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Plants as Bioindicators of Natural and Anthropogenically Derived Contamination

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ABSTRACT

Plants occupy an important position in the ecosystem, being directly in contact with underlying soil, and providing food for animals, including humans, at higher trophic levels. Their use as indicators in studies of both natural and anthropogenically derived contamination is diverse. The visual appearance of plants, in combination with the presence of particular key species or assemblages, may provide clues to the occurrence of contaminants in the underlying strata. Chemical analysis of plant material, either collected from the field or from laboratory-based plant growth trials, can also provide a measure of the environmental mobility of a contaminant. This article discusses the role of plants as bioindicators with reference to examples of preliminary contaminated land assessment; air pollution monitoring, and studies into the environmental significance of contaminants in domestic and codisposed refuse.

Index Entries: Bioindicators; plants; contaminants; air pollution.

INTRODUCTION

As early as 1920 Clements (*1*) stated that "every plant is a measure of the conditions under which it grows. To this extent it is an index of soil and climate, and consequently an indication of other plants and animals in the same spot."

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Within the terrestrial system plants may take up contaminants via roots from the soil or from aerial deposition to the surface, providing a pathway for ingestion by animals including, in some cases, humans, at a higher trophic level. Consequently they can have an important role to play in studies of the flow of contaminants through ecosystems.

The use of plants as indicators of contamination can be divided broadly into two categories: one requiring interpretation of visual features of the plant community, and the other requiring chemical analysis of biological material. The two need not be mutually exclusive.

Visual Indicators

Some species are more tolerant of particular contaminants than others. Hence the community occurring on a significantly contaminated site may be dominated by tolerant species, and have few, or no, intolerant or sensitive species. A universal indicator species is one that normally occurs in locations where there are abnormally high levels of a particular contaminant. These species are the most useful because their presence provides definite evidence of contamination. Species that have developed tolerant ecotypes capable of colonizing contaminated areas, but that also occur in uncontaminated environments, are regarded as local indicators (2). The visual appearance of a plant, including leaf color, vegetative habit, and root structure may also provide clues to the presence of some contaminants.

Chemical Analysis

Analysis of the chemical constituents of plant material provides a measure of the environmental mobility of the chemical within the soil environment. Certain species of plants accumulate particular contaminants within their tissues in proportion to environmental levels and can be used as indicators of the relative levels of contaminants in different locations.

Chemical analysis can be used in a variety of ways. For example, material can be collected from the field and analyzed. Alternatively, or in conjunction with field analysis, bioassays can be established under laboratory conditions, providing an opportunity to ensure controlled environmental conditions (e.g., light, temperature); species selection, and experimental design. A further use of plants is the placement of selected vegetation in predetermined locations. Material may be left *in situ* for a period of time, harvested, and analyzed. This latter approach is more frequently carried out in air pollution studies.

This article will examine, by reference to the following three examples, the use of plants as indicators and monitors of contamination:

1. Visual observation of plant species and assemblages as indicators of soil contamination;
2. Use of moss bags in air pollution studies;

3. Analysis of plant materials to provide information on bioavailability of contaminants.

VISUAL INDICATORS

AERC was recently commissioned by the UK Department of the Environment to review the use of visual indicators in preliminary site inspection of land that may be contaminated, and to draw up a guidance manual that could be used by field personnel. The review considered both abiotic and biotic (plants, invertebrates, small mammals) features. Of the biotic indicators, plants were considered to be an important group.

The use of plants to provide an indication of soil contamination is not a new area. A classic example of the approach is in the field of geobotanical prospecting in which the occurrence of a particular species, or assemblage of species, is a good indicator of the presence of mineral ores. An example of such species is the universal indicator zinc violet (*Viola calaminaria*), which is reported to be tolerant of the zinc-bearing soils (3).

The distribution of a plant within a particular location is governed by a broad range of factors of which the presence or absence of contaminants is just one. Other factors include: soil pH; soil texture; nutrient status; geographical location; water availability and the presence of a seed bank either within the underlying soil or in adjacent land; and the time since colonization occurred.

Plants have a number of advantages over other biological indicators. They are static, and higher plants are readily visible to the naked eye. As a consequence of rooting into the underlying strata they tend to reflect the substrata, and because of the extent of research that has been carried out, particularly in relation to metal and pH, indicator species and symptoms are relatively well documented. However, as plants are seasonal, there may be problems with identification, particularly for the less-experienced surveyor. They tend to be shallow rooting reflecting the surface condition rather than the occurrence of contamination at depth. Other factors that need to be taken into account when interpreting symptoms are the possibility of mimicking symptoms combined with the range of soil and characteristics that may influence plant distribution. Bearing these limitations in mind the following may be relevant indicators.

