal-smelting operations. The lead content of air in European cities ranges from 0.4 to $4.8 \mu\text{g m}^{-3}$ (Blokker 1972), while it has been estimated that the background level from purely geochemical sources would be $0.0005 \mu\text{g m}^{-3}$ (Patterson 1965). Measurements of the atmospheric deposition of lead in some urban and non-urban areas of western Europe and the U.S.A. have been reported by Cawse (1977). Elevated deposition rates of lead are apparent in areas of extreme urbanization, e.g. in New York, or where there has been intense industrial activity, e.g. in central Swansea (Table A-4).

Lead is also added to soils in the form of agricultural chemicals such as pesticides, fertilizers and lime (Table A-5). Sewage sludge containing lead and other metals is commonly applied to agricultural land. Kirkham (1975) has reported an increase in soil lead from 61 to $1,015 \mu\text{g g}^{-1}$ after 35 years of sludge application, this being equivalent to a yearly accumulation of about 80 kg ha^{-1} of lead in the soil to a depth of 30 cm.

The enrichment of surface soils with lead often occurs through the deposition of leaf litter, especially in areas covered with forests which act as a filter for atmospheric lead. Rolfe and Jennett (1973) have reported lead levels of $28,000 \mu\text{g g}^{-1}$ in well decomposed litter and $590 \mu\text{g g}^{-1}$ in soil 0.4 km from a smelter. These values fell to $450 \mu\text{g g}^{-1}$ in well decomposed litter and $32 \mu\text{g g}^{-1}$ in soil 8 km from the same smelter (Table A-6).

Other sources of lead to soil include mine tailings and dumps and lead-emitting operations such as mining, milling and ore concentrate haulage (Rolfe and Jennett 1973). Lead may also enter the soil through floodwater (marine and riverine), sea spray, water erosion of lead-rich mineral areas and the subsoil flow of polluted water.

A number of radioactive decay processes may also contribute to the lead content of the soil. The isotope ^{210}Pb , for instance, is a major constituent of natural radioactive materials. ^{210}Pb may also be present through the decomposition of uranium impurities in phosphate rock used in the manufacture of fertilizers. There is not yet a full understanding of the behaviour of ^{210}Pb in soils (Baltakmens 1974).

2.2 Chemical and physical forms

Soil is a complex matrix composed of several hundred different compounds, of which lead compounds are only a small fraction. The principal forms in which lead may be present in soils are:

- a) in water soluble form
- b) as adsorbed ions on mineral colloids or as a constituent of the crystal lattices of sand, silt and clay-sized minerals
- c) in association with iron, aluminium and, less often, manganese oxides
- d) bound with organic matter in exchangeable form or as organo-metallic complexes.

The soil chemistry of lead compounds is uncertain. The general view is that lead, whether released through geochemical weathering or deposited from external sources, is largely present in the soil in insoluble forms. The water soluble fraction comprises a very small proportion of the readily extractable lead, being present mainly in inorganic forms such as nitrate, bicarbonate and chloride.

A considerable proportion of the total lead may be present in the clay and silt-sized fractions of soils. Trace metals including lead may be bound with clay, either within the lattice structure of the clay particles or at surface and edge exchange sites. Biologically important cations are very readily adsorbed by colloidal clay particles (Mitchell 1964), the approximate order of binding intensity (and hence difficulty of displacement) being $\text{Cu} > \text{Pb} > \text{Ni} > \text{Co} > \text{Zn} > \text{Ba} > \text{Rb} > \text{Sr} > \text{Ca} > \text{Mg} > \text{Na} > \text{Li}$.

The iron and aluminium oxides and hydroxides constitute a reactive group of chemical compounds in soils. Trace metals such as lead may be co-precipitated with or adsorbed by sesquioxides, chiefly amorphous oxides. According to Mitchell (1964) the extraction of soils with ammonium oxalate results in the dissolution of amorphous iron oxide (but little aluminium oxide) and its associated trace elements; some 50 per cent of the total lead and copper can be extracted with ammonium oxalate. Using the same method Le Riche and Weir (1963) obtained values of 41–65 per cent for lead alone. These authors have pointed out that, in addition to liberating the lead associated with the sesquioxides, the use of ammonium oxalate also releases exchangeable forms of the metal and also that associated with soil organic matter.

A considerable amount of lead in the soil may arise from industrial activity, such as in soils exposed to emissions from smelters. Roberts

(1975) has shown that 70 per cent of the deposited lead remained in the surface centimetre of clay cores, 15 per cent in the humus layer and only 5 per cent in the biomass. Very little information, however, is available with regard to the chemical forms of lead present in polluted soils. In a recent study, Olson and Skogerboe (1975) identified a number of lead compounds in a roadside soil. These authors found that the major part of the lead (>50 per cent) was present as sulphate. They considered that sulphuric acid in soil, or formed from sulphur dioxide in the atmosphere, may react with the lead particulates to form lead sulphate. Other lead compounds identified were PbO, PbS, PbO₂, PbO·PbSO₄. The variety of lead compounds produced through gasoline combustion has been described by Ter Haar and Bayard (1971) (Table A-7).

3 Availability of lead in soil

The transfer of lead to plants depends on the plant species, the stage of plant growth, the chemical forms of the metal in the soil, and the soil properties, such as composition, fertility level, pH and moisture status. This large number of factors has led to different methods being used rather arbitrarily to specify the availability of lead in soil for transfer to plants.

3.1 Methods of estimating availability

Several methods have been used to determine the total and available lead content of soils; a number of these are listed in Table 1. Some results of extractions are given in Tables 2 and 3. Certain methods for the determination of total lead have been compared by Scott and Thomas (1977). They have shown that over 98 per cent of the lead can be recovered using a mixture of nitric, sulphuric and perchloric acids in a ratio of 10:1:4.

The laboratory procedures to estimate the available quantity of a metal such as lead normally involve extracting the metal from the soil with various reagents, including water. Water extraction removes the ionic and molecular forms of trace metals present in the soil. Readily exchangeable metal ions from inorganic clay or organic material can be extracted by ion exchange using neutral salts such as ammonium acetate, while more firmly bound ions in the exchange complexes are displaced by H⁺ ions from dilute acetic acid (Berrow and Burridge 1977). The extraction with acetic acid may also cause some dissolution of precipitated sesquioxides, as observed by Swaine and Mitchell (1960). It is to

be noted that the amount of trace metals that can be extracted by neutral ammonium acetate is generally quite small, while a larger amount is extracted by acetic acid (Table 2).

Table 1 Methods for the determination of lead in soil

Investigators	Extraction/Digestion	Source of lead
Adamson (1977)	"Available" Pb extracted with 0.5M HAc (1:40, soil:solvent ratio) and 0.05M NH ₄ -EDTA (1:5, soil:solvent ratio)	Emission from smelters
Alloway and Davies (1971)	Extracted with 2.5% HAc (v:v)	Lead mining areas
Andersson and Nilsson (1972)	Extracted with 2M HCl at 100°C	Sludge-treated soil
Beavington (1975)	Extracted with 0.5N HAc, four-hour shaking	Emission from smelters
Berrow and Burrige (1977)	Extracted with 0.5M HAc, 0.05M EDTA, 1M NH ₄ OAc	Sludge-treated soil
Buchauer (1973)	Total Pb. Soil litter digested with 4:1 HNO ₃ +HClO ₄ , mineral soil boiled with HClO ₄ for two hours	Emission from smelters
Davies (1971)	Total Pb. Soil digested with hot concentrated HNO ₃ , then with hot aqua regia. Available Pb extracted with dilute HAc (5% w/v)	Effluent from mines (non-ferrous ores) and spoil heaps
Griffiths and Wadsworth (1977)	Total Pb. Soil digested with HNO ₃ +HClO ₄	Emission from smelters
John (1972)	Extracted after half-hour shaking with various solvents: 1N NH ₄ OAc, dilute HNO ₃ solutions (1N, 0.5N, 0.25N, 0.1N and 0.01N)	Lead added from soluble salts in pot experiments
Jordan and Hogan (1975)	Extracted by boiling with 0.6% (w/v) HCl. Extraction with concentrated HNO ₃ did not produce any significant difference in Pb content from that extracted by 0.6% HCl	Paints from old dwelling houses
Kerin (1975)	Extracted with 0.1N NH ₄ -lactate+0.4N HAc (pH 3.7)	Emission from smelters
Lagerwerff and Specht (1970)	Extracted after agitating the soil with 1N HCl for one hour	Highway contamination
MacLean <i>et al.</i> (1969)	Extractable Pb, (a) soil equilibrated overnight in 1N NH ₄ OAc then leached, (b) sample equilibrated overnight in 0.1M CaCl ₂	Highway contamination

Table 1 (continued)

Investigators	Extraction/Digestion	Source of lead
Roberts and Goodman (1974)	"Exchangeable" Pb determined by shaking overnight with 0.5N HAc	Emission from smelters
Scott and Thomas (1977)	Total Pb. Comparison of methods: (a) Na ₂ CO ₃ fusion, (b) HF+HClO ₄ digest and (c) HNO ₃ +H ₂ SO ₄ +HClO ₄ digest. Method (c) recommended	Lead added to carbon and silica based soils
Swaine and Mitchell (1960)	Extracted from 2.5% HAc, 1N NH ₄ OAc.	Uncontaminated soils
Ward <i>et al.</i> (1977)	Total Pb. Soil digested with 1:1 HNO ₃ +HF	Contamination from battery factory, smelter area and highway

In Britain, 0.5N acetic acid is widely used in the extraction of available lead. However, Roberts (1975) points out that a major disadvantage of this method is that the metal is extracted at below the normal soil pH, and the results therefore should be regarded as an estimate of maximum availability.

Table 2 Total and extractable lead in soils

Type and location	Lead extracted from soil ($\mu\text{g g}^{-1}$)				Ref.
	Total	HAc	EDTA	NH ₄ OAc	
Sandy loam England	30	0.7	4.3	<0.4	(12)
	25	0.6 ^a	9.5 ^a		(12)
Cultivated podzol Scotland	30	1.1	7 ^b		(68)
	50	1.6	12 ^b		(68)
	70	0.29			(92)
	20	0.24			(92)
Wales	140 ^a	1.3 ^a	41 ^{a,c}		(48)
England	20-150 ^d		5-41 ^{c,d}		(48)

^a Average of two samples

^b EDTA neutralized with NH₃

^c EDTA in NH₄Ac

^d 14 samples

A number of investigations show a good correlation between extractable soil lead using various methods and plant uptake of the metal. Extractants used in these studies have included 1N ammonium acetate (MacLean, Halstead and Finn 1969), and 0.1N ammonium lactate + 0.4N acetic acid (Kerin 1975). Mineral acids have also been used by some workers. John (1972), for instance, has shown a significant correlation between the lead content of soil extracted in 1N nitric acid and the amount of metal in lettuce plants grown in the soil.

To estimate the amount of organically-complexed lead a number of workers have used the chelating agent EDTA. Jones and Clement (1972) have pointed out that while EDTA extracts a considerable proportion of the total lead (Table 2), it is unlikely that all of it in the short term would be available for root uptake. As organic complexing agents are largely confined to the surface layers of the soil, the amount of lead extracted by EDTA from these layers will always be greater than from lower layers (Mitchell 1964).

Thus, it is seen that a number of different extraction methods are used for determining available soil lead. However, in general, the commonly accepted extractant is dilute acetic acid. An exception to this is the extraction of lead from soils rich in organic material, where the use of EDTA may be more appropriate.

3.2 Associations of lead in soil and plants

Lead accumulates in considerable amounts in contaminated soils. A general observation is that plants mostly survive, although growth can be affected. Inhibition of plant growth by lead has been reported by many investigators. For instance, Weiler (1938) reported lead-induced plant toxicity on acid moor soils; Bradshaw (1952) found that 50 per cent of tillers of *Agrostis-Festuca* were dead when grown in lead-contaminated soils; Warren, Delavault, Fletcher and Wilks (1970) observed that lead toxicity to corn, beans, lettuce and radishes was greater under acidic soil conditions. Recently, Tornabene *et al.* (1977) reviewed the literature on growth inhibition by lead, particularly the reduction of vital plant processes such as photosynthesis, mitosis and water absorption. The author of this report has also observed reduced plant growth and inhibition in photosynthesis of oat and mustard plants grown in an acidic brown earth soil (pH 5.6) treated with lead.

Table 3 Extraction from lead amended soils (John 1972)

Soil type and order	Location	Lead extracted from soil ($\mu\text{g g}^{-1}$)									
		Control soils		Soils incubated with 500 $\mu\text{g g}^{-1}$ Pb for 30 days at 25°C							
		1N HNO ₃	1N HNO ₃	0.5N HNO ₃	0.25N HNO ₃	0.1N HNO ₃	0.01N HNO ₃	1N NH ₄ Ac			
1. Glenmore silty clay, Solonchic soil	Okanagan valley, British Columbia	14	489	421	375	161	2	12			
2. Monroe silty loam, Regosolic soil	Fraser valley, British Columbia	7	482	500	511	343	8	82			
3. Benson silty loam, Gleysolic soil	Fraser valley, British Columbia	21	493	518	407	243	3	58			
4. Lulu muck, Organic soil	Fraser valley, British Columbia	13	429	364	161	18	4	34			

With regard to the effect of soil properties on plant uptake of lead, investigations carried out in different parts of the world have often produced controversial evidence. Ter Haar (1972) has critically reviewed the importance of environmental lead pollution. He investigated the effects of lead on several crops grown in greenhouses and near a busy U.S. highway (Table A-24), and found some increase in the lead content of certain plants, particularly in the non-edible parts, such as bean leaves, corn husks, chaff of oats, wheat and rice, which he attributed to airborne lead. Quoting examples from Dedolph, Ter Haar, Holtzman and Lucas (1970) and Motto, Daines, Chilko and Motto (1970), and in view of his own findings, Ter Haar concluded that the possibilities of airborne lead entering the food-chain have been overemphasized. He further cited the data of Marten and Hammond (1966), who showed that even an eightfold increase in the total lead content of soil did not measurably affect the concentration of lead in plants.

