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Could Ornamental Plants Serve as Passive Biomonitors in Urban Areas?

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Abstract. A search for cheap and efficient method to monitor atmospheric particulates in city centres has raised new interest to measure foliar element concentrations after the role of particulate pollution for respiratory illnesses was discovered. Leaf samples of Golden dewdrop (*Duranta repens* L.) collected in Palermo (South of Italy) between 1998 and 2000 were analysed to study the possible use of this shrub as a passive biomonitor for atmospheric pollution in urban areas. Concentrations of Ba, Cd, Cu, Fe, Mg, Mn, Pb and Zn were determined from leaf samples collected from six sampling sites representing either (a) areas of high traffic density or (b) areas not directly affected by the city traffic (e.g. gardens). Most of the elements showed a significant temporal variation but no consistent trends could be seen, i.e. the highest (or lowest) values were not detected consistently at some particular time of the year. Furthermore temporal changes were of same magnitude in polluted versus less polluted areas; no statistically significant interaction between pollution level and collection period was detected. Pollution level (traffic density) was the primary factor to explain spatial variation only in the case of foliar Mg concentrations. On the other hand, variation in foliar concentrations between sampling sites (irrespective of the pollution level) was large. Our results suggest that particulate deposition needs to be quite high before spatial segregation can be done on the basis of foliar element concentrations.

Key words: biomonitoring, atmospheric pollution, foliar concentrations, traffic, particles

1. Introduction

Higher plants have been widely used for more than 20 years for assessing and monitoring soil and atmospheric pollution in urban areas (Wyttenbach *et al.*, 1985; Angoletta *et al.*, 1993; La Malfa *et al.*, 1996; Bargagli, 1998; Monaci *et al.*, 2000). Earlier investigations have shown a positive relation between deposition of atmospheric pollutants and foliar concentrations of the same pollutants in several forest plant species (e.g. Wyttenbach *et al.*, 1985; Berthelsen *et al.*, 1995), common herbs (Cook *et al.*, 1994) and ornamental plants (La Malfa *et al.*, 1996). Interest in the biomonitors has increased lately along the increase of industrial activities and the enlargement of large cities and, consequently, heavier traffic, which has resulted in an increase of soil and air pollution. Recent interest to biomonitors has been further enhanced after the correlation of atmospheric particulates with respiratory diseases was reported (Markert *et al.*, 2000).

This study is part of a more comprehensive evaluation of some ornamental species as possible tools in biomonitoring studies undertaken during a 2 years period (1998–2000) in the city of Palermo, the capital of Sicily (South Italy). *Duranta repens* (Golden dewdrop), a perennial shrub that has not previously been studied as a passive biomonitor, was selected owing to its common use as ornamental plant in the gardens and along avenues of Sicily and well as other Mediterranean cities, where it grows abundantly. The aim of this study was to test the feasibility of leaves of *Duranta repens* as a passive biomonitor in the urban Mediterranean environment. We investigated this by monitoring the effects of different pollution levels (traffic intensity) and collection time (seasons) on the element concentrations in *Duranta* leaves. In addition, to find out the proper method to use the foliage of this species for biomonitoring purposes, the element concentrations in both washed and unwashed leaves were analysed.

2. Materials and Methods

2.1. STUDY AREA

Palermo is the largest city of Sicily with about 1 million inhabitants. The city has a Mediterranean climate and the main anthropogenic activities affecting air quality are associated with traffic and heating systems, while industrial activities are very limited. Soils in the Palermo region are developed on Pleistocene calcarenites or recent alluvial sediments derived from the erosion of calcareous mountains surrounding the city. Urban topsoil mineralogy is dominated by carbonates (calcite and dolomite), aluminium-silicates and quartz (Salvagio Manta *et al.*, 2002). Mean concentrations of Cr, Ni and Mn in soil samples collected from the city centre are low, close to values found in soils in background areas. Soils of green areas are rich in Cd and Mn (greater than 1 and 500 mg/Kg, respectively) (Salvagio Manta *et al.*, 2002).

