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Preliminary studies on the ability of plant barriers to capture lead and cadmium of vehicular origin

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Abstract

The purpose of this study is to determine the type of plant barrier most suitable for the protection of areas adjacent to roadways from the emissions of motor vehicles, as well as to establish the most efficient plant species for use in the barriers. The survey gathered the following samples: (a) grass and soil samples near the major Italian motorway networks and from sites directly exposed to vehicle emissions or protected by plant barriers; (b) samples of leaves from various species of trees, growing both alongside motorways and in urban and remote sites. The results show that the most efficient barriers are those placed immediately alongside the road edge and the most efficient species are deciduous broadleaves and small-needle conifers.

Keywords: Environmental pollution; Heavy metal; Bioaccumulation

1. Introduction

Several studies have examined the distribution of motor vehicle emissions, especially Pb, in the soil and vegetation near roadways, which have shown that their levels decrease as the distance from the road edge increases (Kingston et al., 1988; Ferretti et al., 1991; 1992). A comparison of the results presented by these authors with the Pb levels measured in areas not directly contaminated by this element (Zöttl, 1985; Bussotti et al., 1992) shows that in herbaceous vegetation, Pb drops to values that can be defined as 'not infrequent' (< 10 ppm) at 15–20 m from the road, and to 'background' values (< 5 ppm) at 60 m. In soil, 'not infrequent' (< 100 ppm) and 'background' (< 50 ppm) levels can also be found at more or less the same distances from the road edge. However, it has been shown (Kingston et al., 1988) that the 'proximal' distribution of Pb accounts for only 25% of emissions, while the remainder ends up in so-called 'background contamination' and can fall out at a considerable distance from the source, according to the orographic conformations of the area (Glavac et al., 1987). Several studies have reported on the increased exogenous Pb levels in leaves of trees growing in urban environments (Kovacs et al., 1982; Romero, 1986; Manes et al., 1989; Alfani et al., 1989 and Cappelli et al., 1989). Although top priority in environmental protection strategies should be given to measures aimed at reducing motor vehicle emissions, it is also possible to exploit the capacity of certain plant species to capture and retain pollutants 'in situ', thereby preventing their dissemination over a broader area.

The main biological characteristics which can influence the ability to capture and retain pollutants (which in the case of heavy metal pollutants can be in molecular or particulate form) are the following:

The nature of the contact surface: The efficacy of the various plant organs (leaves, twigs, bark) in retaining pollutants is determined both by the duration of the exposure and by the texture (more rugose or more spongy) of the surface itself. In fact bark shows the

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greatest accumulation capacity, at least as far as heavy metals are concerned (Grodzinska, 1982);
The extent of the leaf surface: in other words the sum total of the surface of all the leaves in the crown;
Shelter factors (Schuepp, 1989): Dry deposition of atmospheric pollutants is enhanced within the microenvironments (spaces between leaves) that exist in the crown of a tree. This behaviour is also the result of the microclimate within these shelters, especially the humidity saturation;
the characteristic features of the leaf surface: The physical characteristics (pubescence and rugosity) and the chemical ones (the extent to which the epicuticular wax structures bind to the pollutants) influence the leaves' capacity to retain particulate matter (Wedding et al., 1977);
The stomatal potential: Gaseous or molecular state pollutants can be absorbed via the stomata. The absorption capacity of the leaves is affected by the intensity of the gaseous exchanges between the tree and the atmosphere;
Phenology: The contact surface of evergreen species remains constant throughout the year, while deciduous species only have a contact surface during their vegetational period. Semi-deciduous species, i.e. those that retain their dead leaves on their branches through the winter (e.g. *Quercus pubescens* Willd and *Carpinus betulus* L.), have a greater pollutant absorption capacity, although they also have an equally great capacity to return these pollutants to the environment during and after precipitations.

The purpose of this study was to check the efficiency of plant barriers in their normal cultural conditions and to determine the most suitable structural models and the specific composition of plant barriers designed to protect surrounding areas from motor vehicle pollution.

2. Materials and methods

2.1. Sampling

Samples were gathered during the summer of 1989 from the following sites: (a) sites along the motorway network, covering about 1000 km of roads in Northern, Central and Southern Italy, with average daily traffic levels ranging from 20 000 to 50 000 vehicles; (b) urban sites (Florence), where traffic is very intense and there are frequent traffic jams and (c) a control site on the Western slopes of the Monti Livornesi (Tuscany), not directly exposed to vehicular emissions. About 30 g of fresh material were gathered for each sample.