Grass is the crop most responsive to changes in airborne lead concentrations, and the data of Lagerwerff and Specht (1970) are typical of many examples that could be given to show high content of lead in the surface soil and the grasses near highways (Table A-14) (see also Lagerwerff 1972). Connor, Erdman, Sims and Ebens (1970) did not find increased lead levels in subsurface soils near highways. They emphasized that the major roadside significance of lead is its accumulation in plants.

In a survey of heavy metal pollution of soil and woodland vegetation around a smelting complex in the Avonmouth industrial area of England, Little and Martin (1972) reported very high levels of lead in surface soils and plant leaves. The leaves contained between 1,000 and 6,000 $\mu\text{g g}^{-1}$ lead of which 30–80 per cent was removed by washing. A similar observation was also made by Ward, Roberts and Brooks (1977a) who found very high concentrations of lead in surface soils and pasture herbage near a smelter region in New Zealand. In these studies, the effect of soil lead on the plant uptake of lead was not discussed. Emphasis was given to the aerial deposition of lead on plants.

On the other hand, several investigators have emphasized that soils can accumulate large amounts of lead from different sources of contamination. In general the accumulation has been found to occur in the 0–20 cm soil which is also the rooting zone for agricultural crops. Since lead is likely to migrate slowly down the profile, unless the surface soil is essentially sandy in character (Korte *et al.* 1976), the net effect should produce a reservoir of lead in contaminated surface soils.

Experimental evidence of the relationship between the content of lead in plants and the level of lead in contaminated soils has been shown by many investigators, (references 4, 28, 44, 52, 62, 89, 99 and others). Based on greenhouse studies, MacLean, Halstead and Finn (1969) demonstrated the influence of cation exchange capacity of soil, organic matter content, phosphate and lime status on the availability of soil lead to plants. John (1972) also carried out controlled environment experiments using different soil types from Canada and New Zealand and found that the lead content of plants was related to such similar soil properties.

In reviewing the uptake of lead by plants Zimdahl and Koeppe (1977) discussed results of several investigations carried out at Colorado State University, the University of Illinois and the University of Missouri, which showed that the level of lead in plants is affected by changes in soil properties.

There are several major lead mining districts in Britain where pollution problems were reported last century. Studies of such mining areas, carried out by Alloway and Davies (1971), showed that high concentrations of lead and other associated metals in the soil markedly increased the plant uptake of metal ions. Thornton (1975) has emphasized a different aspect of soil pollution and reported the death of cattle grazing on contaminated land. According to Thornton, recent work in Britain and New Zealand has shown that grazing livestock can, under certain conditions, involuntarily ingest appreciable quantities of soil. He further estimated that soil ingestion led to a daily intake by cattle of 140–1,400 g soil per day. Under these conditions cattle may possibly ingest up to 10 times more lead and copper in the form of soil than that taken in with herbage.

To measure the differential transport of lead to the roots and shoots, Jones and Clement (1972) investigated the effect of soil lead on ryegrasses grown in 16 agricultural soils of England and Wales under controlled environment conditions. Their results showed that when extractable lead in the soil increased from 5 to 59 $\mu\text{g g}^{-1}$, the lead content of plants increased four times in the root and one and a half times in the shoot (Table A-29). The experiment continued in solution culture confirmed that roots provide a barrier which restricts the movement of lead from soil through the plant to ruminant animals.

Rabinowitz (1972) investigating the uptake of lead by lettuce and oats used an isotope technique to distinguish lead coming from the soil and from the air. The results showed that in plant tops of both species the

contribution to the lead content from soil lead was approximately proportional to the soil lead level. There were also important contributions from airborne lead, particularly in oats grown near roadways. When the diffuse network of roots of both species was analysed it was found that lead concentration approximately equalled that of the soil (Table A-30).

In reviewing the problem of trace metal contamination of soils, Purves (1972) stated that urban soils in Scotland contain, in terms of available content, more than five times as much copper, 17 times as much lead and 18 times as much zinc as rural soils. Giving examples from other investigations, the same author expressed concern for contamination of soils from lead and other associated trace metals, the effect of such contamination on the composition of plants grown for food, and possible consequences to health.

The experimental evidence considered in this report seems to suggest that the lead accumulating in contaminated soils increases the plant uptake of the metal, particularly in the root system. This uptake of lead can be increased under certain soil conditions, such as those having low pH, low cation exchange capacity, low organic matter content and low phosphate levels (Boggess 1977). Zimdahl and Koeppel (1977) suggested that lead is inactivated through deposition in the roots, for instance, in the form of lead phosphate deposits as shown by electron microscope studies. Additional studies are needed to determine whether the rising levels of lead in the soil and plant roots may produce any adverse effect on human health via plant intake.

3.3 Results of uptake experiments

The physiology of metal ion uptake has been studied by plant scientists for many years (Höll and Hampp 1975). With regard to lead, the mechanism of ion release in the soluble and colloidal phases in the soil system and its transport across the soil-root interface are still not well understood. According to Ter Haar (1972) many factors influence the release of lead from soil to crops. These include inorganic and organic colloidal constituents of the soil, cation exchange capacity, pH, concentration of lead and its form in the soil, and other undefined variables. Figure 2 shows pathways of lead from the soil to root surfaces.

The transfer of lead from soil to plant can be expressed as the plant-soil concentration ratio. Some typical examples are given in Table 4. The interpretation of field data can be complicated by a number of factors,

especially the deposition of aerial lead on plant surfaces (Hemphill and Rule 1975, Rabinowitz 1972). The deposition of lead as particulate matter onto the leaf surfaces and its retention depend on the particle size, chemical form of lead and also the nature of the leaf surface and the period of contact. The sampling of plant organs at unspecified growth stages can render somewhat uncertain the correlation of the lead content of vegetation with that of soil (Mitchell and Reith 1966, Wilkins 1978); other complications include the variations in the methods used in the determination of lead in soils and the sampling depth. Usually the total lead content in soil is specified, but in some cases the extractable lead content is given. These factors partly explain the amount of variation in the ratios of lead content in Table 4.

Table 4 Relationship of lead content in soil and plants

Experimental conditions	Plant	Concentration ($\mu\text{g g}^{-1}$)		Plant-soil ratio
		Soil	Plant	
<i>(a) Field studies in contaminated soils</i>				
1. Roadside, U.S.A. 7,500-48,000 cars per day (57)	Grass	225	29	0.1
2. Roadside, New Zealand 5,200 cars per day (103)	Mixed pasture herbage	817	203	0.2
3. Mining and smelters, Midlands, U.K. (96)	Pasture harvested in March	3,320	121	0.04
	in August		25	0.008
4. Smelter area, Yugoslavia (53)	Lettuce	1,438	5.9	0.004
	Radish stems		5.6	0.004
	Radish leaves		6.7	0.005
5. Sludge-treated land, Sweden (5)	Rape (fodder)	44	7.7	0.2
6. Sludge-treated land, U.K. (83)	Lettuce	297	38	0.1
	Other crops		4.3	0.01
<i>(b) Controlled environment studies</i>				
1. Growth chamber; 16 agricultural soils from England and Wales; soils extracted with EDTA in NH_4Ac (48)	Rye-grass roots	5.3	10	1.9
		6.9	12	1.8
	Rye-grass shoots	41	37	0.9
		59	38	0.6
		5.3	5.1	1.0
		6.9	5.2	0.8
		41	6.0	0.1
		59	7.4	0.1

Table 4 (continued)

Experimental conditions	Plant	Concentration ($\mu\text{g g}^{-1}$)		Plant-soil ratio	
		Soil	Plant		
2. Growth chamber; 29 soils from Canada and New Zealand with added Pb; soils extracted with 1N HNO ₃ (45)	Lettuce	484	54	0.1	
	Oats				
	roots	484	57	0.1	
3. Greenhouse and samples near California roadway; total Pb in soil (see Table A-30) (81)	Lettuce				
		roots	97	71	0.7
			280	132	0.5
			650	504	0.8
	Oats		1,300	1,311	1.0
		roots	97	92	0.9
			280	280	1.0
			650	535	0.8
			1,300	1,234	0.9
					0.2
4. Greenhouse; filtered air with $0.09 \mu\text{g m}^{-3}$ total Pb in soil (see Table A-24a) (94)	Lettuce	17	3.2	0.2	
	Cabbage				
	leaves	17	5.8	0.3	
	Bean				
	leaves	17	7.9	0.5	
	Beans	17	1.2	0.07	
Tomatoes	17	0.7	0.04		
Carrots	17	2.1	0.1		
<i>(c) Field studies in uncontaminated soils</i>					
1. Remote site in Scotland; total Pb in soil; averaged data (68)	Pasture herbage	spring-summer	30	1.9	0.06
			50	1.9	0.04
	autumn	30	15.5	0.5	
		50	4.0	0.08	
	winter-spring	30	21.8	0.7	
		50	28.9	0.6	
2. Agricultural soil in New Jersey; total Pb in soil; averaged data (79)	Corn leaves	44	16	0.4	

Generally, a low ratio is found in areas contaminated by emissions from smelters and from mining operations seen in Table 4a (also Allcroft and Blaxter 1950). Soil as an accumulating reservoir can readily acquire very high levels of pollutants but plant uptake may be restricted by the genetic

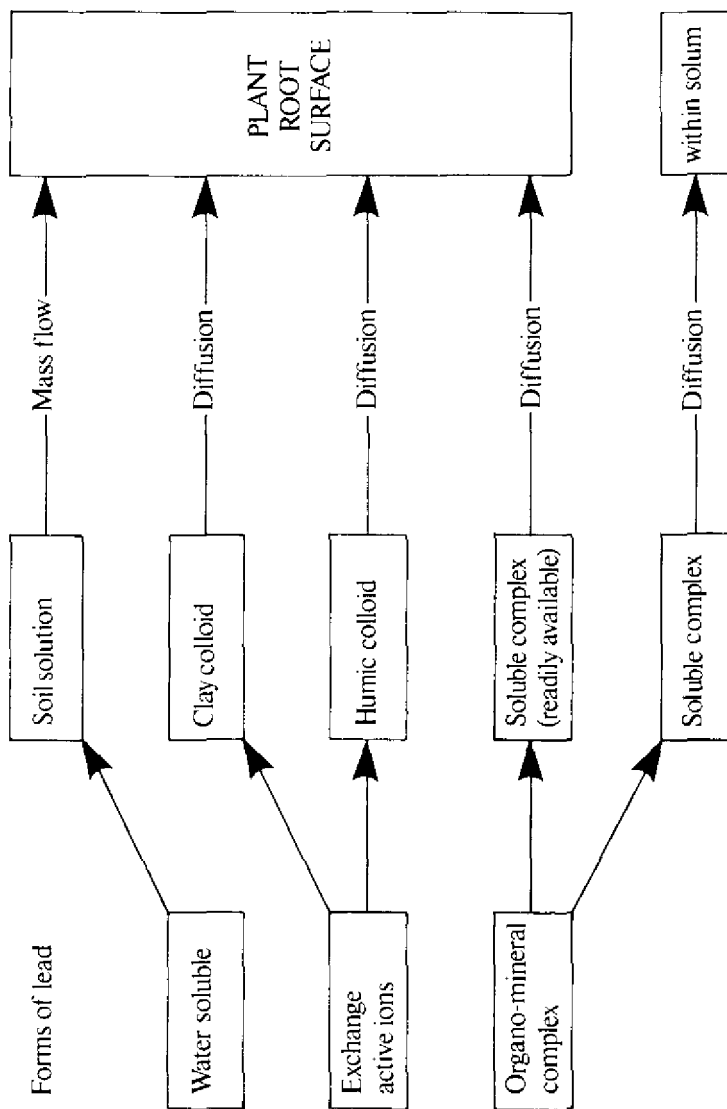


Figure 2 Pathways of lead from soil to plant (adapted from Berrow and Burridge 1977)

limit of tolerance (see discussion on lead tolerance of plants by Höll and Hampp 1975).

Certain limitations imposed in field studies of a pollutant transfer from soil to plant can be overcome in controlled environment experiments (Table 4b). The main point to be noted is the appreciably higher uptake of soil lead by plant organs, especially the root system, from agricultural soils (Jones and Clement 1972). Rabinowitz (1972) found lead concentrations in the roots of lettuce and oats approximately equal to those in soils in which they grew (lead nitrate was added to raise the soil lead levels). In Ter Haar's (1972) experiment, however, in which the soil lead was comprised of the native lead compounds, appreciable amounts of lead were found only in leafy plants or leafy organs (Table 4b, section 4, experiment with unfiltered air, Table A-24a).

Examples of lead transfer to plants in areas apparently uncontaminated or remote from any sources of industrial contamination are given in Table 4c. It is interesting to note that during the dormant period of growth the rye-grasses showed a higher plant-soil ratio, this possibly being due to the transfer of lead from roots to shoots with stunted growth (Mitchell and Reith 1966).

To assess the level of pollution in different plant species and soil types, the plant-soil ratio must be considered along with the absolute concentrations of pollutants in the materials involved. For instance, the ratio for the March harvest of pastures from contaminated areas in the Midlands, U.K., was only 0.04 (Table 4a), but the average lead concentration of herbage was $121 \mu\text{g g}^{-1}$ ranging from 53 to $288 \mu\text{g g}^{-1}$ (Thornton 1975). Such levels may be dangerous for grazing animals. According to Allcroft and Blaxter (1950), both non-pregnant sheep and cattle can survive a daily intake of up to 5 mg of lead per kg of body weight, i.e. the limit of tolerance is up to about $160 \mu\text{g g}^{-1}$ lead in the diet (assuming a 300 kg steer consumes 9 kg of dry matter per day). For pregnant ewes, a concentration as low as $30 \mu\text{g g}^{-1}$ in the diet could prove toxic.

It appears that because of the immobility of lead in the soil, the plant-soil ratio is in most cases very low; these low values are also partly attributable to the accumulation of lead in the root system. Because of unequal concentrations within the plant, it is questionable to use a single value of the plant-soil ratio as an indicator of the pollution of the soil-plant system unless sufficient data are available to define the transport from soil to root to shoot.