Golden dewdrop (*Duranta repens* L.) is a perennial, evergreen shrub of maximum height about 4.5 m with many four angled shoots. Leaves are simple, 2–8 cm long, elliptic to ovate, serrate and toothed, surface is smooth on the upper side but hairy on the lower side. Lifespan of the leaves is approximately 2 years. No clear annual rhythm can be seen in leaf senescence but new leaves are formed and old leaves are shed more or less year-round. Furthermore, no clear colour change before shedding take place, i.e. leaves are shed although still green. Leaves were collected at six sampling sites in the city of Palermo representing a range of traffic and urbanisation densities. According to the Town Council (Cammarata *et al.*, 2002), four of the sites represent the most polluted parts of the city: (a) Roma Street (Via Roma) is one of the main avenues and has very high traffic density and urbanisation level; (b) Palmerino Street (Via Palm) is a long avenue with high urbanization and fast-moving traffic densities; (c) Archirafi Street (Via Arch) has a

Table I. Air quality measured as: carbon monoxide (CO), sulphur dioxide (SO_2), nitrogen dioxide (NO_2), ozone (O_3), total suspended particulates (TSP) and particles smaller than 10 mm in diameter (PM_{10}) in the proximity of polluted sites and garden sites during the study period (Mazzon and Salfi, 2002). Values are expressed as range of the annual mean values for polluted sites and as an annual mean value for garden sites since measurements from only one garden site was available

	1998		1999		2000	
Pollutant	Polluted	Garden	Polluted	Garden	Polluted	Garden
CO mg/m^3	2–3.1	0.3	1.9–2.7	0.2	1.6–2.6	0.2
SO_2 μg/m3	10.5–25.7	2.0	7.9–9.7	2.8	5.6–9.8	1.9
NO_2 μg/m3	60.7–88.1	22.5	48.1–69	14.3	51.2–73.7	14.1
O_3 μg/m3*	23	64	33	87	29	85
TSP μg/m3	60–107	42	59–121	49	59–94	51
PM_{10} μg/m3	33–48	25	36–52	23	34–46	25

*Measured only in one polluted site

very high traffic density throughout the year except in summer time and (d) Marchese Ugo Street (Via Ugo) has slowly moving light traffic. Two of the sites were established on gardens to represent areas with no direct exposure to traffic: (e) Villa Trabia (Vil. Trab) is an historical house located in the city centre with a garden to which no cars are admitted; and (f) Villa Igiea (Vil. Igie) is a garden located far from the city centre in a sparsely populated area with light and slowly moving traffic. The term "polluted" will be used in the following to refer to the locations representing more contaminated areas (i.e. Via Roma, Via Arch, Via Ugo and Via Palm), whereas the term "garden" will refer to Vil. Trab and Vil. Igie. According to the local environmental authorities air quality in the proximity of our polluted sites was, in most of the quality parameters used, notably worse than in the proximity of our garden sites (Table I).

Even though the air quality measuring stations are not exactly the same as our sampling sites, they are close by and represent the same traffic density as our sites (Mazzon and Salfi, 2002). From the point of view of the present results it is important to notice that the amount of inhalable fraction of atmospheric particles (PM_{10}) was, for example in 1999, from 50% to well over 100% higher in polluted sites than in the garden site (Table I). Because air quality measurements were conducted fairly close to the city centre (Mazzon and Salfi, 2002) we presume that considering Villa Igiea (the garden further away from Palermo centre) this difference in air quality would have been even greater.

2.2. SAMPLE COLLECTION AND MEASUREMENTS

From each of the six sampling sites leaf samples of similar age and similar crown position were collected from three healthy looking plants every 2 months during

1998–2000 (making total of 12 collection periods), resulting in a total of 72 samples. Several branches were cut off from all sides of the canopy at 1.5–3 m above the ground level. In the laboratory, about 500 g of fresh, mature leaves, including the petioles, were separated from the branches.

Samples were separated into two subsamples, one was washed in distilled water till washing water was completely clean whereas the other half was left unwashed. Samples were dried overnight at 70–80 °C and ground. From the dried and ground samples about 150 mg of each subsample was digested in open vessels microwave oven system (PROLABO A 301) using a mixture of 8 mL of 60% HNO_3 and 6 mL of 70% $HClO_4$, at a power level of 45 W. The concentrations of the elements (Ba, Cd, Cu, Fe, Mg, Mn, Pb and Zn) were determined by simultaneous inductively coupled plasma mass spectrometry (ICP/MS) (Mod. FISONS 3410). Accuracy was checked by analysing standard reference material (BCR 62-olive leaves) and the recovery range was from 90 to 95%.