Assessment of the efficiency of the barriers. Three hundred and eighty samples of herbaceous vegetation and 384 topsoil samples (0–5 cm depth) were gathered from 135 sites alongside motorways with and without plant barriers. Each sample gathered was randomized so as to represent 1 m^2. The specific composition of each barrier, as well as its vertical stratification and its exact position in relation to the road was recorded. The samples were taken at different distances from the road edge, from sites directly exposed to traffic emissions and others protected by the barrier.

Assessment of the efficiency of the different species. Six hundred and ninety one samples of leaves were gathered from trees along the motorway network, in an urban area (Florence) and in one control site. The samples gathered represent 82 different plant species. Samples were collected from the lower section of the crown of trees (4–5 m above ground) and from the median section of shrubs (about 1–1.5 m above ground), which are the parts most directly exposed to emissions; samples were also taken in such a way as to represent all four cardinal directions.

2.2. Analyses

In order to assess the overall efficiency of a species or a plant barrier, Pb and Cd analyses were performed on unwashed samples. The data, expressed in ppm ($\mu g.g^{-1}$ dry wt.), therefore represent the total content (depos-

Table 1
Percentage of the different tree and shrub species used in barriers surveyed[a]

Species	%
Robinia pseudacacia L.	24
Nerium oleander L.	7
Acer spp.	6
Populus nigra L.	6
Ligustrum spp.	6
Cupressus arizonica Greene	5
Pinus halepensis Mill.	4
Quercus cerris L.	4
Pyracantha spp.	4
Alnus cordata Loisel	3
Eucalyptus spp.	3
Prunus spp.	3
Quercus pubescens Willd.	3
Ulmus spp.	3
Castanea sativa Mill.	2
Laurus nobilis L.	2
Pittosporum tobira Ait.	2
Vitis vinifera L.	2
Betula spp.	1
Cedrus spp.	1
Crataegus spp.	1
Fraxinus excelsior L.	1
Malus spp.	1
Pinus pinaster Ait.	1
Pinus pinea L.	1
Pinus sylvestris L.	1
Rubus spp.	1
Sambucus nigra L.	1
Viburnum tinus L.	1

[a]frequency, $n = 100$.

Table 2
Position and structure of barriers surveyed

Distance from road edge (m)	Single layer barriers %[a]	Double layer barriers (%)[b]	Total %[c]
0–1	8	35	16
1–3	13	22	16
3–5	33	17	28
5–10	35	22	31
10–20	11	4	9

[a](n = 52).
[b](n = 23).
[c](n = 75).

ited, adsorbed and absorbed) of these elements. Samples were oven-dried at 65°C and then ground finely. All measurements were performed at the central laboratory of Società Autostrade SpA by solid spectrophotometry using a Gruen SM 20 Zeeman effect spectrophotometer, interfaced with an IBM AT 286 computer and electronic Sartorius Micro M 500 P scales, all entirely managed by software. With this test procedure and these instruments it was possible to analyse each sample 'as is', i.e. without putting it through further treatments. Three measurements were performed on each sample and the final value is the mean of the three.

2.3. Statistics

The results are expressed in descriptive statistics (no., min., max., median, mean, standard deviation (S.D.)). Correlations were calculated using Pearson's r coefficient; the significance of the differences was tested with Student's T test.

3. Results and discussion

3.1. The efficiency of the barriers

Of the barriers examined, 52 are single-layer and 23 are double-layer. Among the 29 taxa making up the barriers (Table 1), the only one which is represented with

Table 3
Pb and Cd in grass samples collected at different distances from the road edge