A typical example of the translocation of lead from soil to plant organs

in a grassland situation may be cited from the work of Jones and Clement (1972), who investigated the levels of extractable lead in some British soils and the amount taken up by the roots and shoots of rye-grasses (Table A-29). It appears that the concentration of lead in roots was nearly equal to or about two times more than that in the soils studied. If, however, the total content of lead in the plough layer soil is taken into account on a hectare basis and the lead content of grass roots considered on the basis of uptake per hectare, the proportion of the lead in the soil entering the grass roots would amount to less than 0.1 per cent of the total lead. In discussing the uptake of lead by plants in general, Boggess (1977) has made an observation that there seems to be about a tenfold reduction from roots to foliage and a like reduction from foliage to fruit. Thus, if $100 \mu\text{g g}^{-1}$ of lead was taken up by the roots, the grain would contain about $1 \mu\text{g g}^{-1}$.

4 Distribution of lead in soil

4.1 Background levels

The average concentration of lead in the earth's lithosphere is about $16 \mu\text{g g}^{-1}$ (Swaine 1955). The level of lead in uncontaminated soils is dependent on the parent materials, the degree of weathering and the organic matter content. The distribution of lead in such soils would therefore vary in different geographical regions. Lisk (1972) suggests $10 \mu\text{g g}^{-1}$ as an average lead level in soils. The background levels of lead in the surface and subsoil layers of different regions are summarized in Table 5 and given in more detail in Tables A-8 to A-13.

In the U.S.A. the total lead content of soil has been reported to range between $10\text{--}700 \mu\text{g g}^{-1}$ (Lisk 1972), the upper limit evidently indicating a highly polluted soil. Connor, Shimp and Tedrow (1957) found a range of lead content of $6\text{--}155 \mu\text{g g}^{-1}$ with an average $73 \mu\text{g g}^{-1}$ in the surface horizon of a number of American podzols and podzolic soils (Table A-9). The lead content of agricultural soils of England and Wales has been reported to range between 5 and $1,200 \mu\text{g g}^{-1}$ with a mean of $57 \mu\text{g g}^{-1}$ (Archer 1977). A range of $20\text{--}114 \mu\text{g g}^{-1}$, with an average of $53 \mu\text{g g}^{-1}$, was found for lead in the topsoil of some tropical soils (Table A-12).

Analyses of 441 agricultural surface soils collected throughout British Columbia showed an average lead concentration of $10 \mu\text{g g}^{-1}$ (John 1975). In an examination of the distribution of lead with depths, Mills and

Table 5 Background level of lead in surface and subsoil layers of soil

Soil type and location	Reference	Main soil horizons (depth in cm)	Concentration ($\mu\text{g g}^{-1}$)
Brown podzolic soil, Leslie series, Scotland	Table A-10, Soil No. 1 (92)	S* (5-18)	20
		B ₂ (46-56)	10
		C (97-109)	10
Podzol soil, Strichen series, Scotland	Table A-10, Soil No. 7 (92)	S* (0-18)	80
		B ₂ (61-69)	30
		C (102-109)	70
Non-calcareous gley (g) soil, Ettrick series, Scotland	Table A-10, Soil No. 7 (92)	A ₁ (g) (5-13)	40
		A ₂ (g) (13-23)	15
		B ₂ (g) (41-51)	20
		C (g) (91-107)	15
Brown earth, Charity series, England	Table A-8, Soil No. 1 (59)	A (0-8)	48
		B (71-76)	24
Podzol soil, Armadale series, Canada	Table A-11, Soil No. 1 (b) (111)	A ₀ (0-5)	28
		A ₂ (0-13)	6
		B ₂ (18-33)	9
		C (64+)	10
Grey-brown podzolic soil, Guelph series, Canada	Table A-11, Soil No. 3 (a) (111)	A ₁ (0-10)	33
		A ₂ (20-46)	26
		B ₂ (46-61)	30
		C (69+)	22
Podzol soil (Wisconsin drift), U.S.A.	Table A-9, Soil No. 1 (32)	A	8
		B	24
		C	22
Grey-brown podzolic soil (Kansan drift), U.S.A.	Table A-9, Soil No. 6 (31)	A	30
		B	101
		C	116
Ferrallitic red soil (Sol rouge ferrallitique) sur embréchite), Cameroun	Table A-12, Soil No. 1 (72)	B ₂ (0-60)	45
		B ₂ (60-200)	19
		B ₂ Fe (200-430)	74
		BC (430-550)	4
		C (550-600)	5
Planosol with degraded solonetz-solod structure (Sol sodique à structure dégradée-solonetz solodise), Cameroun	Table A-12, Soil No. 4 (72)	(0-10)	35
		(20-30)	42
		(70-90)	6
		(90-120)	4

Table 5 (continued)

Soil type and location	Reference	Main soil horizons (depth in cm)	Concentration ($\mu\text{g g}^{-1}$)
Soil profiles from Schwarzach valley, Bavaria, Germany	Data averaged from several profiles on granite and gneiss rocks (70)	Surface horizon	45
		Subsoil horizon	30
		C-horizon	31
		Rock	27

* cultivated layer

Zwarich (1975) found concentrations in a number of Canadian soil profiles from Manitoba ranging from 7–23 $\mu\text{g g}^{-1}$ with an average of 17 $\mu\text{g g}^{-1}$ in the A horizons (surface) and 10–23 $\mu\text{g g}^{-1}$ with an average of 19 $\mu\text{g g}^{-1}$ in the C horizons (parent material). The surface samples of cultivated and non-cultivated soils did not, however, show any difference in the lead content. The investigators consider this to be due to the minimal use of metal-containing agricultural chemicals in the region of Manitoba.

In Scotland, Swaine and Mitchell (1960) found that the surface horizons of most soils are higher in lead than in the lower horizons (Table A-10), this increase being attributed to accumulation through plant residues. There may also be a possibility of contamination from motor traffic or industrial activity from long-range transport and deposition even in these remote areas. One uncultivated Scottish soil which contained 20–30 $\mu\text{g g}^{-1}$ lead in the lower horizons had a total lead content as high as 550 $\mu\text{g g}^{-1}$ in the surface (A_1) horizon.

Data on the distribution of lead in the different soil particle size fractions are few. Investigating some brown earth soils in England, Le Riche and Weir (1963) found that 14–20 per cent of the total lead was present in the clay fraction, 10–20 per cent in the silt fraction and 8–28 per cent in the sand fraction (Table A-8). The concentration in the clay fraction represents the lead bound with both layer silicates and dispersed organic matter. A study of some American grey-brown podzolic soils showed enrichment of lead and other associated trace metals in the clay fraction (Table A-9).

4.2 Levels in contaminated soil

The contamination of soil by lead has been reported by many investigators from different parts of the world. Such studies, however, have been in most cases based on complaints of lead poisoning or of possible hazards arising from contamination. Some typical examples of the contamination of soil by lead are:

- a) roadside accumulation from the combustion of gasoline (references 36, 57, 64, 94, 102, 103, 105, 112)
- b) emissions from smelters (references 1, 10, 23, 25, 30, 44, 53, 61, 103)
- c) contamination in mining areas (references 4, 30, 47, 52, 91, 96)
- d) sewage sludge disposal (references 5, 41, 54, 58, 77, 80, 107).

Since lead is considered to be one of the most immobile elements in soils, it is particularly important to investigate what happens to the metal entering the soil environment through the surface layer. There is a shortage of data on the distribution of the different forms of lead in soil profiles. Some data on the distribution of lead in the surface and subsurface layers of soils contaminated from different sources are reported in Tables A-14 to A-21 and summarized in Table 6. If the background level of total lead in soils is taken to be in the range of 15–25 $\mu\text{g g}^{-1}$ (Aubert and Pinta 1977), it appears that the contamination of surface soils can produce approximately sixfold (e.g. woodland soils of Mississippi) to six-thousandfold (e.g. smelter area soils of New Zealand) increases in the level of lead.

4.3 Distribution with depth

Profile data are available showing the variation in the background level of lead in some soils, but this information is mostly concerned with total lead content, rather than differentiating between the different forms of lead (Tables A-8 to A-13). The usefulness of such data is further limited by the wide margin of experimental error involved in the semi-quantitative estimation of often very small amounts of lead. Therefore, at least a twofold difference in the data would be required in order to indicate a significant difference in the vertical distribution of the metal in soils.

The translocation of lead is not a simple mechanical process as there are a number of factors which determine the mobility of lead ions in the complex soil environment. In the podzolization process, clay and

Table 6 Lead content of soils contaminated from different sources

Location and source of contamination	Reference to Appendix Table (and site number)	Depth (cm)	Concentration ($\mu\text{g g}^{-1}$)
U.S. highway, Maryland (57)	Table A-14 (site 1, 8 m from road)	0-5	522
		5-10	460
		10-15	416
Smelting complex of Avonmouth area, Severnside, U.K. (61)	Table A-16	0-3	126
		3-6	27
		6-9	10
Smelting region, Northern Yugoslavia (53)	Table A-22	1-8	55-4,644
Industrial region of Auckland city, New Zealand (103)	Table A-23		Highest levels (5,000-9,000)
Battery factory area	(sites 1-5)	0-5	1,600-31,000
Smelter area	(sites 8-13)	0-5	1,100-126,000
Roadside area	(sites 17-22)	0-5	500-1,100
Sludge-treated area, U.K. (83)	Table A-20	0-7.5	183
		7.5-15	161
		15-30	113
Near battery smelter, Minnesota, U.S.A. (64)	Table A-17	2.5	680
		15	95
Woodland soils from Mississippi valley mining district, U.S.A. (52)	Table A-19 (mineralized area)	A horizon	124
		B horizon	67
		C horizon	117
Lead paint contamination from old wooden houses in Christchurch, New Zealand (50)	Table A-21	0-10	400-7,500
		10-20	50-4,000
		20-30	20-1,200
		30-40	20-400

sesquioxides move downwards and may carry with them the lead ions held in adsorbed (clay and sesquioxides) or in co-precipitated (sesquioxides) forms. Results of a study by Le Riche and Weir (1963) show an increased level of lead in clay-sized particles in the B horizon, when compared with the total lead of the soil. Organic acids produced from the decay of soil organic matter in the upper layer of podzolic soils can also be effective in mobilizing metal ions (Bolter and Butz 1975).

It is known that soil organic matter acts as a sink for heavy metals, and this is substantiated by the reported accumulation of lead in the top layer of soils, especially those rich in organic material (references 24, 59, 72,

93, 111). Wright, Levick and Atkins (1955) have observed lead enrichment in the A₀ horizon of some Canadian podzol and brown podzolic soils, and considered that the organic matter largely contributed to this accumulation.

In contaminated soils the concentration of lead is frequently reported for the surface layer, and in some cases to a depth corresponding to the rooting zone. The high accumulation of lead occurs in the top layer mainly because the pollutant lead enters the soil environment through the soil surface. Secondly, the accumulation occurs also through the deposition of plant residues. It has been noted that in a number of contaminated areas the concentrations of lead at a depth of 15–20 cm below the soil surface closely approach the background levels (Lagerwerff and Specht 1970, Rolfe and Jennett 1973 and others).

There is some experimental evidence concerning the movement of lead in soils. Tso (1970) has found that limited amounts of ²¹⁰Pb were removed from soils by leaching with water. In discussing observations from soil column studies, Zimdahl and Hassett (1977) stated that leaching with deionized water removed between 1.6 and 6.2 per cent of the total lead in the soil. These authors quoted further results from field studies in Illinois and stated that after six years of lead addition to the plough layer of a Drummer silt loam soil the movement of lead was detected to a depth of 46–91 cm.

4.4 Soil properties affecting the distribution of lead

There is little information on the interactions of lead with the chemical and physical constituents of soil. However, a study by MacLean *et al.* (1969) has shown that soil type, cation exchange capacity, organic carbon content and phosphate level can all affect the availability of soil lead for plant uptake. Recent studies at Colorado State University and at the University of Illinois have shown that lead in the soil varies depending on these soil properties (Zimdahl and Hassett 1977).

Swaine and Mitchell (1960), examining over 100 Scottish soil profiles, found that conditions of restricted drainage caused a marked increase in the mobilization of the extractable trace metals such as lead, copper, vanadium and nickel. In a recent study involving approximately 250 soil profiles, Bradley, Rudeforth and Wilkins (1978) found a positive relationship between lead content and soil wetness. It has been demonstrated that iron, cobalt, nickel, zinc, lead, vanadium and molybdenum are

mobilized when soils are flooded and incubated anaerobically with plant material (Kee and Bloomfield 1962). Recently Bloomfield and Pruden (1975) have shown that the anaerobic incubation of metal-contaminated sewage sludge increased the release of extractable lead. These observations indicate that gleying is likely to increase trace metal uptake by plants grown in soils with impeded drainage.

The chemistry of trace metals in water-logged soils is poorly understood. Information available on copper and zinc suggests that the equilibria of trace metals in flooded soils are sometimes dependent on the stability of other solid phases which are sensitive to impeded drainage conditions (Beckwith, Tiller and Suwadhi 1975). These investigators stated that the trace metals are released due to the breakdown of iron oxide minerals (release of copper and zinc) and manganese minerals (release of cobalt), and it is possible that this breakdown also leads to the release of trace metals such as lead which may be co-precipitated with sesquioxides.

The effect of soil pH on the extractability of trace metals has been examined by a number of investigators. Bloomfield and Pruden (1975) observed that liming decreased water soluble lead but increased exchangeable lead (extractable in acetic acid and EDTA). This may be partly explained by observations of Randhawa and Broadbent (1965), who studied organo-metallic complex formation, and stated that in such a complex the metal may be considered an electron acceptor and the complexing agent an electron donor. According to Randhawa and Broadbent (1965), complexing agents have considerable affinity for hydrogen ions as well as for metal ions. Hydrogen ions compete with the metal ion for complexing sites, so that a decrease in pH results in a reduction in the amount of metal complexed.

In laboratory experiments Zunino, Peirano, Aguilera and Schalscha (1975) observed that organic matter extracted from the soil is obtained in the form of negatively charged polymeric materials whose functional groups are $-COOH$ and the phenolic and alcoholic OH groups. Due to this chemical configuration it is possible that extracted soil organic matter when mixed with metallic solutions will form metallic complexes, having the organic molecule as the central group co-ordinated with one or more metal ions (Clark and Turner 1969).

MacLean *et al.* (1969) have suggested that humic compounds in the soil organic matter may complex with divalent metal ions and hence reduce the plant availability of lead. They cite observations by Schnitzer and

Hoffman (1967) showing that the quantity of lead complexed per unit of fulvic acid was relatively high compared with that of several other metals. Bolter and Butz (1975) have also shown that complexing of lead, copper, zinc and cadmium increased with increasing concentration of natural water-soluble organic acids.