2.3. DATA ANALYSIS

The data were analysed by means of repeated measures analysis of variance with collection period (12 collections) and washing (unwashed vs. washed with distilled water) as within-subject factors and pollution level (sites having high traffic density vs. gardens) and sampling sites (6 sites) as between-subjects factors (because each sampling site can represent only one of the two pollution levels, the factor “site” is nested under the factor “pollution level”, c.f. Table II). Interaction terms between above factors (i.e. collection × washing, collection × pollution level, collection × washing × pollution level) are within-subjects factors.

In case collection period turned out to be statistically significant in ANOVA every collection period (except the first one) was compared to the preceding one by means of LSD-method (Saville, 1990). When studying the spatial variation (pollution level and sites) formal statistical multiple comparisons were not performed for the site-specific treatment means but 95% confidence interval error bars for the treatment means are presented in the figures (Figure 1). Group means having non-overlapping error bars are statistically different ($p < 0.05$) from each other’s. In case assumptions of analysis of variance were not fulfilled, logarithmic transformation was applied.

3. Results

The pollution level explained significantly foliar element concentrations only in the case of Mg (Table II). Sampling sites as such, on the other hand were significantly different with respect to foliar concentrations of many elements (Table II, Figure 1). Differences between element concentrations at the different sampling sites were statistically significant for Ba, Mn, Pb and Zn (and near significant in Cu: Figure 1; Table II). In the case of Cu spatial variation arose from high concentrations in samples collected from Via Roma (Figure 1). Foliar Fe and Mn concentrations

Table II. Analysis of variance (F-values with significance symbols) for Ba, Cd, Cu, Fe, Mg, Mn, Pb (log transformed) and Zn concentrations

Source of variation	Ba	Cd	Cu	Fe	Mg	Mn	Pb (log)	Zn
Within-subjects factors								
Collection	3.76**	21.86***	1.58ns	1.65ns	4.28***	1.72ns	2.73**	5.75***
Coll*Pollution	1.08ns	0.94ns	1.49ns	1.51ns	1.52ns	0.91ns	0.32ns	0.74ns
Washing	15.01*	0.07ns	5.67°	16.95*	6.93°	11.38*	32.25**	32.79**
Wash*Poll	0.59ns	0.15ns	0.12ns	0.29ns	2.25ns	0.29ns	1.55ns	0.79ns
Coll*Wash	0.48ns	1.02ns	0.98ns	0.79ns	1.04ns	0.91ns	0.67ns	1.19ns
Coll*Wash*Poll	0.60ns	0.84ns	1.24ns	0.94ns	1.38ns	1.4ns	0.43ns	0.6ns
Between-subjects factors								
Pollution	0.29ns	0.09ns	0.08ns	0.02ns	26.17**	0.001ns	0.21ns	0.51ns
Site (Poll)	4.68*	3.35ns	3.4°	3.37ns	1.28ns	6.44**	3.31*	27.16***

Significance symbols: ns = $p > 0.1$, ° = $p < 0.1$, * = $p < 0.05$, ** = $p < 0.01$, *** = $p < 0.001$