Distance (m)	B[a] W/B[b]	n	Min.	Max.	Median	Mean	S.D.
Pb							
0–1	B						
	W/B	56	2.68	293.72	32.70	49.00	60.24
1–3	B	12	5.04	74.55	12.60	17.98	12.60
	W/B	24	1.15	89.78	16.40	24.49	16.40
3–5	B	54	2.78	81.87	10.11	17.07	16.26
	W/B	27	6.14	161.53	23.01	35.50	36.26
5–7	B	14	1.01	36.14	11.06	13.82	10.38
	W/B	15	2.11	71.12	14.67	21.12	17.40
7–10	B	46	2.12	175.85	6.91	13.30	26.44
	W/B	14	1.073	135.70	6.59	22.75	35.38
10–15	B	39	1.32	51.52	4.75	7.79	9.74
	W/B	19	2.31	29.30	6.40	8.44	7.11
15–20	B	13	2.22	28.56	6.98	8.06	6.97
	W/B	14	1.62	26.99	5.46	9.00	7.70
>20	B	14	1.25	7.61	4.39	4.20	1.76
	W/B	19	1.38	33.68	3.63	6.87	9.73
Cd							
0–1	B						
	W/B	56	0.02	2.01	0.24	0.31	0.32
1–3	B	12	0.02	0.26	0.09	0.10	0.07
	W/B	24	0.01	0.51	0.11	0.15	0.13
3–5	B	54	0.04	0.65	0.14	0.18	0.14
	W/B	27	0.03	2.12	0.07	0.23	0.41
5–7	B	14	0.03	0.77	0.10	0.15	0.18
	W/B	15	0.02	0.16	0.08	0.09	0.05
7–10	B	46	0.01	0.36	0.14	0.14	0.07
	W/B	14	0.02	0.49	0.09	0.12	0.11
10–15	B	39	0.02	0.36	0.11	0.13	0.07
	W/B	19	0.02	0.24	0.06	0.07	0.05
15–20	B	13	0.01	0.19	0.07	0.09	0.06
	W/B	14	0.00	0.18	0.04	0.05	0.04
>20	B	14	0.00	0.36	0.07	0.08	0.09
	W/B	19	0.01	0.17	0.06	0.08	0.06

[a]Behind plant barrier.
[b]without plant barrier.

Table 4
Pb and Cd in topsoil samples collected at different distances from the road edge

Distance (m)	B[a] W/B[b]	n	Min.	Max.	Median	Mean	S.D.
Pb							
0–1	B						
	W/B	75	13.63	3868	411.25	611.11	628.79
1–3	B	12	48.41	574.40	153.41	225.19	171.15
	W/B	34	21.04	862.85	188.57	259.93	207.18
3–5	B	28	32.02	632.78	106.69	154.86	130.75
	W/B	44	21.02	942.38	151.79	187.28	169.86
5–7	B	18	23.02	785.86	92.46	166.11	196.46
	W/B	27	13.89	662.15	92.31	152.81	163.39
7–10	B	17	29.25	379.73	83.48	118.25	86.33
	W/B	26	21.08	808.13	68.84	111.65	152.88
10–15	B	24	22.90	223.17	74.74	89.90	54.90
	W/B	33	17.91	194.74	53.70	69.22	42.06
15–20	B	20	2.16	170.87	55.10	64.92	42.69
	W/B	26	3.07	373.70	50.12	90.56	93.41
>20	B	31	19.53	210.53	49.34	54.59	35.65
	W/B	17	23.99	353.48	46.26	81.55	98.74
Cd							
0–1	B						
	W/B	75	0.11	8.82	0.79	1.60	1.95
1–3	B	12	0.13	1.03	0.49	0.53	0.28
	W/B	34	0.08	2.12	0.46	0.64	0.53
3–5	B	28	0.10	1.63	0.41	0.55	0.44
	W/B	44	0.07	3.59	0.36	0.60	0.78
5–7	B	18	0.11	2.78	0.34	0.79	0.85
	W/B	27	0.03	5.17	0.34	0.65	1.01
7–10	B	17	0.12	1.33	0.34	0.39	0.27
	W/B	26	0.12	0.90	0.25	0.32	0.21
10–15	B	24	0.13	1.47	0.30	0.43	0.35
	W/B	33	0.08	2.15	0.22	0.32	0.38
15–20	B	20	0.01	0.95	0.24	0.29	0.22
	W/B	26	0.05	1.02	0.23	0.30	0.24
>20	B	31	0.05	2.36	0.21	0.42	0.49
	W/B	17	0.09	0.40	0.15	0.19	0.01

[a]Behind plant barrier.
[b]without plant barrier.

high frequency is *Robinia pseudacacia* L., accounting for 24% of the samples. Of the species, 87% were broadleaves, and of these 65% were deciduous trees. Table 2 illustrates the position of the barriers in relation to the road edge.