Two additional soil properties could be cited affecting the forms of lead in soil. Zimdahl and Hassett (1977) have cited the work of Nriagu (1972, 1973a, 1973b) concerning the role of indigenous soil phosphate as a potential buffer for lead. Using pure clay systems Bittell and Miller (1974) measured the selectivity coefficients of Pb^{++} , Cd^{++} and Ca^{++} and found that Pb^{++} was preferentially adsorbed over Ca^{++} , whereas the exchange of Cd^{++} for Ca^{++} had a selectivity coefficient near unity.

5 Accumulation in soil

Typical examples of land subjected to differing sources of lead pollution are considered here to assess the degree of accumulation of lead in the soil environment. The areas considered include rural areas away from sources, urban roadsides, sites subjected to the deposition of smelter emissions, land used for the disposal of sewage sludge and contaminated forest regions.

5.1 Rural land

Although removed from local sources, the soil in rural, unpolluted regions accumulates lead from deposition of the widely dispersed pollution from general sources. A minimal deposition rate of lead in such regions can be taken as $1.7 \mu\text{g cm}^{-2} \text{y}^{-1}$ or $0.17 \text{ kg ha}^{-1} \text{y}^{-1}$ (Cawse 1977). This is equivalent to an annual deposition of approximately 2,000 tonnes of lead to the British soil area under pastures and meadows, and of approximately 44,000 tonnes of lead deposited to similar land in the U.S.A. (estimated from FAO Production Yearbook 1970, Vol. 24).

Although lead is one of the least mobile elements, small amounts of lead are continuously being leached through soil profiles. For instance, Korte, *et al.* (1976) found considerable mobility of lead in a loamy sand soil of North Carolina. Fuller, Korte, Niebla and Alesii (1976) have shown under laboratory controlled conditions that the lead is mobilized in a number of soils when leached with a solution of $AlCl_3$ and $FeCl_2$ at pH3.

Residence times of lead in soil, however, are estimated to be of the order of several hundred years. Therefore, the trend in soils subjected to increasing inputs is to increase the accumulation of lead. Wilkins (1978) has shown that the level of lead is continuously rising in soils with an increase of 17–46 per cent over a period of about 100 years, equivalent to an increase of between 3 and 20 kg ha⁻¹ (Williams 1974). Cawse (1974), taking into account the removal by crops, has also shown a gradual accumulation of lead in the soil.

In reviewing the biological effects of lead emissions, Roberts (1975) considered that soils in general must be accumulating lead at a slow rate, and this is substantiated by the fact that the lead content of Swedish mosses has increased from 25 µg g⁻¹ in the 19th century to the present level of 75 µg g⁻¹ (Ruhling and Tyler 1969). In discussing the change in composition of lead aerosols in Arctic regions with time (data cited from Murozumi, Chow and Patterson 1969), Elias, Hirao and Patterson (1975) reported that the Pb/(K + Ca) ratio in snow dusts increased from 0.0001 in 800 B.C. to 0.05 in 1965, indicating a five-hundredfold increase in the concentration of lead in the dusts. Such large increases are considered to be due to the onset of the industrial revolution of 1750 and the use of leaded fuels after 1925.

5.2 Roadside land

Areas located near highways accumulate lead in two ways—solid particles deposited on the roadway and then washed onto the nearby soil, and dispersed particles in the air deposited directly on plants and soil. Examples of roadside contamination of soils have been reported in many publications. Typical levels of lead in surface soil are 150–540 µg g⁻¹ (Lagerwerff and Specht 1970) and 500–1,100 µg g⁻¹ (Ward *et al.* 1977a). There is obvious dependence on the amount of traffic and distance from the road.

Rolfe and Jennett (1973) carried out a detailed investigation of the input, accumulation and output of lead in a typical mid-western ecosystem in Illinois. The site comprised 220 km² of land exposed mainly to contamination from automobile sources. The 30 km² urban area received annually about 75 per cent of the total lead input and the 190 km² rural area received only 25 per cent of the total input. The total deposition of lead was estimated to be 6.5 kg ha⁻¹ y⁻¹ in the urban area and 0.4 kg ha⁻¹ y⁻¹ in the rural area.

The surface drainage discharge of the lead amounted to $0.2 \text{ kg ha}^{-1} \text{ y}^{-1}$ from the urban area and $0.01 \text{ kg ha}^{-1} \text{ y}^{-1}$ from the rural area (Rolfe and Jennett 1973). This corresponds to about two per cent of the total input to each area, indicating considerable accumulation of the lead in roadside and rural soils.

5.3 Land near smelters

The deposition to soil of lead from smelters is obviously quite variable. Rolfe and Jennett (1973) quote values as high as $240 \text{ kg ha}^{-1} \text{ y}^{-1}$, dropping to $6 \text{ kg ha}^{-1} \text{ y}^{-1}$ at a distance 5 km from a smelter. Relatively high levels of lead in soil can accumulate, for instance up to a maximum of $1,930 \mu\text{g g}^{-1}$ in south-east Missouri (Rolfe and Jennett 1973), $9,000 \mu\text{g g}^{-1}$ in Yugoslavia (Kerin 1975), $1,173 \mu\text{g g}^{-1}$ in north Humberside, U.K. (Adamson 1977) and $126,000 \mu\text{g g}^{-1}$ in New Zealand (Ward *et al.* 1977a).

Vegetation near smelters may accumulate lead to several times background. Most of this is surface contamination (Rolfe and Jennett 1973). Leaf litter has been shown to have a strong ability to retain lead. As much as 94 per cent of lead in surface soil near a smelter has been associated with leaf litter (Rolfe and Jennett 1973).

5.4 Land receiving sewage sludge treatment

Arable lands in industrial countries are being increasingly used for disposal of sewage sludge. In the U.K., about 45 per cent of the sludge produced annually is utilized in agriculture (Davis and Coker 1979). Richardson (1977) reported an increase from 60 to $245 \mu\text{g g}^{-1}$ of lead in the soil (0–15 cm) which received sludge application over a period of 75 years, an annual increase of about 4 kg ha^{-1} . A similar observation was made by Andersson and Nilsson (1972) who showed an increase of $18 \mu\text{g g}^{-1}$ of lead in Swedish soil (0–20 cm) treated with sludge for 12 years, an annual increase of 3 kg ha^{-1} . A very high accumulation of lead in soil (0–30 cm) was found by Kirkham (1975), with an annual increment of 81 kg ha^{-1} over a treatment period of 35 years.

In all these investigations, the lead content of plants showed only a small increase, suggesting that the lead in sludge is held mostly in the form of organic complexes not readily available to plants.

5.5 Deciduous forest environment

The distribution and cycling of lead in a mixed deciduous forest in eastern Tennessee has been investigated in detail (Van Hook, Harris and Henderson 1977, Wiersma 1979). Deposition to the forest area was estimated to be of the order of $0.3 \text{ kg ha}^{-1} \text{ y}^{-1}$. Leaf surface area of the forest overstorey is an effective filter for lead particles, accounting for a large part of the initial deposition (Wiersma 1979). Leaf litter retains a large part of the accumulated lead (Van Hook *et al.* 1977).

In estimating the residence time of lead in the surface organic matter of a forest in south-east Sweden, Tyler (1978) leached an organic mor horizon with a solution simulating rain-water of pH 4.2 and showed that it would take more than 200 years to decrease the lead content by 10 per cent in the contaminated organic matter. It may be pointed out that the leaching of an organic horizon consisting of decomposed leaf litter would release organic acids, which could be instrumental in solubilizing the metal ions in the form of organo-metallic complexes (Bolter and Butz 1975). Trace metals released in this process will migrate to the surface and subsoil horizons, react with clays and sesquioxides, and partly be taken up by micro-organisms and higher plants.

6 Summary and conclusions

1. A survey of the available literature on the distribution of lead in an uncontaminated surface soil indicates the baseline levels in a number of different geographical areas are in the region of $48\text{--}160 \mu\text{g g}^{-1}$ in England, $20\text{--}80 \mu\text{g g}^{-1}$ in Scotland, $6\text{--}155 \mu\text{g g}^{-1}$ in the U.S.A., $21\text{--}108 \mu\text{g g}^{-1}$ in Canada and $20\text{--}114 \mu\text{g g}^{-1}$ in some tropical soils from Cameroun. The lead content of some agricultural soils of England and Wales was found to vary quite widely, the mean being $57 \mu\text{g g}^{-1}$.

2. Lead can exist either in a water-soluble ionic or molecular form, in an exchangeable form, complexed with organic matter, or as insoluble compounds including sulphate, carbonate, oxide and those co-precipitated with sesquioxides. Lead compounds identified in roadside soils include PbSO_4 , PbO and PbS associated with some $\text{PbO}\cdot\text{PbSO}_4$ and PbO_2 .

3. Knowledge of the chemical and physical forms of lead in the soil colloidal system (layer silicates, sesquioxides and humic matter), particularly in contaminated areas, is very limited. However, there is some evidence that certain soil properties affect the distribution of lead in the

soil. Such properties are pH, organic matter content, cation exchange capacity, phosphate level and the amount of clay in the soil.

4. The concentration of lead in soil in general is increasing, even in some areas remote from industrial sources of contamination. Only in areas located close to the source of the metal emissions does lead become a health hazard. Because of the general immobility of lead, the metal accumulates in surface soils, the rate of accumulation depending on the nature of the contamination and the organic matter status of the soil. Experimental evidences suggest that lead moves downward with time. Six years after lead addition to the plough layer of a soil in Illinois, the movement was detected to a depth of 46–91 cm.

5. Roadside contamination from automobile emissions considerably increases the level of lead in the soil, for example $150\text{--}540\ \mu\text{g g}^{-1}$ of total lead is reported in some soils of the U.S.A., $500\text{--}1,100\ \mu\text{g g}^{-1}$ of total lead in New Zealand and up to $126\ \mu\text{g g}^{-1}$ of acetic acid-extractable lead in England. Soils in smelter regions contain very high amounts of lead, for example up to a maximum of $1,173\ \mu\text{g g}^{-1}$ of total lead is reported in some soils of England, $1,930\ \mu\text{g g}^{-1}$ in south-east Missouri, $9,000\ \mu\text{g g}^{-1}$ in Yugoslavia and $126,000\ \mu\text{g g}^{-1}$ in New Zealand. Soils in the Midlands, U.K., contaminated with lead from old mines and smelter operations, contained up to $72,000\ \mu\text{g g}^{-1}$ of total lead.

6. Increased lead level in soil results in an increased uptake by plants, this lead being largely concentrated in the root system. The general observation is that plants mostly survive in lead contaminated soils although growth can be affected. In a grassland situation the proportion of the lead in the soil entering the root system would amount to less than 0.1 per cent of the total lead. Studies of the uptake of lead by plants in general seem to suggest a tenfold reduction from roots to foliage and a like reduction from foliage to fruit.

7. The lead content of grasses from roadside areas was found to be very high in some investigations, for example up to $68\ \mu\text{g g}^{-1}$ (washed samples) in the U.S.A., $203\ \mu\text{g g}^{-1}$ (accounting for 31 per cent of the lead being washable) in New Zealand. In the Midlands, grasses grown in areas contaminated with lead from old mines and smelter operations contained up to $288\ \mu\text{g g}^{-1}$ of lead, thus posing a health hazard to grazing cattle. These observations are considered to be exceptional rather than general.

8. The residence time of lead in soil is quite long, of the order of several hundred years, dependent on the nature of the contamination, the soil characteristics and other factors. The present problem of lead

contamination of soils will remain for a considerable period of time, and there is a need to monitor the level of lead in soils and plants in contaminated areas.

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Glossary of soil science terms*

A₀ horizon: Organic horizon lying above the mineral soil. Presently known as O horizon with subdivisions O₁ and O₂. They result from litter derived from dead plants and animals. Occurring commonly in forested areas, they are generally absent in grassland.

A horizon: A mineral soil horizon with some organic matter lying at or near the surface. Characterized as a zone of maximum leaching or eluviation. Further subdivided into A₁, A₂, etc.

A₁ horizon: Topmost mineral horizon containing a strong admixture of humified organic matter which tends to impart a darker colour than that of the lower horizons.

A₁(g): When horizon A₁ is water-logged, the horizon is known as A₁(g), 'g' for gleying.

A₂ horizon: Horizon of maximum eluviation (or removal) of clay and sesquioxides. Sandy in texture and lighter in colour than the A₁. When water-logged the horizon is known as A₂(g).

Association, soil association: A group of defined taxonomic soil units occurring together in an individual and characteristic pattern over a geographical region, comparable to plant association. Also termed as soil catena.

B horizon: Soil horizon below the surface A horizon, sometimes referred to as the subsoil. Characterized as a zone of maximum accumulation of materials such as clays and sesquioxides. Further subdivided into B₁, B₂ etc.

* See also glossary of soil science terms indexed by Townsend (1973) and Brady (1974).