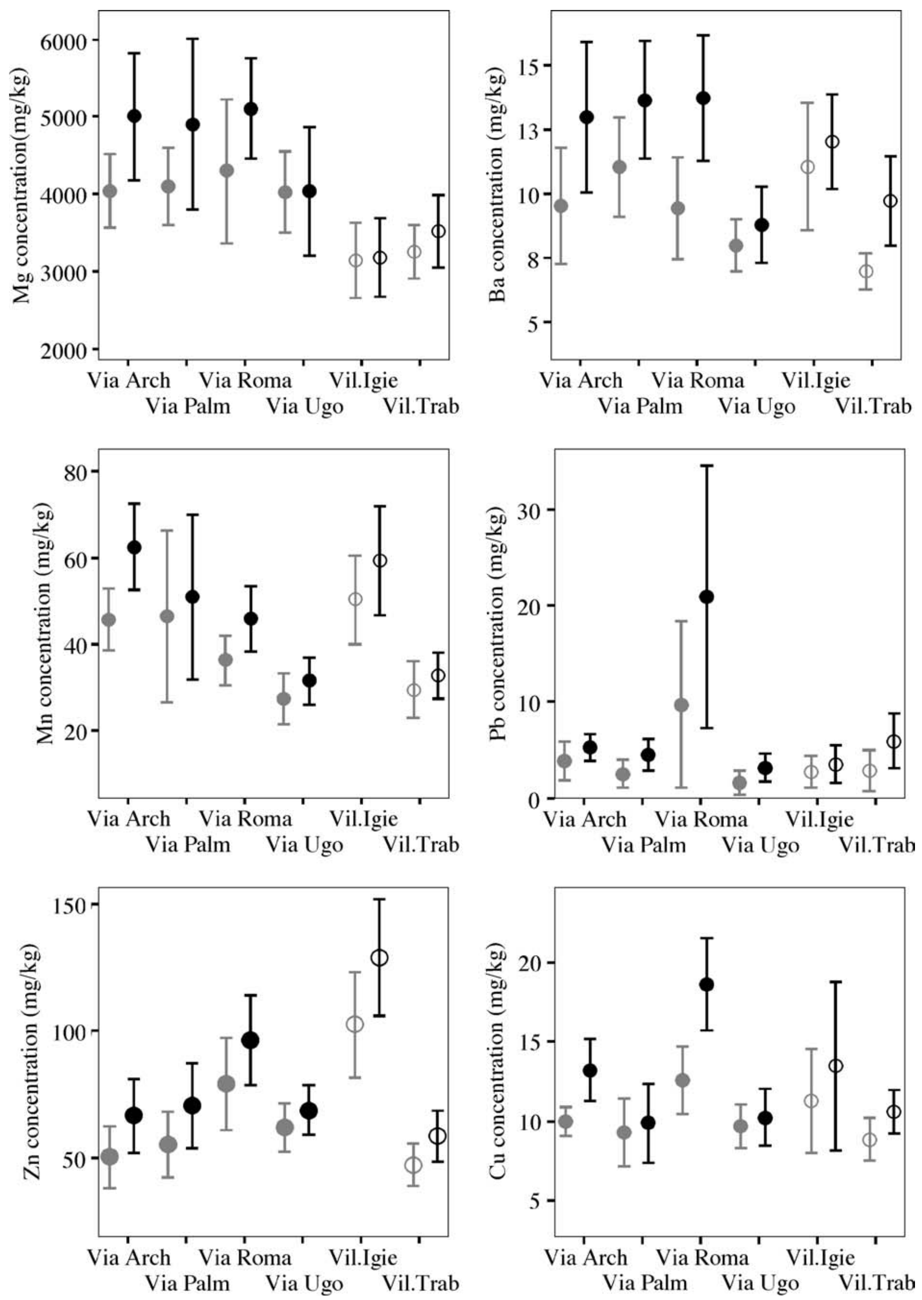

Figure 1. Concentrations of Mg, Mn, Pb, Zn, Cu, Fe and Cd in *Duranta repens* foliage collected from the six sampling sites. Values represent means ± 95% confidence intervals of the 12 collection periods in every site. Closed symbols refer to polluted sites and open symbols to gardens. Grey bars represent washed samples and black bars unwashed samples.

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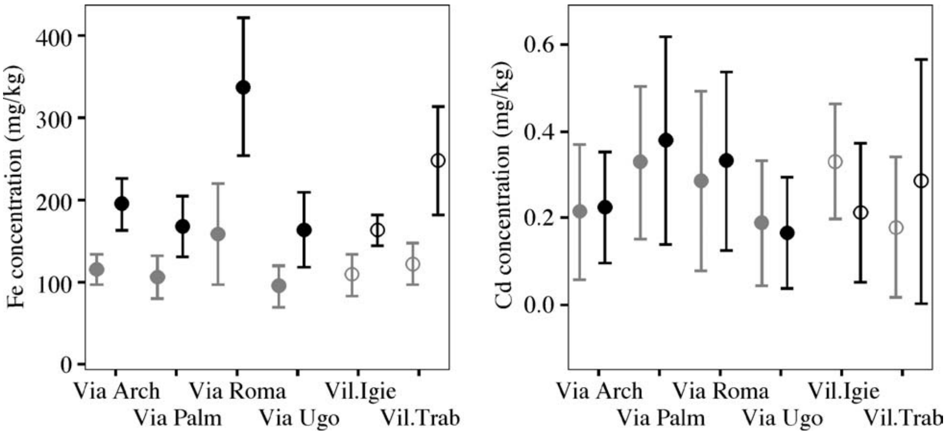