For the purposes of this study, the authors felt it was necessary to distinguish between absolute efficiency (E_a) and relative efficiency (E_r). Absolute efficiency results from the presence of the barrier, in that it constitutes an obstacle for the spread of pollutants; while relative efficiency, given equal structural and specific characteristics (composition, height, depth), will depend on the distance of the barrier from the road. The findings are analysed according to the criteria of efficiency described above:

As a comparison between all different grass and soil samples from sites located at different distances from the road, protected by a barrier or not (E_a);

As a comparison between topsoil samples gathered from sites all located at the same distance from the road, but protected by different kinds of barriers (E_r).

Tables 3 and 4 contain the descriptive statistics of the Pb and Cd content in grass and soil samples gathered from sites at different distances from the road edge. In all cases the concentrations decrease as the distance from the road edge increases, although there is a very high dispersion of values. Overall, the correlations between distance from road edge and Pb and Cd concentrations are very significant ($P < 0.01$), both in grass samples (Pb: $r = -0.95$; Cd: $r = -0.89$) and in topsoil (Pb: $r = -0.97$; Cd: $r = -0.89$).

The differences between samples gathered from protected and exposed sites are more marked in the grass samples (this difference is more significant in the 3–5 m distance class $P < 0.05$), than in the topsoil, since the

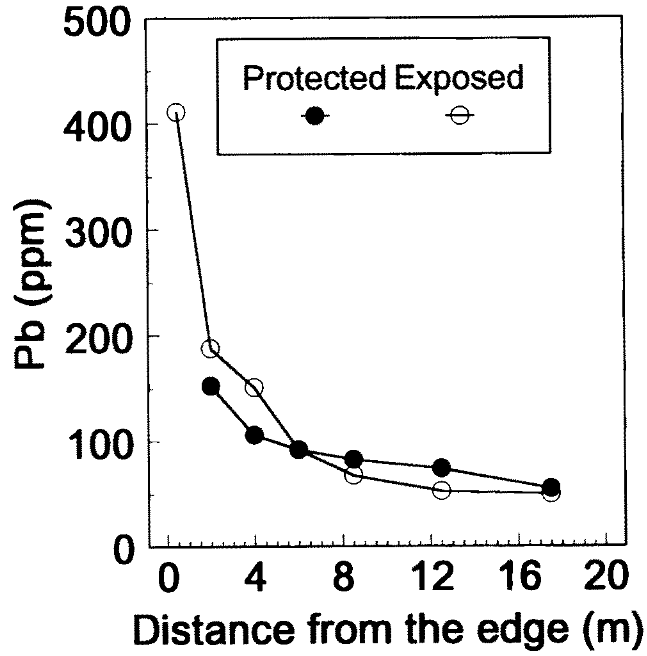

Fig. 1. Median Pb concentrations in grass samples taken at varying distances from the edge of the motorway, in exposed and protected sites (in front of and behind plant barriers) (absolute efficiency of the barriers).

soil is subjected to a continuous accumulation process while grass is affected only by the exposure that occurs after it sprouts. In this particular case, the absorption of Pb through the roots is inhibited by the alkaline reaction of the soils at the motorway sites, which are normally soils transported from elsewhere (Ferretti et al., 1992). At 12.5 m from the road Pb and Cd concentrations reach levels that are defined as 'not infrequent' in both protected and exposed sampling sites.

Overall, there is a very significant positive correlation ($P < 0.01$) between Pb and Cd concentrations both in grass ($r = 0.83$) and in topsoil samples ($r = 0.98$). The enrichment factors (E_f, concentration at road edge/concentration measured at a distance of more than 20 m) are higher for Pb (grass, 4.8–11; soil, 7.5–8.9) than for Cd (grass, 2.5–4.2; soil, 3–4.9), thus confirming that Pb is a more suitable tracer for the monitoring of motor vehicle pollution. Ferretti et al. (1992) have also reported significant correlations between traffic volume and Pb and Cd content. Figs. 1 and 2, constructed on the median values, show the absolute efficiency of barriers as observed in topsoil and grass samples for Pb. In samples gathered as far as 5–7 m from the road edge, pollutant concentrations are always lower in sites protected by a barrier.