- B₂ horizon:** Zone of maximum accumulation which is the actual B horizon; the B₁ horizon being a transitional layer between A and B. When water-logged the horizon is known as B₂(g).
- B₂fe horizon:** B₂ horizon with maximum accumulation of ferruginous materials.
- Brown earth:** A term used by British soil scientists for soils with less developed B horizon. Typically found under deciduous forest, the soils are slightly acid. Most agricultural soils of Great Britain fall into this group which in many areas is considered a climax soil in equilibrium with its environment.
- Brown earth (Britain) ≡ Brown forest soil (U.S.A.) ≡ Sol brun acide (France) ≡ Braunerde (Germany).
- Brown podzolic soil:** A term used by U.S. soil scientists for soils similar to podzols but lacking the distinct A₁ horizon characteristic of the podzol group (see podzol).
- C horizon:** Unconsolidated material underlying the solum (A and B horizons). Sometimes called the parent material from which the solum developed. When water-logged the horizon is referred to as C(g).
- Chernozem, chernozemic:** A group of soils having a thick, very dark-coloured, organic matter rich A horizon, underlain by a lighter coloured transitional horizon above a zone of CaCO₃ accumulation. Occurs in a cool subhumid climate under a vegetation of tall and mid-grass prairie.
- Clay:** A soil fraction with particle size less than 2 μm, showing colloidal properties. Constituted mostly of layer silicate type minerals (see layer silicates).
- Ferrallitic soil:** A term used by French soil scientists for tropical and subtropical soils characterized by the presence of a horizon from which most of the combined silica has been removed by weathering, leaving oxides of Fe and Al and quartz. These soils are also referred to as latosols, ground-water laterites.
- Gley soil, gleysolic, gleying:** When the water table frequently reaches the soil surface, the soil profile becomes very poorly drained and periodically water-logged, resulting in the reduction of iron and other elements and in grey colours and mottles. This process (referred to as gleying) gives rise to gley soil and gleysolic (i.e. gley-like) soil.
- Grey-brown podzolic soil:** An American term for soils with a thin, moderately dark A₁ horizon and with a greyish-brown A₂ horizon, underlain by a B horizon containing high percentage of bases and

- appreciable quantity of illuviated clay. Grey-brown podzolic soil (U.S.A.) = Brown earth (Britain) = Sols lessivés (France), as reported by Le Riche and Weir (1963).
- Layer silicates:** The tetrahedral (e.g. silicon tetrahedron) and octahedral (e.g. Al octahedron) units are connected together to form a silicate layer. Minerals which are built of such layers of silicates (e.g. aluminosilicate layer) are called layer silicates. The layer silicates contribute to the formation of an important group of clay minerals.
- Mor layer:** A layer of little decomposed organic material, found in forest areas. Constituted of leafy, fibrous and particulate matter. Corresponds to the O₁ horizon.
- O₁ horizon:** An organic horizon with little decomposed plant and animal residues, lying at the soil surface above the A horizon. See also A₀ horizon.
- O₂ horizon:** An organic horizon with well decomposed litter, lying below the O₁ horizon.
- Organic soil:** A soil which contains a high percentage (>20 per cent) of organic matter throughout the surface and subsoil layers.
- Planosol:** A soil group of hydromorphic soils (1949 U.S. Soil Classification), with surface horizons underlain by B horizons—cemented or compacted. Some planosol soils have profiles that are similar to solonetz-solod profiles (see solonetz-solod).
- Podzol, podzolization:** Podzol soils are formed in cool-temperate to temperate, humid climates, under coniferous and deciduous forest. Characterized by a highly leached, grey coloured A₂ horizon. The soil-forming process involves acid leaching of the organic horizon at the surface, removal of clay and dissolved sesquioxides from the mineral surface layer to the subsoil horizons. This process is known as podzolization.
- Regosol, regosolic:** Soils without definite genetic horizons and developing from or on deep, unconsolidated, soft mineral deposits such as sand, loess or glacial drift.
- Series, soil series:** The basic unit of soil classification, being a subdivision of a family and consisting of soils that are essentially alike in all major profile characteristics.
- Solonetz, solod:** A group of saline-alkali soils from which soluble salts have been largely removed, but with high exchangeable Na (or Mg) which often leads to the dispersal of organic matter at the soil surface (hence the term “black alkali”). At the early stage of this soil-

forming process, the soils are known as solonetz (Russian term) and at later stage as solod or sodic soils.

Solum: The surface and subsoil horizons (or layers) above the parent material or C horizon are collectively referred to as the solum.

Type, soil type: The lowest unit in the natural system of soil classification, a subdivision of a soil series and consisting of or describing soils that are alike in all characteristics including the textures of the A horizon.

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Table A-1 Concentration of lead, zinc, copper, nickel and cadmium in soils, lithosphere and rocks*

Soil/Rock	Total content in $\mu\text{g g}^{-1}$ (dry matter)				
	Pb	Zn	Cu	Ni	Cd
A. Soil					
Average	10	50	20	40	0.5
Usual range	2-200	10-300	2-100	5-500	0.01-0.7
B. Lithosphere					
average	16	80	70	100	0.18
C. Rock					
Igneous	16	80	70	100	0.13
Limestone	5-10	4-20	5-20	3-10	—
Sandstone	10-40	5-20	10-40	2-10	—
Shale	20	50-300	30-150	20-100	0.3

* From Table VI of Baker and Chessin (1975)

Table A-2 Concentration of lead, zinc, copper, nickel, cadmium and cobalt in soils derived from various parent materials in England and Wales*
($\mu\text{g g}^{-1}$ air-dry basis)

Parent Material	Pb		Zn		Cu		Ni		Cd		Co
	Total	Extr. HAc	Total	Extr. HAc	Total	Extr. EDTA	Total	Extr. HAc	Total	Total	
Boulder clay N.E. England	72	3.9	90	4.6	20	5.1	40	2.0	1.7	7	
Boulder clay E. England	29	<3.4	75	6.4	17	5.3	26	<2.9	<0.8	12	
Sands	34	<2.6	67	16.9	17	11.3	14	<2.6	<1.7	5	
Fen peats	25	<2.3	77	7.1	25	6.5	26	<2.5	<0.8	19	
Clays	40	<3.1	102	8.3	25	6.1	32	<1.4	<1.0	13	
Glacial sands and gravels	55	<4.3	71	5.7	16	4.3	32	<2.0	<1.1	6	
Alluvium	72	<4.9	88	10.1	21	10.0	26	<2.2	<1.3	9	
Paleozoic shales	75	<2.3	99	8.7	25	3.8	22	<1.0	<1.1	8	
Chalks	32	<3.5	85	6.9	16	3.5	28	<1.9	<1.0	18	
Acid igneous	51	<0.7	82	8.4	25	5.0	25	<0.8	<1.1	n.d.	
Keuper marl	32	<3.2	74	8.4	15	5.1	29	<3.0	<0.9	10	
Limestones	79	<3.5	119	9.0	18	4.4	31	<2.5	<1.5	8	
Sandstones	29	<2.8	62	4.2	25	2.4	29	<1.8	<1.1	3	
Boulder clay N.W. England	70	4.1	68	4.6	15	3.4	30	1.8	<1.4	5	

* From Tables IV and V of Archer (1977)

Table A-3 Concentration of lead, copper, nickel, chromium and manganese in some Scottish surface soils derived from different parent rocks*

Parent rocks	Total concentration in $\mu\text{g g}^{-1}$ (oven-dry basis)				
	Pb	Cu	Ni	Cr	Mn
Serpentine	20	20	800	3,000	3,000
Olivine gabbro	20	40	50	300	5,000
Andesite	40	10	10	60	800
Granite	20	<10	10	5	700
Granitic gneiss	70	25	40	200	1,000
Quartz mica schist	80	100	80	150	3,000
Shale	20	10	40	200	1,000
Sandstone	<20	<10	15	30	200
Quartzite	60	40	50	250	1,000

* From Table 8.7 of Mitchell (1964)

Table A-4 Annual deposition of lead and other ions at several sites in western Europe and U.S.A.*
($\mu\text{g cm}^{-2} \text{y}^{-1}$)

	Non-urban				Urban		
	U.K. (average of 7 sites)	U.S.A. Tennessee	U.S.A. Upper Great Lakes	Holland Texel (1975)	U.S.A. New York (1972-75)	U.K. central Swansea (1972-75)	Germany Gottingen (1972)
Pb	2.7	2.3	1.2	1.5	7.9	6.2	2.3
Zn	7.4	5.4	5.3	4.0	—	10.0	4.7
Cu	2.2	2.8	0.64	0.29	—	3.6	1.1
Ni	1.8	—	0.37	—	0.66	2.2	—
SO ₄	783.0	—	250.0	430.0	—	—	—
NO ₃	329.0	—	6.2	200.0	—	—	—
Cl	1,634.0	—	53.0	570.0	—	1,300.0	—

* From Tables 1 and 2 of Cawse (1977)

Note: $\mu\text{g cm}^{-2} \times 0.1 = \text{kg ha}^{-1}$

Table A-5 Concentration of lead, nickel, cadmium, chromium, mercury and zinc in source materials causing pollution of environment

Source materials	Total concentration ($\mu\text{g g}^{-1}$)					
	Pb	Ni	Cd	Cr	Hg	Zn
Limestone ¹	9	20	0.04	11	0.04	
Superphosphate ¹	7-92	7-32	7.3-170	66-243	—	
Fossil fuel ²						
Coal	25	15	—	10	0.012	
Oil	0.3	10	0.01	0.3	10	
Sewage sludge ³						
Sweden	281	121	12.7	872	6	2,055
(93 plants)	(52-2,914)	(16-2,120)	(2-171)	(20-40,615)	(<0.1-35)	(705-14,700)
Michigan U.S.A.	1,380	371	74	2,031	5.5	3,315
(57 plants)	(80-26,000)	(12-2,800)	(2-1,100)	(22-30,000)	(0.1-56)	(72-6,400)
England and Wales	820	510	<200	980	—	4,100
(42 plants)	(120-3,000)	(20-5,300)	(<60-1,500)	(40-8,800)	—	(700-49,000)

¹ Cited from Lisk (1972)

² Cited from Bertine and Goldberg (1971)

³ Cited from Page (1974), range within parenthesis

Table A-6 Lead content of leaf litter and soil around a smelter in south-east Missouri, U.S.A.*
(Cited from Rolfe and Jennett 1973)

Soil/litter	Distance from smelter (km)						
	0.4	0.8	1.6	3.2	4.8	6.4	8.0
	Concentration ($\mu\text{g g}^{-1}$)						
O ₁	9,400	3,200	1,200	590	450	160	150
OH	28,000	16,000	4,200	1,700	930	460	450
Soil	590	150	60	48	46 [†]	38	32

* Average of samples from 5-8 sites in different directions from the smelter

† One anomalously high value omitted

O₁ = slightly decomposed leaf litter

OH = well decomposed leaf litter

soil = 0 - 2.5 cm (80 mesh sieve)

Table A-7 Lead compounds in samples of automobile exhaust as determined by electron microprobe

(Cited from Ter Haar and Bayard 1971)

Lead compound	Percentage of total particles sampled				
	Black bag ^a		Eight mile road ^b		
	Zero time	18-hour	Near road	400 yard	Rural site ^c
PbCl ₂	10.4	8.3	11.2	10.5	5.4
PbBr ₂	5.5	0.5	4.0	0.7	0.1
PbBrCl	32.0	12.0	4.4	0.6	1.6
Pb(OH)Cl	7.7	7.2	4.0	8.8	4.0
Pb(OH)Br	2.2	0.1	2.0	1.1	—
(PbO) ₂ ·PbCl ₂	5.2	5.6	2.8	5.6	1.5
(PbO) ₂ ·PbBr ₂	1.1	0.1	0.7	0.3	—
(PbO) ₂ ·PbBrCl	31.4	1.6	2.0	0.6	1.0
PbCO ₃	1.2	13.8	15.6	14.6	30.2
Pb ₃ (PO ₄) ₂	—	—	0.2	0.3	—
PbO _x	2.2	21.2	12.0	25.0	20.5
(PbO) ₂ ·PbCO ₃	1.0	29.6	37.9	21.3	27.5
PbO·PbSO ₄	—	0.1	1.0	4.6	5.0
PbSO ₄	0.1	—	2.2	6.0	3.2

^a Sample collected directly from tail pipe in a black bag to prevent irradiation of exhaust. Analysed immediately and again 18 hours later to determine the effect of ageing

^b State highway in Detroit carrying about 100,000 cars a day

^c Samples were taken 400 yards from a lightly travelled roadway

Table A-8 Distribution of lead, copper, nickel, chromium, cobalt and zirconium in some brown earth profiles of England*

(Cited from Le Riche and Weir 1963)

1. Soil from Charity series, Buckinghamshire (Profile Bu 55), under beech wood on the Chiltern Hills, developed on chalky head material.

Soil and fractions	Wt of fractions (mg)	Pb	Cu	Ni	Cr	Co	Zr
<i>A horizon, samples from 0-8 cm</i>							
Soil	1,000	48	9.6	26	56	13	410
Extract (Ex)	36	31	3.5	5.0	6.8	1.1	28
Sand (S)	503	4.0	2.0	6.4	15	<1.5	240
Silt (S)	280	9.0	1.7	5.6	13	<0.8	70
Clay (C)	123	7.7	4.3	7.0	11	1.2	15
Ex+S+S+C	942	52	11.5	24	46	12-14	353
<i>B horizon sample from 71-76 cm</i>							
Soil	1,000	24	13.5	49	94	19	360
Extract	64	15	6.3	14	15	13	54
Sand	404	<2.4	1.6	6.5	21	<1.2	190
Silt	265	3.2	1.6	8.5	16	1.1	60
Clay	246	5.7	4.7	15	22	1.7	30
Ex+S+S+C	979	24-26	14.2	44	74	16-17	330

Table A-8 (continued)**2. Soil from Hatfield series, Hertfordshire (Profile Ht 115) Cultivated soil from the vale of St. Albans, formed on loamy drift resembling loess.**

Soil and fraction	Wt of fraction (mg)	Pb	Cu	Ni	Cr	Co	Zr
<i>A horizon, sample from 0-8 cm</i>							
Soil	1,000	71	20	22	64	8.2	410
Extract	35	29	10.5	6.0	9.5	6.6	23
Sand	550	6.6	3.3	5.5	14	1.6	190
Silt	261	14	2.1	6.3	18	1.3	81
Clay	99	10	4.0	5.5	8	0.6	14
Ex+S+S+C	945	60	19.9	23	50	8-10	310
<i>B horizon, sample from 71-76 cm</i>							
Soil	1,000	20	13.5	38	90	11	460
Extract	52	13	7.0	10	12	6.8	35
Sand	483	5.5	2.4	5.8	24	<1.4	190
Silt	188	1.9	1.1	4.1	11	0.9	47
Clay	209	5.6	6.0	12	20	1.9	21
Ex+S+S+C	932	26	16.5	32	67	10-12	290

* Extract weight on 450°C basis, remainder 105°C basis. Extract was prepared by treating soil with ammonium oxalate (pH 3.3), and the soil residue was separated into sand, silt and clay. Trace metal analyses were made with the emission spectrograph.