Trees

The occurrence of mature trees provides some evidence to indicate that the site has been disused for a relatively long period of time. Hence contamination, if present, is historical rather than of recent origin. Young saplings growing alongside mature trees provides further evidence of a balanced ecosystem. If it is at all possible to examine the roots of a tree,

Table 1
Examples of Indicator Species

Species	Common name	Waste or contaminant
Armeria maritima	Thrift	Cu (inland sites)
Silene vulgaris	Bladder campion	Zn (inland sites)
Agrostis tenuis	Common bent	Cu, Zn, Cd, Pb
Minuartia verna	Vernal sandwort	Cu, Pb, Ag, Zn
Festuca ovina	Sheep's fescue	Zn, Pb, Cd
Viola lutea	Mountain pansy	Zn, Pb
Attriplex spp.	Orache	Salinity, e.g., power station ash

the presence of a shallow rooting system may indicate contamination at depth. This type of rooting, combined with leaf loss, is one of the more obvious signs of the presence of landfill gas.

Surface Vegetation

A number of clues can be obtained from the appearance, extent of cover, and presence of indicator species. Bare patches in an otherwise well-vegetated area, are one of the most obvious characteristics of a potentially contaminated site. Causes can include disturbance, contamination, soil infertility, or periodic waterlogging. However, when caused by contamination there may be deposits on the soil surface, staining, and/or a characteristic odor. The presence of indicator species is a further guide to the presence of a particular types of contaminant. Some examples are included in Table 1.

The most widely described effects of metal toxicity on plants are inhibited root growth, depressed shoot and leaf growth, and general chlorosis of the younger leaves (*4,5*). Other aspects that have been noted on the roots of leguminous species are the occurrence of small white nodules as opposed to larger, pink, nodules, which have the capacity to fix nitrogen (*6*).

In conclusion, plants are generally the most useful biotic indicators since they are static, they root directly into the medium that may be contaminated, and discontinuities in plant communities are readily visible. Limitations arise from seasonality and the fact that their distribution/abundance and symptoms are also influenced by other ecological factors.

MOSS BAGS AS MONITORS OF AIR POLLUTANTS

Moss bags have been used as a monitoring technique, primarily for metals, since the early 1970s (*7,8*). Moss has a number of characteristics that provide a high retention capacity. These are related to its high cation exchange capacity, morphology, and ability to absorb and retain water. A

Table 2
PCB Concentration Detected in Moss Bags
in Two Surveys Around an Incinerator

		PCB Concentration μ g·kg^{-1}					
		0–40		0–100		>100	
	Range	No. of samples	%	No. of samples	%	No. of samples	%
Survey 1	6–225	110	86	126	98	2	0
Survey 2	1–96	35	80	9	20	0	0

common approach is to fill a flat nylon envelope constructed from fine net with sphagnum moss. The moss bags can then be left at points within the area of study for a predetermined period of time, usually in the order of a few weeks. The principal advantages to moss bags are that they are relatively cheap, do not require a power supply, and hence are suitable for surveys of spatial patterns involving a large number of sampling locations.

In the UK, AERC has been responsible for the design and implementation of an external environmental monitoring program around an incinerator designed to destroy wastes originating primarily from the petrochemical, pharmaceutical, agro-chemical, printing, electrical, and general chemical and engineering industries. This program has been based on the analysis of soils, vegetation, and moss bags, used primarily to assess relative atmospheric emissions. All media were analyzed for a selected number of "signpost" metallic contaminants and PCBs. Although moss bags have been used frequently for investigation of metal distibution, to our knowledge there are few examples of their use to monitor PCBs.

Two surveys were carried out, the first being coverage of a large area (330 km^2) at 128 sites, and the second being a more intensive study of the area within the immediate vicinity of the incinerator and other industrial processes. The recovery of moss bags after the survey period was high, being in the order of 97%. The concentration of PCBs within the moss bags in both surveys is indicated in Table 2. With the exception of an elevation recorded within the industrial complex in the first survey, the data were comparable. Since the incinerator was not operative during the first survey, an alternative low level source of PCBs is indicated.

ANALYSIS OF PLANT MATERIAL

Vegetation analysis has been used as one component of extensive and long-running investigations into the environmental mobility of contaminants in domestic and codisposed refuse. These studies have included

Table 3
Initial Concentrations of Cadmium, Copper, Lead, and Zinc within Refuse, Topsoil, and Compost[a]

Matrix	Cd	Cu	Pb	Zn
Refuse	8.94	964	1517	1930
Topsoil	0.09	63	97	153
Compost	0.12	96	146	207

[a]Values as $mg \cdot kg^{-1}$.