As far as relative efficiency is concerned, the findings reported in Fig. 3 show the reduction coefficients (R_c) of Pb in topsoil samples taken at varying distances from the road, as compared to the concentration found in the soil samples collected at the road edge (R_c = 1–ppm at a specified distance from the road/ppm at the road edge). This coefficient increases as the distance from the

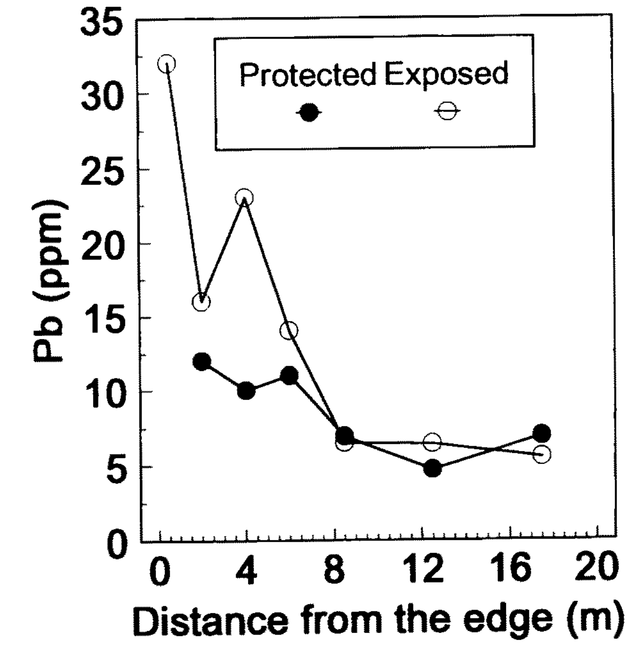

Fig. 2. Median Pb concentrations in topsoil samples taken at varying distances from the edge of the motorway, in exposed and protected sites (absolute efficiency of the barriers).

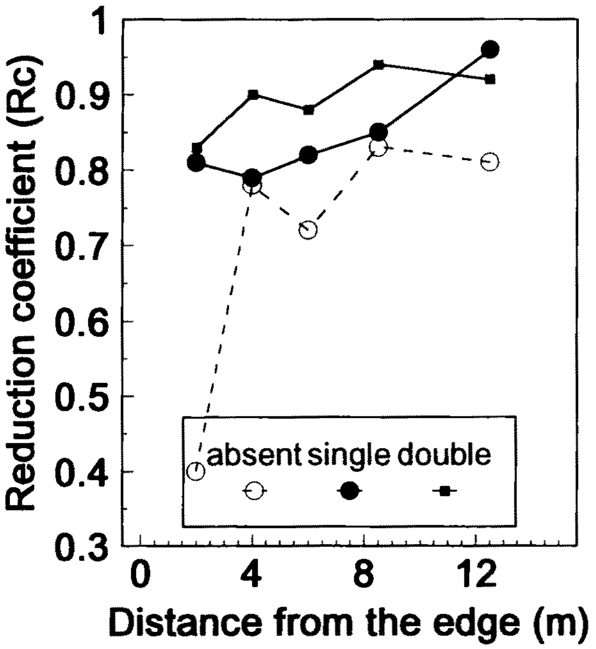

Fig. 3. Reduction coefficients (1–ppm in sample taken at distance n / ppm in sample taken at road edge) of Pb concentrations in topsoil in relation to the type of plant barrier (absent, single and double layer barrier), for barriers placed < 1 m from road edge (relative efficiency of the barriers).