Figure 1. (Continued).

varied from high to low in both polluted (Via Roma, Via Palm, Via Arch and Via Ugo) and garden (Vil. Trab and Vil. Igie) sites (Figure 1). Spatial variation of Pb is clearly due to the high value found in leaves sampled in Via Roma (Figure 1). The highest foliar Zn concentrations, then again, were detected in one of the gardens (Vil. Igie, Figure 1).

Washing with distilled water was able to remove particle deposited on leaf surface, because clear trend for higher concentrations in unwashed samples could be seen in Ba, Fe, Mn, Pb and Zn (Figure 1). On the other hand, in cases of Ba, Cu, Fe and Mn the magnitude of the effect of washing varied in different sampling sites (Figure 1).

Temporal fluctuations were remarkable in all the studied elements except in the cases of Cu, Fe and Mn (Table II). However, just weak trends could be seen in this temporal variation. Only Pb and Zn concentrations showed slight increase in samples collected during winter (Figure 2).

In other elements, either essential nutrients (e.g. Mg) or in elements most likely of anthropogenic origin (e.g. Ba) there were no uniform changes in the course of time. The highest (or the lowest) values were not consistently detected during some particular time of the year (Figure 2). Temporal changes were of same magnitude in polluted and less polluted areas: i.e. we detected no statistically significant interaction between the pollution level and collection period (Table II).

4. Discussion

4.1. SPATIAL VARIATIONS

Since the amount of particulate air pollutants, and hence supposedly also elements in particles or adhered to particles, was much higher in polluted sites than in gardens