Table 4
Metal Application Rate to the Four Media[a]

Treatment	Cu/Zn	Pb	Cd
1	156	31	3.1
2	313	63	6.3
3	625	125	12.5
4	1250	250	25
5	2500	500	50
6	5000	1000	100

[a]Values as $mg \cdot kg^{-1}$.

collection and analysis of indigenous vegetation as well as the establishment of pot and field-based trials in which specific species of plant have been selected as bioindicators. Other components of these investigations have been the analysis of invertebrates, small mammals, and soils, and studies into the speciation of contaminants within refuse of different ages. The range of contaminants investigated has been broad, including phenols, pesticides, and heavy metals.

The biological availability of a metal is a function of both the metal and the medium in which it is dispersed. This was illustrated by a laboratory-based trial in which the uptake of lead, copper, zinc, and cadmium from 10-yr-old refuse, topsoil, compost, and sand was compared. Each growth medium was spiked with a cocktail of metals supplied as the soluble salts of copper chloride, zinc chloride, lead acetate, and cadmium chloride. Initial concentrations of each metal, and application rates, are included in Tables 3 and 4.

The treatments were replicated and each pot seeded with *Lolium perenne* var. 23. After 12 weeks, vegetation was harvested and samples digested and analyzed for lead, copper, zinc, and cadmium. Uptake and survival was markedly different for the four media. The seedlings failed to survive on the sand but survived on the refuse at all treatments (Table 5). At comparable concentrations uptake from the refuse was generally lower than from either compost or topsoil (Table 6).

Table 5
Plant Survival on Soil Media Spiked with Metals

Treatment	Refuse	Topsoil	Compost	Sand
1	+	+	+	-
2	+	+	+	-
3	+	+	-	-
4	+	-	-	-
5	+	-	-	-
6	+	-	-	-

+, Survival; – nonsurvival.

Table 6
Metal Uptake by Lolium Perrene from Various Soil Media[a]

	Soil medium		
Treatment	Refuse	Topsoil	Compost
Copper			
1	14.2 ± 1.3	24.3 ± 1.5	23.3 ± 2.8
2	14.6 ± 2.8	34.5 ± 3.8	26.9 ± 3.5
3	29.7 ± 2.6	43.5 ± 1.1	—
4	17.2 ± 1.8	—	—
5	29.6 ± 3.7	—	—
6	46.9 ± 2.4	—	—
Cadmium			
1	4.7 ± 0.4	24.7 ± 1.4	15.7 ± 0.9
2	8.0 ± 1.2	20.0 ± 1.4	37.3 ± 2.8
3	9.1 ± 1.1	52.1 ± 2.4	—
4	11.5 ± 0.4	—	—
5	32.6 ± 4.7	—	—
6	52.9 ± 1.8	—	—
Lead			
1	19.9 ± 0.3	20.5 ± 0.3	15.6 ± 0.6
2	23.5 ± 0.9	32.1 ± 1.1	20.2 ± 1.2
3	27.3 ± 0.3	49.2 ± 0.8	—
4	36.4 ± 0.9	—	—
5	52.7 ± 1.5	—	—
6	70.4 ± 1.7	—	—
Zinc			
1	130 ± 10	198 ± 9	307 ± 16
2	132 ± 11	280 ± 18	439 ± 36
3	171 ± 14	668 ± 29	—
4	137 ± 17	—	—
5	332 ± 18	—	—
6	445 ± 33	—	—

[a]Values as $mg \cdot kg^{-1}$.

The data from this and other studies have been used to obtain a greater understanding of the mechanisms by which contaminants are immobilized in refuse. This, in turn, has provided a basis for determining the impact of landfills on the surrounding environment, and the development of restoration techniques (*9*).

CONCLUSIONS

Plant material can provide a valuable tool in the assessment of contamination, whether from natural or anthropogenically derived sources. In the context of preliminary site inspection they, in conjunction with other features of the site, can assist in determining both the degree and nature of contamination. Plants also have a valuable role to play in the next stage of an assessment, once the extent of contamination within the underlying strata has been determined. In this context they can be used in the assessment of environmental mobility as a basis for determining risk to targets, and whether remedial action is required. However, plants only provide information on one contaminant pathway, and others, including uptake via soil microorganisms and invertebrates, may also need to be considered.

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