(Results as $\mu\text{g g}^{-1}$, oven-dry basis)

Table A-9 Distribution of lead, zinc, copper, nickel, chromium and cobalt in some soil profiles of the U.S.A.*

(Cited from Connor *et al.* 1957)

Soil	Horizon†	Pb	Zn	Cu	Ni	Cr	Co
1. Podzol soil (Wisconsin drift)							
<i>(i) Analysis of total soil</i>							
Sandy loam							
Parent material:	A	8	16	4	3	17	n.d.
Grey acid sandstone	B	24	62	9	13	48	1
(Pocono)	C	22	68	13	14	43	3
Location:							
Tobyhanna,							
Pennsylvania							
<i>(ii) Analysis of clay fraction</i>							
	A	44	98	135	15	101	n.d.
	B	75	217	75	82	177	3
	C	72	256	117	91	140	10
2. Podzol soil (Kansan drift)							
<i>(i) Analysis of total soil</i>							
Sandy loam							
Parent material:	A	6	14	4	2	12	n.d.
Grey acid sandstone	B	21	60	8	11	44	1
(Pocono)	C	30	61	9	15	51	1
Location:							
Jim Thorpe,							
Pennsylvania							
<i>(ii) Analysis of clay fraction</i>							
	A	38	94	64	17	81	n.d.
	B	62	206	94	45	102	2
	C	126	206	97	51	160	5
3. Grey brown podzolic soil (Wisconsin drift)							
<i>(i) Analysis of total soil</i>							
Squires silt loam							
Parent material:	A	138	169	13	18	22	3
Calcareous	B	122	209	18	29	7	7
Location:	C	109	302	36	45	8	5
McAfee,							
New Jersey							
<i>(ii) Analysis of clay fraction</i>							
	A	30	318	56	45	83	9
	B	29	402	70	44	108	12
	C	31	226	142	41	94	7

Table A-9 (continued)

Soil	Horizon [†]	Pb	Zn	Cu	Ni	Cr	Co
4. Red podzolic soil							
<i>(i) Analysis of total soil</i>							
Ammandale silt loam							
Parent material:	A	155	320	17	30	28	4
Gneissic and	B	89	277	21	25	30	6
carbonate rock	C	61	256	68	32	8	12
Location:							
Flanders,							
New Jersey							
<i>(ii) Analysis of clay fraction</i>							
	A	40	271	66	187	43	4
	B	26	249	79	120	34	14
	C	37	248	85	148	31	10
5. Grey brown podzolic soil (Wisconsin drift)							
<i>(i) Analysis of total soil</i>							
Wethersfield loam							
Parent material:	A	103	102	40	17	10	4
Red acid shale	B	129	167	44	25	18	4
(Brunswick)	C	101	146	98	21	21	3
Location:							
Metuchen,							
New Jersey							
<i>(ii) Analysis of clay fraction</i>							
	A	63	352	115	103	134	10
	B	84	297	76	84	134	4
	C	94	273	110	92	167	12
6. Grey brown podzolic soil (Kansan drift)							
<i>(i) Analysis of total soil</i>							
Norton loam							
Parent material:	A	30	86	30	38	20	5
Red acid shale	B	101	122	29	77	15	4
(Brunswick)	C	116	218	41	45	33	5
Location:							
East Millstone,							
New Jersey							
<i>(ii) Analysis of clay fraction</i>							
	A	44	440	69	121	167	10
	B	75	253	65	103	157	13
	C	72	231	88	84	164	12

* The total contents were analysed spectrochemically (31), samples oven-dried (110°C) and digested with HNO₃ + HClO₄ (organic matter removed). Precision of data within ±5–15 per cent.

† A = surface layer, B = subsoil layer and C = parent material, n.d. = not detected.
(Results as µg g⁻¹, oven-dry basis)

Table A-10 Distribution of lead, copper, nickel, chromium and cobalt in some soil profiles of Scotland*

(Cited from Swaine and Mitchell 1960)

Soil	Horizon	Depth (cm)								Clay %	Loss on ignition %
			Pb	Cu	Ni	Cr	Co	pH			
1. Brown podzolic soil (Leslie series)											
Freely drained,	S	5-18	20	7	600	3,500	40	4.2	10.3	39.2	
formed on	B2	20-30	10	15	5,000	2,000	200	6.2	17.6	7.4	
serpentine till.	B2	46-56	10	15	3,000	2,000	150	6.8	16.1	5.8	
Leslie series,	B-C	66-76	10	25	3,000	3,000	200	7.7	14.4	5.4	
Aberdeenshire	C	97-109	10	25	3,000	3,000	200	7.5	16.5	5.6	
2. Brown podzolic soil (Glebe series)											
Imperfectly	S	0-20	20	30	70	300	40	6.0	19.5	14.7	
drained with	B2	30-38	10	30	70	100	40	5.6	15.4	7.1	
gleyed B and	B3(g)	41-48	10	30	70	200	40	5.7	11.2	5.7	
C horizons,	B3(g)	51-61	10	40	70	300	40	5.9	17.5	6.2	
formed on olivine	C(g)	91-112	10	40	70	300	40	6.1	20.8	3.6	
gabbro till, Glebe series, Aberdeenshire.											
3. Brown forest soil (Darleith series)											
Freely drained,	S	2.5-18	40	25	25	80	10	6.0	20.2	14.8	
low base status	B2	25-36	10	30	20	60	20	6.4	11.0	7.8	
on andesitic	B-C	46-66	10	20	20	40	20	6.5	9.1	7.1	
moraine,	C	74-84	10	20	15	150	20	6.6	9.4	5.2	
Darleith series, Renfrewshire											
4. Peaty gleyed podzol soil with iron pan (Charr series)											
Poorly drained	H	18-23	50	3	4	7	<1	4.2	—	65.7	
above, freely	A2	25-36	15	<5	8	25	<3	4.4	6.3	5.8	
drained below	A2	43-53	20	<5	10	30	<3	4.6	11.2	9.5	
pan on granitic	B1	53	20	<5	10	50	3	—	—	16.0	
till, Charr	B2	53-64	30	<5	15	30	3	4.9	12.3	6.2	
series,	B2-C	79-91	30	<5	8	20	3	4.8	6.3	3.4	
Kincardineshire	C	102-117	20	<5	10	20	3	4.9	7.6	3.1	

Table A-10 (continued)

Soil	Horizon	Depth		Pb	Cu	Ni	Cr	Co	pH	Clay %	Loss on ignition %
		(cm)									
5. Podzol soil (Countesswells series)											
Freely drained,	S	0-25	70	25	40	200	10	5.4	12.7	8.9	
on granitic	B2	30-36	30	30	60	150	20	5.4	8.1	3.5	
gneiss till,	B2	41-51	30	50	50	150	20	5.5	15.5	3.3	
Countesswells	B3	61-76	20	50	80	150	20	5.3	17.7	3.1	
series,	C(g)	94-104	20	50	80	200	20	5.4	20.6	3.3	
Aberdeenshire											
6. Podzol soil (Strichen series)											
Freely drained,	S	0-18	80	25	80	150	25	6.5	33.2	10.2	
on quartz	B2	33-48	50	30	100	150	30	5.3	16.8	6.3	
mica schist till,	B2	61-69	30	40	150	150	40	5.3	14.4	8.0	
Strichen series,	B3	81-97	30	40	150	150	40	5.4	20.0	5.1	
Kincardineshire	C	102-109	70	40	70	200	30	5.4	18.5	4.4	
7. Non-calcareous gley soil (Ettrick series)											
Poorly drained,	A1(g)	5-13	40	5	40	250	10	4.8	25.8	15.2	
on silurian	A2(g)	13-23	15	20	80	250	20	5.3	43.1	5.2	
slate till,	B2(g)	28-36	10	40	80	250	30	5.2	46.8	8.5	
Ettrick series,	B2(g)	41-51	20	40	100	200	25	5.6	46.3	5.3	
Roxburghshire	B3(g)	61-76	15	40	100	200	20	7.3	49.9	4.7	
	C(g)	91-107	15	40	80	200	20	8.3	49.8	7.1	
8. Peaty podzol with iron pan† (Haupland series)											
Freely drained	A2	2.5-5	40	<5	8	20	<3	4.0	7.8	10.4	
below pan,	B2	13-36	10	<5	15	20	4	4.4	13.8	5.5	
on sandstone	B3	56-69	10	<5	20	25	4	5.0	13.7	1.9	
till,	C	89-102	10	<5	15	10	3	5.2	12.7	2.1	
Haupland series,											
Ayrshire											

* The total trace metal contents of soils were determined by semi-quantitative spectrographic assessment with a precision order of 30-50 per cent and smaller variations must be disregarded. The surface layer denoted "S" is cultivated.

† The discontinuous iron pan (B1) at 5 cm is unfortunately not available.

(Results as $\mu\text{g g}^{-1}$, air-dry basis)

Table A-11 Distribution of lead, zinc, copper and cobalt in some soil profiles of Canada*
(Cited from Wright *et al.* 1955)

Soil	Horizon	Depth (cm)	Pb	Zn	Cu	Co	pH	Organic matter %
1. Podzol soil								
<i>(a) Charlottetown series</i>								
Surface soil texture is	A0	0-5	28	46	13	3.0	3.6	48.1
fine sandy loam (pH 3.9),	A1	0-2.5	15	21	10	3.0	3.9	10.5
changing to loam in B21	A2	2.5-10	9	11	5	1.4	4.3	1.6
sandstone fragments in	B21	10-20	18	64	21	10.3	4.6	2.9
the parent material	B22	20-33	11	57	16	9.9	4.8	1.0
(pH 4.9)	C	66+	12	47	18	9.3	4.9	0.3
<i>(b) Armadale series</i>								
Surface soil texture is	A0	0-5	28	39	9	1.3	3.5	59.8
fine sandy loam (pH 4.3),	A2	0-13	6	10	1	0.8	4.3	0.7
same texture all through	B1	13-18	10	30	6	5.6	4.4	1.8
the profile. Parent	B2	18-33	9	41	8	9.9	4.9	1.1
material—sandstone	C	64+	10	39	12	9.2	5.2	0.2
2. Brown podzolic soil								
<i>(a) Gatineau series</i>								
Surface soil texture is	A0	0-5	108	150	23	7.5	6.3	38.6
sandy loam (pH 6.3),	B1	0-10	18	94	6	10.4	5.3	7.5
same texture continues	B21	10-46	15	142	4	18.2	6.1	3.6
downward. Parent	B22	46-76	17	83	10	12.7	6.1	1.1
material—gravels	C	76+	13	53	6	9.0	6.0	0.2
and boulders (pH 6.0)								
<i>(b) Northfield series†</i>								
Surface soil texture is	A0‡	0-5	—	—	—	—	—	—
loam (pH 4.5) same								
texture continues	B1	0-15	30	61	12	9.0	4.5	12.3
downward. Parent	B21	15-36	27	73	12	8.8	4.8	2.5
material—slate and	B22	36-51	33	54	12	10.2	5.0	1.7
granite fragments	C	51+	21	54	18	13.2	5.1	0.6
(pH 5.1)								

Table A-11 (continued)

Soil	Horizon	Depth (cm)	Pb	Zn	Cu	Co	pH	Organic matter %
3. Grey brown podzolic soil								
<i>(a) Guelph series</i>								
Surface soil texture is loam (pH 7.2), changing clay loam in B2.	A1	0-10	33	85	11	7.8	7.2	8.1
	A21	10-20	27	79	7	9.2	7.2	1.7
	A22	20-46	26	75	7	9.4	7.1	1.4
Parent material—calcareous (pH 8.0)	B2	46-61	30	85	14	10.1	7.4	1.0
	B3	61-69	31	87	16	9.5	7.6	0.8
	C	69+	22	70	11	5.9	8.0	0.4
<i>(b) Huron series</i>								
Surface soil texture is clay loam (pH 7.3), changing to clay in B2.	A1	0-10	21	76	10	8.0	7.3	5.4
	A21	10-20	22	71	6	9.7	6.7	1.8
	A22	20-33	17	71	10	10.6	6.3	0.8
Calcareous parent material (pH 8.0)	B2	33-56	19	89	19	11.7	7.7	0.6
	C	56+	16	62	17	8.1	8.0	0.3
4. Brown forest soil								
<i>(a) Wolford series</i>								
Surface soil texture is loam (pH 7.6), changing to clay loam in B2.	A11	0-5	23	74	19	9.6	7.6	15.6
	A12	5-13	19	67	11	9.9	7.7	11.5
	B1	13-18	18	60	8	10.7	7.7	4.6
Calcareous parent material (pH 8.2)	B2	18-30	18	72	9	11.2	7.7	0.5
	B3	30-41	14	68	10	11.0	7.9	1.0
	C1	41-51	11	50	17	9.2	8.2	0.4
	C2	51+	8	37	15	7.3	8.2	0.5
<i>(b) Grenville series</i>								
Surface soil texture is sandy loam, (pH 6.7)	A1	0-10	22	57	7	7.6	6.7	10.4
	B1	10-20	20	58	6	11.3	6.4	1.7
(same texture all through the profile).	B21	20-46	22	47	5	10.6	6.3	1.3
	B22	46-51	19	46	8	11.1	6.0	1.0
Calcareous parent material (pH 7.5)	B3	51-76	16	45	14	10.6	6.3	1.0
	C	76+	14	36	13	7.5	7.5	—

* The soil was digested with HF-HClO₄. The metal contents were determined by the dithiozone method

† Series name tentative

‡ Sample was lost

(Results as $\mu\text{g g}^{-1}$, air-dry basis)

Table A-12 Distribution of lead, copper, nickel, chromium, cobalt and zirconium in some tropical soils of Cameroun*
(Cited from Nalovic and Pinta 1972)

Horizon No.	Depth (cm)	$\mu\text{g g}^{-1}$						Organic matter %	Clay %	pH
		Pb	Cu	Ni	Cr	Co	Zr			
1. Sol rouge ferrallitique sur embréchite (Ferrallitic red soil)										
B2	0-60	45	39	65	1,120	19.3	155	0.5	42.1	5.3
B2	60-200	19	34	39	1,262	2.6	243	0.1	26.1	4.9
B2fe	200-430	74	63	80	1,220	10.4	100	0.1	34.2	5.1
BC	430-550	4.4	9.4	69	281	12.2	500	—	30.3	5.2
C	550-600	5.3	9.9	64	472	12.7	490	—	19.1	5.3
2. Sol à sesquioxydes de fer—ferrugineux (Ferruginous tropical soil)										
A1	0.1-10	114	7.3	4.2	34	4.1	180	1.45	9.6	6.5
A1	10-18	132	5.7	3.7	46	3.7	229	1.40	10.4	6.2
A1	18-30	107	5.4	2.9	36	3.1	195	1.07	11.6	6.2
A2	30-45	87	6.5	6.4	40	5.0	174	0.82	13.8	5.9
B2	45-100	19	4.6	8.9	20	12.8	560	0.36	26.1	5.6
B2	100-110	57	8.5	6.5	9.4	13.2	116	0.19	25.6	5.7
BC	110-160	43	7.3	7.6	9.4	8.1	94	0.12	27.5	5.8
—	160-250	73	9.2	5.4	9.4	7.5	61	0.12	27.8	5.8
3. Sol brunifié tropical (Brown soil)										
—	0-10	20	54	196	192	39	1,390	9.1	30.2	6.2
A1	10-25	28	67	227	277	44	1,220	7.4	26.5	6.2
B	25-83	22	72	224	198	44	673	44	55.7	5.9
C1	83-150	9.5	59	630	307	51	452	0.9	21.0	6.6
4. Sol sodique à structure dégradée—Solonetz solodisé (Planosol, degraded solonetz-solod structure)										
—	0-10	35	13.8	12.2	78	7	593	1.4	16.0	6.2
—	10-20	30	8.7	11.4	42	2.9	213	0.5	21.8	6.3
—	20-30	42	10.7	13.1	48	4.6	834	0.4	25.0	6.6
—	30-70	12	20	22	63	10.1	497	0.3	37.5	7.3
—	70-90	6.3	20	25.3	55	14.5	716	0.2	36.9	8.4
—	90-120	4.4	16.7	26.7	75	16.7	810	0.1	37.1	8.4

* Profile and horizon nomenclature is according to the French system of soil classification. The metal contents were determined by the emission spectrography.