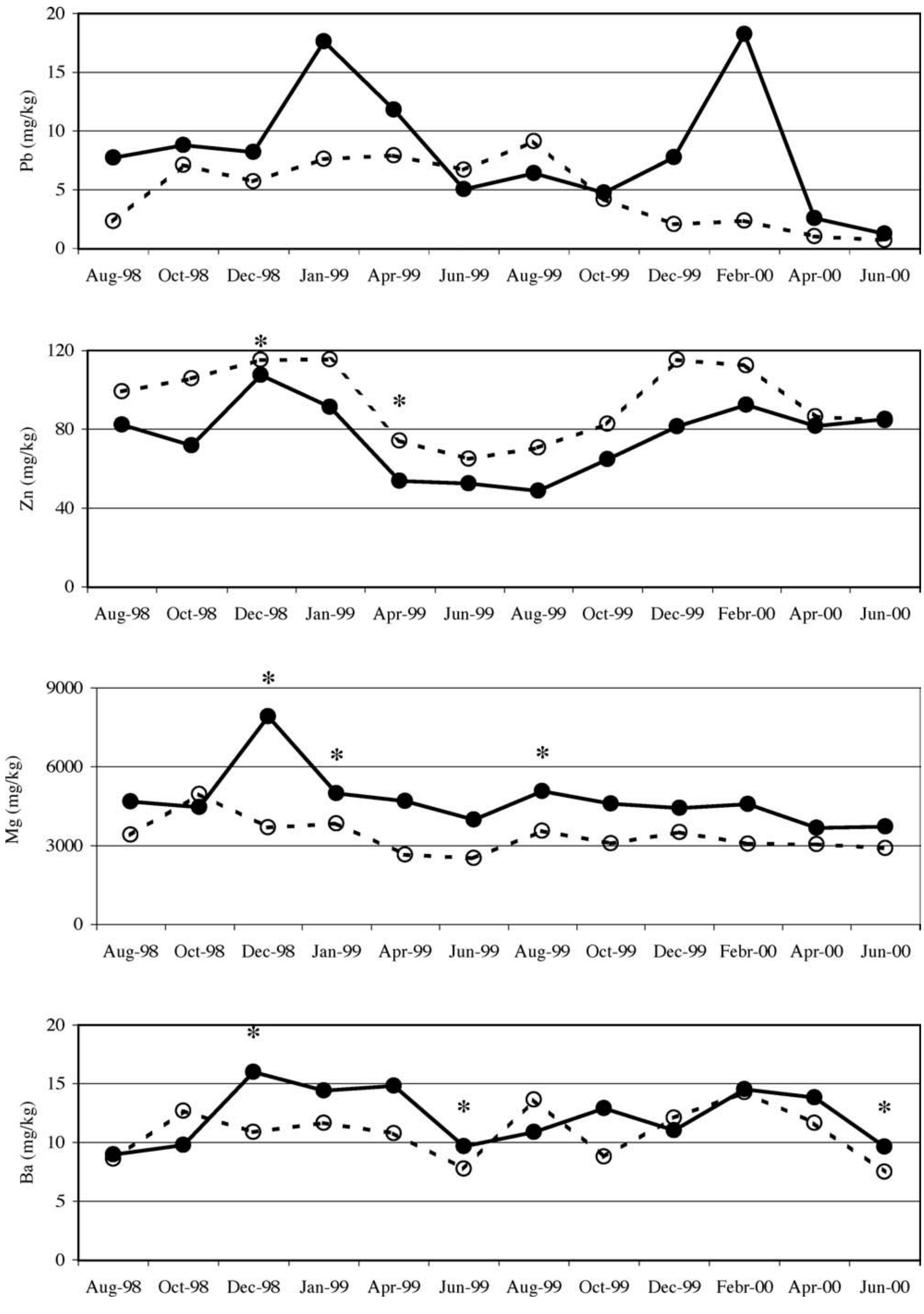

Figure 2. Temporal fluctuation in Pb, Zn, Mg and Ba concentrations in *Duranta repens* foliage during the study period (August 1998–June 2000). Solid line represent polluted sites and dashed line garden sites. Asterisk indicates collection period significantly different ($p < 0.05$) from the preceding one (see Material and Methods for details).

during the study we expected to see corresponding differences in foliar element concentrations as well. Pollution level, however, turned out to be primary factor explaining foliar element concentrations only in the case of Mg that showed higher values in sites close to heavy traffic. This suggests that either (i) pollution level has to be quite high before difference to background values can be detected with this species or (ii) in background areas (gardens) foliar concentrations increase because of soil dust or because pollutants persist in the air and are transported to the gardens. In addition, high buildings surrounding the gardens can contribute to this trend by obstructing pollution dispersion (i.e. so called resuspension phenomenon, see below).

Elements that showed significant differences between sample sites (Ba, Mn, Pb and Zn) originate mainly from anthropogenic sources. Because metallurgical industrial activities in the study area are absent Ba, Pb and Zn found in the air are most likely related with traffic density since they are produced by tyre wear and broke shoe abrasion (Angoletta *et al.*, 1993; Cook *et al.*, 1994). Zinc originates also from fluid leakage (Monaci *et al.*, 2000) and vehicle component detachment. In the present data foliar Zn concentrations were in general higher than values found in leaves of *Quercus ilex* sampled in polluted sites of Florence (Monaci *et al.*, 2000). Like Zn, Pb is correlated with traffic level (Wyttenbach *et al.*, 1985; Alfai *et al.*, 1995; Berthelsen *et al.*, 1995; Huhn *et al.*, 1995; La Malfa *et al.*, 1996; Monaci *et al.*, 2000). In addition, because Pb mobilized in organic surface soils is not readily taken up by higher plants (Berthelsen *et al.*, 1995), differences between polluted versus garden sites are most likely due to airborne Pb deposited onto leaf surfaces. In the present study the highest Pb levels were recorded in Via Roma, the site with the heaviest traffic nearby and where the sample plants grew closest to traffic. In the other polluted sites foliar Pb levels were more or less on the same levels than in the gardens. This suggests that *D. repens* is able to reflect airborne Pb only when the deposition levels are high enough.

Due to the phasing out of leaded petrol Zn has proposed to be more reliable tracer of motor vehicle emissions than Pb (Monaci *et al.*, 2000). In the present data, however, Zn concentrations in samples collected in the vicinity of urban roads were not significantly higher than those collected from the gardens. In contrast, highest values were measured in samples collected from one of the gardens (Vil. Igie). This can be either due to the fact that Zn originates from local soil or that resuspension phenomena generated by the presence of the hotel buildings obstructed the pollutant dispersion. Salvagio Manta *et al.* (2002) found urban topsoil of Palermo to be rich in Pb, Zn and Cu, with a mean values of 202, 63 and 0.68 mg/Kg, respectively. Besides Pb and Zn nowadays also foliar Ba is considered as a good indicator for vehicle emission (Monaci and Bargagli, 1997). Here the highest Ba values were recorded close to traffic but, then again, even in gardens relatively high values could be detected. This suggests, as in the case of Pb, that deposition has to be quite high before spatial segregation can be done on the basis of foliar samples.