Table 5
Pb and Cd in leaf samples collected in different sites

Sampling site	Group of trees	n	Min.	Max.	Median	Mean	S.D.
Pb							
Motorway							
<3 m	Conifers	5	7.83	26.87	17.99	18.66	7.74
	Evergreen br.	34	0.38	91.77	10.21	13.29	15.20
	Deciduous br.	28	1.00	172.67	15.82	34.72	41.30
	Conifers	17	0.91	65.36	14.83	17.40	16.79
	Evergreen br.	9	2.64	30.24	7.80	9.41	8.26
	Deciduous br.	45	3.10	70.09	17.09	20.52	15.64
7–15 m	Conifers	5	5.92	18.61	9.88	10.21	5.15
	Evergreen br.	17	0.65	29.53	3.39	6.45	7.32
	Deciduous br.	52	2.03	64.48	9.13	13.03	12.59
Urban site	Conifers	59	1.33	132.00	17.65	27.99	22.69
	Evergreen br.	59	2.30	218.84	13.49	17.21	27.87
	Deciduous br.	152	2.02	157.68	16.07	22.32	22.08
Control	Conifers	17	0.28	2.10	0.97	1.07	0.56
	Evergreen br.	31	0.32	3.74	1.15	1.49	1.00
	Deciduous br.	39	0.39	4.39	1.53	1.66	0.89
Cd							
Motorway							
<3 m	Conifers	5	0.03	0.22	0.05	0.09	0.08
	Evergreen br.	34	0.01	0.29	0.06	0.08	0.08
	Deciduous br.	28	0.01	0.58	0.06	0.13	0.14
3–7 m	Conifers	17	0.01	0.27	0.09	0.11	0.09
	Evergreen br.	9	0.01	0.07	0.05	0.05	0.02
	Deciduous br.	45	0.01	0.36	0.06	0.09	0.07
7–15 m	Conifers	5	0.02	0.35	0.07	0.14	0.14
	Evergreen br.	17	0.01	0.09	0.06	0.06	0.02
	Deciduous br.	52	0.01	0.40	0.06	0.09	0.089
Urban site	Conifers	59	0.01	0.47	0.07	0.10	0.09
	Evergreen br.	59	0.03	0.88	0.07	0.12	0.14
	Deciduous br.	152	0.02	4.77	0.08	0.16	0.43
Control	Conifers	17	0.02	0.52	0.06	0.09	0.11
	Evergreen br.	31	0.02	0.22	0.05	0.07	0.04
	Deciduous br.	39	0.02	0.14	0.04	0.05	0.06

br., broadleaves

road increases, and it is always higher in sites protected by double-layer barriers placed right at the road edge, although these differences decrease as the distance from the road edge increases. The data concerning barriers placed at greater distances from the roads edge and those concerning Cd levels are not presented in this paper, since they display considerable fluctuations and no typical behaviour can be identified.

3.2. The efficiency of the different plant species

Mean 'background' concentrations in the leaves of trees not directly exposed to contamination are 0.5–2 ppm of Pb and <0.1 ppm of Cd (Table 5 and Fig. 4). The Cd/Pb ratio ranges from 1:10–1:70. Similar results were obtained in other surveys analysing the leaves of tree species growing in remote forest sites (Bussotti et al., 1992) whereas in all urban and motorway sites the content of both elements is always higher (Table 5 and Fig. 4). The Cd/Pb ratio in urban and motorway sites range from 1:100 to 1:1000, the difference between these values and those of the control sites is determined mainly by an increase in the Pb content. The correlation between Pb and Cd is very significant ($P < 0.01$) both in samples from the motorway sites ($r = 0.878$) and in those from urban sites ($r = 0.813$), whereas it is not significant in the samples gathered in the control site.

Analysis of the findings in terms of groups of species (grouped according to their characteristic features) does not appear to show any significant differences ($P > 0.05$) in Pb content between the leaves of conifers and deciduous broadleaves, while evergreen broadleaves have the lowest concentrations (and here the difference is significant in most cases, with $P < 0.05$). There are greater fluctuations in the concentrations of Cd. In Table 6 the mean enrichment factors (E_f = ppm in leaves of trees in exposed sites/ppm in leaves of trees in control site) for Pb and Cd are given for each species. It is not possible to compare these data, since the exposure conditions are not the same for all species, but in any case they can at least be considered indicative. These