Table A-13 Distribution of lead, nickel, chromium and cobalt in some soil profiles of Lancashire, England*
(Cited from Butler 1954)

Soil	Depth (cm)	Pb	Ni	Cr	Co	Loss on ignition %	pH
1. Meadow or Gley soil (Salop series)							
Poorly drained, formed	0-10	78	21	36	7.5	15.2	6.4
on triassic drift,	13-23	52	21	38	10	5.5	5.2
Salop series,	28-38	20	20	32	10	3.9	5.4
Profile No. La 18	46-56	15	26	61	10	3.9	5.7
	61+	15	36	76	25	2.9	5.9
2. Meadow or Gley soil (Hallsworth series)							
Poorly drained, formed	2.5-13	160	14	35	10	17.9	6.6
on carboniferous drift,	25-30	35	4.2	24	<5	6.8	6.5
Hallsworth series,	36-46	45	17	50	10	6.4	6.6
Profile No. La 41	66-76	20	19	48	10	4.6	6.4
	97-107	25	21	58	20	4.0	5.6
3. Brown earth soil (Jepson series)							
Freely drained, formed	0-13	78	23	32	10	14.0	7.9
on carboniferous shale,	18-28	35	24	40	15	6.8	5.8
Jepson series,	33-43	45	17	41	10	6.0	5.2
Profile No. La 42	48-58	45	35	55	20	5.2	5.4
	61-69	40	44	66	20	4.3	5.2
4. Meadow or Gley soil (Hallsworth series)							
Poorly drained, formed	2.5-13	100	22	51	25	16.5	5.0
on carboniferous shale,	15-25	115	22	67	25	11.9	5.1
Hallsworth series,	28-38	25	28	84	30	12.1	5.2
Profile No. La 26	41-51	15	40	103	30	9.3	5.1
	53-61	20	42	104	25	9.1	4.5
	61+	20	45	94	30	8.4	4.7

* The total trace metal contents of soils were determined spectrographically (Hilger quartz spectrograph), with a precision order of $\pm 10-40$ per cent.

(Results as $\mu\text{g g}^{-1}$, oven-dry basis)

Table A-14 Distribution of lead, zinc, nickel and cadmium in some roadside grasses and soils of the U.S.A.*

(Cited from Lagerwerff and Specht 1970)

Site	Metals	Metres from road	Metal content in $\mu\text{g g}^{-1}$ dry matter				
			Grass	Soil depth (cm)			
				0-5	5-10	10-15	
1. West of U.S. 1 at Beltsville, Maryland Soil type: Sassafra sandy loam Grass: Tall fescue. Traffic density: 20,000 cars/24 hour	Pb	8	68.2	522	460	416	
		16	47.5	378	260	104	
		32	26.3	164	108	69	
	Zn	8	32.0	172	94	72	
		16	28.5	66	48	42	
		32	27.3	54	46	42	
	Ni	8	5.0	4.7	1.0	0.8	
		16	3.8	2.4	0.9	0.6	
		32	2.8	2.2	0.6	0.6	
	Cd	8	0.95	1.45	0.76	0.54	
		16	0.73	0.40	0.38	0.28	
		32	0.50	0.22	0.20	0.20	
	2. West of southbound lanes, Washington- Baltimore Parkway Bladensburg, Maryland Soil type: Collington silt loam Grass: Tall fescue Traffic density: 48,000 cars/24 hour	Pb	8	51.3	540	300	98
			16	30.0	202	105	60
			32	18.5	140	60	38
		Zn	8	40.0	162	86	36
			16	34.5	110	28	20
			32	30.3	44	20	18
Ni		8	3.8	7.4	5.6	1.4	
		16	2.5	4.4	1.6	0.79	
		32	1.3	2.4	1.2	0.57	
Cd		8	0.75	0.94	0.70	0.30	
		16	0.63	0.68	0.44	0.18	
		32	0.48	0.24	0.18	0.12	

Table A-14 (continued)

Site	Metals	Metres from road	Metal content in $\mu\text{g g}^{-1}$ dry matter			
			Grass	Soil depth (cm)		
				0-5	5-10	10-15
3. West of Interstate 29, Platte City, Missouri Soil type: Knox silt loam Grass: blue grass Traffic density: 7,500 cars/24 hour	Pb	8	21.3	242	112	95
		16	12.5	140	104	66
		32	7.5	61	55	60
	Zn	8	36.3	54	24	16
		16	32.8	60	21	16
		32	29.0	15	11	14
	Cd	8	0.49	0.90	0.66	0.58
		16	0.37	0.77	0.70	0.61
		32	0.25	0.68	0.51	0.52
4. North of Seymour Road, Cincinnati, Ohio Soil type: Cincinnati silt loam Grass: orchard grass Traffic density: 23,000 cars/24 hour	Pb	8	31.3	150	29	11
		16	26.0	101	14	8.2
		32	7.6	55	10	6.1
	Zn	8	85.0	72	24	11
		16	72.4	60	16	10
		32	67.1	34	11	8.3
	Cd	8	0.74	1.82	0.44	0.28
		16	0.49	1.51	0.31	0.26
		32	0.26	1.02	0.24	0.18

* Soils were digested with HCl, and grasses with $\text{HNO}_3 + \text{HClO}_4$. Metal contents were determined by atomic absorption spectrophotometry.

Table A-15 Distribution of lead, zinc, copper and cadmium in some contaminated soils of Wollongong city area, N.S.W., Australia*
(Cited from Beavington 1975)

Site and source of contamination	Depth (cm)	Acetic acid extract $\mu\text{g g}^{-1}$			EDTA extract $\mu\text{g g}^{-1}$
		Pb	Zn	Cd	Cu
Soils from six profiles were collected from urban areas of Wollongong, contaminated mainly from industrial emission	0-5	17.0	102.5	1.0	488.3
	5-15	1.6	39.4	0.3	51.3
	15-30	0.7	15.2	0.1	26.2
	30-45	0.6	2.1	0.1	12.2
	45-60	0.4	1.0	0.1	8.7

* Soils were extracted with 0.5N acetic acid (Pb, Zn and Cd) and 0.02M EDTA (Cu), metal contents were determined by atomic absorption spectrophotometry.

Table A-16 Distribution of lead, zinc and cadmium in some contaminated soils from Avonmouth area of Severnside, England*
(Cited from Little and Martin 1972)

Source of contamination	Area	Depth (cm)	$\mu\text{g g}^{-1}$ (oven-dry basis)		
			Pb	Zn	Cd
The Avonmouth industrial complex of Severnside includes the largest lead and zinc smelting plant in the world	Extends from	0-3	126 ± 4.0	1,000 ± 15	6.5 ± 0.2
	Clevedon and	3-6	27 ± 4.5	720 ± 19	0.4 ± 0.1
	Abbots Leigh in	6-9	10 ± 0.0	280 ± 5	1.5 ± 0.0
	North Somerset	9-12	1 ± 0.0	175 ± 5	1.2 ± 0.25
	to Aust and	12-15	10 ± 1.0	250 ± 0	1.6 ± 0.4
	Frampton Cotterell in South Gloucestershire	15-18	4 ± 2.0	220 ± 5	1.2 ± 0.2

* Heavy metals were extracted with 2.5 per cent acetic acid.

Table A-17 Lead content of contaminated grasses and soils in Minnesota, U.S.A.*
(Cited from Marten and Hammond 1966)

Site	Location of soil samples	Soil Pb ($\mu\text{g g}^{-1}$ dry wt)	Pb content of bromegrass ($\mu\text{g g}^{-1}$ dry wt)		
			First crop	Second crop	Third crop
Soils were collected from near a battery smelter, from the bank of a four-lane highway.	Surface (25 mm) soil near smelter	680	12.5	4.9	34.5
	Surface (25 mm) soil near highway	59	3.0	2.7	6.5
	Subsoil (150 mm depth) near smelter	95	3.9	3.0	11.8
Soil texture: sandy loam, experiment laid out in pots.	Control (normal greenhouse soil)	12	3.5	3.0	5.4

* Pb in soil and plants was analysed by the dithiozone method.

Table A-18 Distribution of lead, zinc, copper and cadmium in some contaminated soils from Bristol area, England
(Cited from Griffiths and Wadsworth 1977)

Farms and distance from the industrial complex (km)*	Depth (mm)	Total content†				Available content†			pH	Organic matter %
		Pb	Zn	Cu	Cd	Zn	Cu	Cd		
3 km in the direction of the wind	0-75	163	816	23	8.6	117	9	2.9	6.8	8.6
	75-150	102	408	20	3.7	29	8	1.0	7.2	5.8
5 km in the direction of the wind	0-75	107	448	29	4.1	45	10	1.1	6.5	10.8
	75-150	67	283	29	2.0	15	9	0.4	7.1	5.4
7 km in the direction of the wind	0-75	75	258	17	2.0	18	5	0.6	6.7	10.5
	75-150	75	163	15	0.7	4	3	0.2	6.9	5.4
17 km in the direction against the wind	0-75	39	143	13	0.5	4	6	0.2	7.0	7.6
	75-150	37	149	13	0.6	4	5	0.2	7.4	5.9
27 km in the direction against the wind	0-75	49	153	20	0.5	4	9	0.2	6.4	9.4
	75-150	42	132	17	0.2	1	7	0.2	7.1	4.6

* Located in Avonmouth, Bristol area. The industrial complex includes large non-ferrous smelting works. The main complaints were (a) lack of thrift in young stock and (b) a need for uneconomic levels of feeding the dairy herds.

† For total amount of Pb, Zn, Cu and Cd the soil was digested with $\text{HNO}_3 + \text{HClO}_4$, the contents determined by atomic absorption. Available Zn and Cd were extracted with 0.5M acetic acid, available Cu with ammonium EDTA at pH 7.

(Results as $\mu\text{g ml}^{-1}$ of dry soil)

Table A-19 Lead and zinc content of some woodland soils and plants of the Upper Mississippi Valley district, U.S.A.*
(Cited from Keith 1969)

Soil/plant characteristics		Mineralized area within mining district		Non-mineralized area outside but contiguous to mining district	
		Pb	Zn	Pb	Zn
<i>Soil analysis</i>					
Soils belong mostly to Bruinizem (developed under prairie vegetation) and grey brown podzolics (formed under deciduous forests).	A Horizon	124	1,007	18	58
	B Horizon	67	144	13	48
	C Horizon	117	1,019	13	49
<i>Plant analysis</i>					
Vegetation is characterized as southern hardwood forest, interspersed with patches of oak savanna and prairie	Elm, stems	78	1,240	102	604
		leaves	26	266	29
	Maple, stems	135	490	119	555
		leaves	62	370	44
	Oak, stems	99	614	150	440
		leaves	57	554	61

* Metal contents of soils (average of 152 samples) are expressed as $\mu\text{g g}^{-1}$ of oven-dry soil, and of plants (average of 256 samples) expressed as $\mu\text{g g}^{-1}$ of plant ash. Metal analysis was done by colorimetric method and emission spectrography.

Table A-20 Distribution of lead, zinc, copper, nickel and cadmium in some sludge-treated soils of England and Wales
(Cited from Richardson 1977)

Site and source of contamination*	Depth (cm)	Total content ($\mu\text{g g}^{-1}$)				
		Pb	Zn	Cu	Ni	Cd
Soils were sampled from nine sites with a long history of sewage sludge application; mostly under grass cover	0-7.5	183	329	174	76	1.1
	7.5-15	161	260	121	54	0.88
	15-30	113	220	76	43	0.58

* See page 14 of the paper by Richardson (1977).

Table A-21 Lead content of some contaminated soils of Christchurch, New Zealand*
(Cited from Jordan and Hogan 1975)

Site and source of contamination	Depth (cm)	Pb ($\mu\text{g g}^{-1}$ of dry soil)	
		Wooden dwelling house area	Brick dwelling house area
Soil samples were from plots in Christchurch town, contaminated mainly by Pb-based paints, from old houses	0-10	400-7,500	20-85
	10-20	50-4,000	15-60
	20-30	20-1,200	14-50
	30-40	20-400	10-20

* Soils were digested with 0.6 per cent HCl and metal content determined by atomic absorption spectrography.

See Figures 5 and 6 of the paper by Jordan and Hogan (1975) showing the variation in the level of lead in soils at different distances from the housing areas.