Airborne Mn originates from brake shoe abrasion (Monaci *et al.*, 2000), soil dust and asphalt. In the present study the differences found between the sites are probably due to the different soil properties. Salvagio Manta *et al.* (2002) found that also in green areas of the Palermo soils contained high amounts of Mn. The contribution of soil dust to levels of Mn, as well as to other elements, can be further enhanced by resuspension effect. Resuspension effect was also observed by Monaci and Bargagli (1997) and Capannesi *et al.* (1980) and it is due to, for example, buildings that obstruct the pollution dispersion hence contamination level stays high further away from pollution sources.

Iron, that originates not only from anthropogenic sources but also from soils – Al_2O_3 + Fe_2O_3 were found to form 35% of the bulk soil collected from Palermo region (Salvagio Manta *et al.*, 2002) – was clearly accumulating on leaf surfaces: differences between sample sites were higher in unwashed compared to washed samples. In contrast to Fe, that showed higher concentrations in unwashed in all sample sites, washing removed Cu adhered on leaf surfaces significantly only in two of the sample sites (Via Arch. and Via Roma). Deposition of Cd was most likely too low for reliable spatial segregation by means of methods used here.

4.2. TEMPORAL VARIATIONS

Temporal changes that happen due to processes that involve plant physiology mainly concern phloem mobile nutrients such as N, P, K and Mg (Marschner, 1995). When metals, not essential for plants, show changes in time the reasons are more likely to be due to anthropogenic effects than due to plant physiological factors. In the present study the elements studied not essential for plants are Ba, Cd and Pb. Decrease of Pb towards the end of the study (2000) was most likely due to the introduction of unleaded petrol. Barium, on the hand, fluctuated temporally without any clear trend. Since samples were collected in the same stage of development in polluted and less polluted sites, time fluctuation for the other element concentrations (Mg and Zn) was not due to a specific physiological function, but rather changes in anthropogenic activities and/or weather conditions. Further, because there is no seasonality in physiological leaf senescence (leaves senesce and fall year-round) and, hence, neither in element retranslocation processes, this give support to anthropogenic and/or weather effects.

4.3. EFFECTS OF WASHING

In some studies washing with water (or water + detergent) has shown to be ineffective to remove particles adhered to leaf surfaces (see e.g. Kozlov *et al.*, 2000). Here, however, plain distilled water was enough to results in differences in element concentrations in washed versus unwashed foliage. Even though in case of most elements the trend between the sample sites seen in unwashed samples remained in washed samples the concentrations were in most cases significantly lower when measured from washed samples. Consequently if differences between sites are small they might remain uncovered if only washed samples are used. Hence in biomonitoring studies we recommend to use unwashed samples in case only one method is to be used. On the other hand, using both washed and unwashed samples can give additional information if one is, for example, interested to measure also the nutritional status of the plants (see Rautio, 2000) or to assess the ecotoxicological effects of contaminants in plants (Rossini Oliva and Raitio, 2003).

5. Conclusions

Results of this study show that traffic is the most important pollution source in Palermo. In biomonitoring studies the effect of sampling time seems not to be crucial when using evergreen species like *Duranta repens* that has not a clear seasonality in leaf senescence and thus in nutrient retranslocation processes. Results suggest that Pb is still an important indicator for traffic emission and that, besides Pb, foliar Ba concentrations can be used to monitor dispersion of traffic pollutants. *Duranta repens,* a very common ornamental shrub in Mediterranean cities, is a suitable species for biomonitoring studies with the advantage that it can be used at any time of the year. However, our investigation demonstrates that particulate deposition needs to be quite high before spatial segregation can be done on the basis of element concentrations in *Duranta* foliage. Because sample washing further reduces differences between sample sites, with species like *Duranta repens* we recommend to use unwashed samples if only one method is chosen to monitor particulate air pollutants.

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