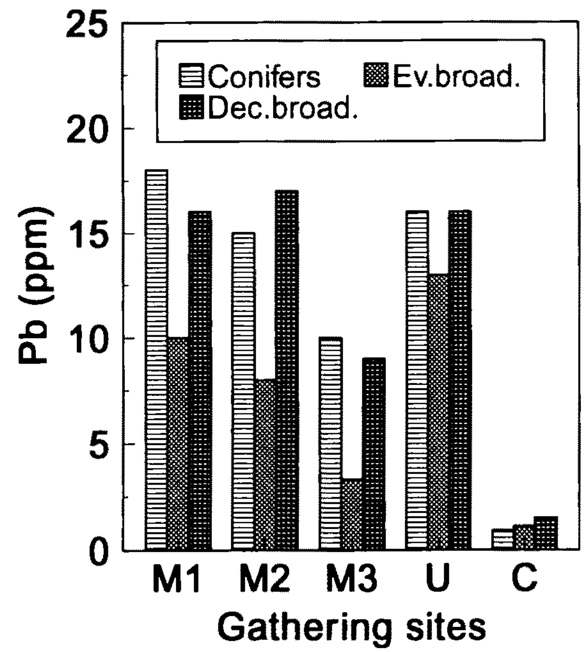

Fig. 4. Pb and Cd concentrations in groups of species (Conifers, Evergreen broadleaves and Deciduous broadleaves) sampled in several urban and motorway sites. M1, Motorway site 0–3 m from the edge; M2, Motorway site 3–7 m from the edge; M3, Motorway site 7–15 m from the edge; U, Urban site; C, Control site.

findings show that, among the broadleaves, the highest accumulation of Pb is found in species with large and/or rugose leaves (*Castanea sativa* Mill., *Acer* spp., *Tilia* spp., *Ulmus* spp.), which agrees with the findings reported by Wedding et al. (1977); while shrub species

Table 6
Mean enrichment factors of Pb and Cd in leaves exposed to motor vehicle traffic in urban and motorway sites, as compared to leaves not exposed[a]

F[b]	Leaf species
Pb	
>30	*Cupressus* spp.; *Cedrus* spp.; *Pinus* spp.; *Castanea sativa* Ait.
20–30	*Acer* spp.
15–20	*Ulmus* spp.; *Tilia* spp.
10–15	*Robinia pseudacacia* L.; *Quercus* spp.; *Prunus* spp.; *Ligustrum* spp.
>10	*Populus* spp.; *Laurus nobilis* L.; *Lagerstroemia indica* L.; *Pyracantha* spp.
Cd	
>3	*Castanea sativa* Mill.; *Quercus* spp. (deciduous species); *Prunus* spp.; *Populus* spp.
2–3	*Acer* spp.; *Tilia* spp.; *Ulmus* spp.; *Laurus nobilis* L.
<2	*Cupressus* spp.; *Pinus* spp.; *Robinia pseudacacia* L.; *Quercus ilex* L.; *Ligustrum* spp.; *Pyracantha* spp.

[a]ppm in leaves from exposed sites / ppm in leaves from control site
[B]without plant barrier.

are less efficient. Among the conifers, the most efficient species are those with small needles or leaves (cypresses and cedars). The highest accumulation of Cd in deciduous broadleaves is found in the Salicaceae, followed by *Castanea sativa* and maples (once again, appearing to be among the most efficient species). Among the evergreen broadleaves high levels of Cd (0.2–0.3 ppm) were found in *Laurus nobilis* L. and *Prunus laurocerasus* L. Among conifers, the data relating to Cd are identical to those relating to Pb.

4. Conclusions

Since there is a rapid reduction of Pb and Cd concentrations within the first few metres from the edge of roadways, the main role of plant barriers is not so much to protect the environment in the immediate vicinity of the roadway (for this purpose, it would be sufficient to widen the protection strip alongside the motorway), but rather, through the increase of the impact surfaces, to eliminate considerable quantities of heavy metals and road dust from the environment, preventing them from being transported further afield and from contributing to background pollution. Distance from the road and height of the barrier will have an influence on the efficiency of a plant barrier. There are complex problems involved in choosing which species to use. The findings show that deciduous broadleaves are highly efficient, but their efficiency is restricted to the summer months and although shrub species have not proved particularly efficient, they have a very important role to play in forming the bottom layer of the barrier. The results described in this paper, although still preliminary, do allow us to suggest a model for a mixed barrier, made up of evergreen and deciduous species, as well as semi-deciduous species. The barrier should be tall and deep, compact both horizontally and vertically, and placed right at the road edge. This way the barrier can also perform a useful aesthetic function and reduce noise pollution. But it is important to bear in mind that the accumulated heavy metals can revert to the environment through the process of abscission unless fallen leaves are regularly removed.

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