Table A-22 Lead content of some contaminated soils and plants of Yugoslavia*
(Cited from Kerin 1975)

Area	Site No	Pb in contaminated soils			Radishes		
		Total $\mu\text{g g}^{-1}$	Extractable $\mu\text{g g}^{-1}$	Extractable as % total	Lettuce $\mu\text{g g}^{-1}$	Leaves $\mu\text{g g}^{-1}$	Stems $\mu\text{g g}^{-1}$
Area located around a 300-year-old Pb smelter in northern Yugoslavia.	1	3,055.0	556.4	18.2	11.02	10.47	11.04
	2	4,644.0	624.2	13.4	8.82	11.72	15.0
	3	55.0	910.3	6.0	—	5.27	—
	4	799.3	63.8	7.9	5.98	3.58	2.78
	5	672.7	35.1	5.2	3.92	4.77	1.46
Pb contamination extended more than 7 km from the smelter with highest levels of 5,000–9,000 $\mu\text{g g}^{-1}$ soil.	6	685.1	23.8	3.4	3.24	4.53	—
	7	944.3	143.5	15.1	9.63	9.96	3.80
	8	873.3	33.1	3.7	3.10	5.62	3.44
	9	361.1	8.6	2.3	2.85	4.43	—
	10	2,289.8	134.6	5.8	4.18	6.88	1.36
Background values		(40.1)	(7.0)	(5.8)	(2.63)	(3.37)	(1.56)

* Total Pb of soil was analysed by digesting the soil (1–8 cm) with 1 : 1 HNO_3 , extractable Pb by treating the soil with 0.1N NH_4 - lactate + 0.4N acetic acid. Pb in soils and plants was determined by the colorimetric dithiozone method. Pb content of soil is expressed on air-dry weight basis (see Table 8 of the paper by Kerin 1975).

Table A-23 Lead contamination of some soils and plants of New Zealand*
(Cited from Ward *et al.* 1977a)

Sampling site	Site No.	Soil Pb % dry wt	Pb content ($\mu\text{g g}^{-1}$ dry wt)									
			Perennial rye-grass		White clover		Poa annua		Yorkshire fog		Flatweeds	
			Roots (R)	Leaves (L)	R	L	R	L	R	L	R	L
Battery factory and adjacent thorough-fare area	1	0.16	595	1,048	465	1,078	350	428	361	530	307	943
	2	0.51	566	1,088	948	1,138	985	1,216	515	1,840	258	678
	3	0.97	1,407	2,329	1,041	2,007	1,039	1,162	1,144	1,617	786	1,418
Smelter area	4	1.5	586	1,456	980	1,864	864	1,675	680	1,345	775	1,205
	5	3.1	560	1,784	2,156	2,364	2,059	2,923	761	1,227	956	1,058
	8	12.6	2,830	4,305	2,379	3,012	1,659	2,232	2,533	3,896	2,881	4,667
	10	0.11	1,098	1,710	1,246	1,763	1,290	1,974	572	1,896	1,125	1,645
	11	10.30	7,322	8,923	2,923	4,295	3,904	6,864	3,573	5,143	3,526	8,397
Thorough-fare transect (Pb mainly from vehicle exhaust)	12	0.31	172	642	130	372	887	874	761	1,189	440	846
	13	0.46	258	524	246	465	157	223	206	372	208	425
	17	0.10	186	345	165	405	192	398	165	325	140	385
	18	0.08	120	248	105	265	119	260	121	265	145	240
	19	0.05	65	205	48	185	56	202	60	165	54	145
	20	0.11	205	465	185	470	195	480	256	548	245	546
	21	0.08	145	260	125	280	120	275	135	290	160	275
	22	0.07	60	195	52	145	55	186	75	192	60	160

* Area is located in an industrial region of Auckland city, at the intersection of two major suburban thoroughfares (traffic density of about 5,200 motor vehicles per day). Surface soils (0-5 cm) were digested with 1:1 HNO₃+HF, and plant samples (unwashed) were ashed at 450°C and taken up in 2M HCl. The metal content was determined by atomic absorption spectrophotometry.

Table A-24 Lead in soils and crops

(Cited from Ter Haar 1972)

(a) Greenhouse studies, U.S.A.

	Pb content ($\mu\text{g g}^{-1}$ dry wt)	
	Unfiltered air ($1.45 \mu\text{g Pb m}^{-3}$)	Filtered air ($0.09 \mu\text{g Pb m}^{-3}$)
Soil	17.1	17.1
Leaf lettuce	6.6	3.2
Cabbage—leaves	4.5	5.8
Tomatoes	0.59	0.72
Beans	1.4	1.2
Bean leaves	20.9	7.9
Sweet corn—kernel	0.22	0.27
cob	0.48	0.69
husk	6.9	1.8
Carrots	1.7	2.1
Potatoes	0.30	0.33
Wheat	0.18	0.16

(b) Field studies near highways in U.S.A.

Metres from road	9.14	36.56	158.5
Air $\mu\text{g Pb m}^{-3}$	2.3	1.7	1.1
	Pb content ($\mu\text{g g}^{-1}$ dry wt)		
Soil	65	40	25
Leaf lettuce	6.5	5.0	4.8
Cabbage—head	0.56	0.86	0.83
Tomatoes	1.3	1.2	1.6
Beans	1.9	1.2	0.9
Potatoes	0.48	0.64	0.40
Sweet corn—kernel	0.39	0.21	0.83
cob	0.74	0.55	0.68
husk	12.6	6.6	5.7
Soybeans—beans	0.28	0.12	0.10
husk	15.9	8.0	5.3
Oats—kernel	0.47	—	0.53
chaff	31.4	15.5	12.8
Carrots	1.6	—	1.5
Wheat—kernel	0.62	0.42	0.48
chaff	17.8	9.8	6.2

Table A-25 Distribution of lead, zinc and copper in plants and soils contaminated by lead mining in Britain*

(Cited from Alloway and Davies 1971)

Metals in soil and plant ($\mu\text{g g}^{-1}$ dry wt basis)

Soil and source of contamination	Expt	Sample	Contaminated			Control		
			Pb	Zn	Cu	Pb	Zn	Cu
Field sites are located in lead-mining areas in	Field	Soil (total)	1,726	547	437	60	121	19
		Herbage	25.8	165	152	3.3	33.3	11.9
Wales	Glass house	Soil	11,200	330	278	44.0	152	23.6
		Radish (roots)	499	55.4	16.6	10.0	43.4	9.4
		Radish (leaves)	136	57.8	13.6	9.9	4.8	15.6

* See Table 1 of the paper by Alloway and Davies (1971) for field data and Table 4(b) for glasshouse data. Uncontaminated (control) field data are average of values from three sites at Frongoch, and the data from contaminated areas are average of values from ten sites. Plant samples were dry ashed at 430°C, the ash taken up in 0.1N HNO₃ and metal contents determined by atomic absorption spectrophotometry.

Table A-26 Distribution of lead, zinc and copper in herbage and soils of England*
(Cited from Thornton 1975)

Area	Total content in soil ($\mu\text{g g}^{-1}$)				Time of harvest	Herbage ($\mu\text{g g}^{-1}$ dry matter)			
	Pb	Zn	Cu			Pb	Zn	Cu	
1. Contaminated alluvium	435	368	620		October	11 (7-15)	53 (26-95)	9 (4-20)	
S.W. England	(60-1,000)	(114-1,020)	(35-2,000)		May	7 (2-10)	65 (34-130)	15 (7-20)	
Control alluvium	85	121	44		October	8 (6-10)	39 (27-46)	8 (6-10)	
S.W. England	(72-96)	(67-180)	(36-50)		May	8	36	12	
2. Contaminated upland	215	207	314		October	10 (5-15)	42 (26-116)	9 (4-22)	
S.W. England	(62-850)	(58-380)	(29-2,000)		May	4 (2-13)	31 (16-49)	9 (4-15)	
Control upland	94	110	50		October	11 (9-15)	39 (20-65)	7 (4-10)	
S.W. England	(48-144)	(42-166)	(16-120)		May	7 (2-10)	31 (22-45)	12 (7-21)	
3. Contaminated area	3,320	247	46		March	121 (53-288)	73 (43-132)	12 (7-15)	
Midlands	(115-72,000)	(41-1,260)	(10-204)		August	25 (5-70)	39 (24-120)	9 (5-14)	
Control area	165	128	48		March	68 (43-114)	94 (72-123)	21 (14-34)	
Midlands	(75-307)	(70-284)	(21-150)		August	11 (5-16)	52 (31-110)	11 (7-16)	

* Soils sampled from 0-15 cm depth. Range of metal concentration in parenthesis.

Table A-27 Distribution of lead, zinc, copper, nickel, chromium, cadmium and cobalt in plants and in soils treated with sludge in Sweden*
(Cited from Andersson and Nilsson 1972)

Site	Sample	Concentration ($\mu\text{g g}^{-1}$ dry matter)						
		Pb	Zn	Cu	Ni	Cr	Cd	Co
Field trial with sewage sludge started in 1956 in Sweden.	Sewage sludge	293	4,890	1,960	88	176	11.0	12.2
	Soil (control)	25.7	97.9	25.5	28.2	36.1	1.2	14.2
	Soil (sludge-treated)	43.9	368.8	90.5	43.3	61.0	1.7	14.6
Sludge applied every second year at approx. 7 tons of dry matter $\text{ha}^{-1} \text{y}^{-1}$	Rape (fodder) grown in:							
	Control soil	5.2	34.3	3.9	4.9	2.6	0.6	1.6
	Sludge-treated soil	7.7	114.5	8.3	9.2	4.1	0.6	1.9

* Since 1956 sewage sludge has been applied every second year at the rate of 7 tons dry matter $\text{ha}^{-1} \text{y}^{-1}$. For analysis, top soil samples (0-20 cm) were taken in 1968, sludge samples from the 1969 application and plant samples from the 1970 crop. Soil samples were extracted with 2M HCl. Sludge and plant samples were dry ashed at 450°C, metals taken up in 1:1 HCl. The metal contents were determined by atomic absorption.

Table A-28 Distribution of lead, zinc, copper and nickel in plants and in soils treated with sludge in England*
(Cited from Richardson 1977)

		Pb ($\mu\text{g g}^{-1}$)	Zn ($\mu\text{g g}^{-1}$)	Cu ($\mu\text{g g}^{-1}$)	Ni ($\mu\text{g g}^{-1}$)
	†				
Total soil	T	297	310	91	28
metal levels	U	44	59	24	18
Lettuce	T	38	276	14	18
	U	14	50	12	17
Carrots	T	5.3	107	6.2	15
	U	3.2	19	5	4.7
Parsnips	T	3.2	104	7.5	9.5
	U	2.2	18	4	2.7
Red beet	T	2.2	181	16	35
	U	3.2	37	7.8	19
Leeks	T	7.5	141	10	85
	U	4.2	32	4.8	50
Cabbage	T	5.3	124	5.5	20
	U	3.2	33	4.8	5.5
Runner beans	T	2.2	48	4.5	24
	U	2.2	35	4.3	6.3

* Vegetable crops were grown at a site on a sandy loam soil where digested sewage sludge had been applied for approximately 15 years. Samples of the same crop were collected from an adjacent field which had received no sludge (see page 11 of the paper by Richardson 1977).

† T = treated (pH = 6.4, organic matter = 5.0%). U = untreated (pH = 6.6, organic matter = 2.2%).

Table A-29 Lead content of perennial rye-grass grown in some soils of England and Wales*
(Cited from Jones and Clement 1972)

Location	Soil Pb extracted with NH ₄ Ac + EDTA μg g ⁻¹	Pb content of plants		Pb uptake by plants	
		Root μg g ⁻¹	Shoot μg g ⁻¹	Root μg	Shoot μg
Nottingham	5.3	10.0	5.1	29.8	17.4
Northumberland	6.9	11.9	5.2	44.1	29.7
Lancashire	40.8	36.8	6.0	90.5	33.1
Cardigan	59.0	37.8	7.4	110.0	27.3

* Soils were collected from experimental husbandry farms of ADAS. Experiment was done in a controlled environment cabinet with filtered air, day/night temperatures of 23°/18°C and a 16-hour photoperiod.

Table A-30 Lead in soil and plant roots, experiment done in Los Angeles, U.S.A.*
(Cited from Rabinowitz 1972)

Location	Soil (total Pb) μg g ⁻¹	μg g ⁻¹ Pb, dry wt	
		Lettuce roots	Oats roots
Pot experiment was done	1,300	1,311	1,234
in UCLA using a clay loam	650	504	535
soil (pH 6.7) treated	280	132	280
with Pb(NO ₃) ₂ at different	97	71	92
levels			

* Some of the atmospheric Pb (4–10 μg g⁻¹) was found in the tap roots of lettuce grown near the highway (experiment was done in pot soils with stable isotope tracer).

Table A-31 Leaching rates of heavy metal ions in forest organic layer*
(Cited from Tyler 1978)

Metal	Metal ions leached as % total content in organic matter					Initial metal content of the organic matter in leaching bed (mg/200 g dry wt)
	Leaching solution in litres per sq. m.					
	500	1,000	1,500	2,000	2,700	
<i>(a) Uncontaminated organic matter (control)</i>						
Zn	5.3	9.8	14.5	19.1	25.5	24.8±0.66
Cd	6.1	11.0	15.7	21.7	32.8	0.182±0.008
Ni	7.1	16.6	27.3	34.6	44.0	1.98±0.07
Cu	3.2	4.9	7.5	9.7	12.1	3.80±0.08
Pb	0.55	0.97	1.4	1.8	2.2	19.6±0.24
V	3.2	5.0	7.8	9.1	10.5	1.92±0.09
Cr	2.2	2.6	3.6	5.8	8.9	0.98±0.02
pH of percolate	4.44	4.48	4.6	4.53	4.5	
<i>(b) Contaminated organic matter</i>						
Zn	4.9	7.7	10.8	13.7	17.9	3080±22
Cd	2.7	4.3	5.6	7.2	9.3	4.56±0.04
Ni	2.5	4.4	6.5	9.1	11.4	4.28±0.06
Cu	0.64	0.93	1.2	1.4	1.68	2640±36
Pb	0.13	0.17	0.19	0.22	0.24	148±2.5
V	15.4	21.3	27.7	33.7	39.9	2.48±0.10
Cr	0.4	0.6	0.8	1.1	1.5	3.60±0.10
pH of percolate	6.24	6.34	6.42	6.18	6.09	

* The experiment was done at room temperature, pH of the leaching solution being 4.2. Leaching bed was made from sieved and thoroughly mixed samples of purely organic needle mor layer from contaminated and uncontaminated spruce forest sites in south-east Sweden.

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