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Original Research

Changes in Heavy Metal Accumulation Depending on Traffic Density in Some Landscape Plants

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Abstract

Air pollution is among the major problems stemming from modern urban life. Millions of people worldwide die from air pollution every year. Especially heavy metals have great importance among these pollutants. Because heavy metals can stay in nature for a long time without deterioration, and their concentration in the environment is constantly increasing. They also tend to bioaccumulate. Many heavy metals arise from exhaust gases, car wheels, vehicles, and vehicle corrosion in cities. Determining heavy metal concentrations in plants is important both for determining the ability of plants to remove heavy metals from the air, and thus to be used as a means of increasing air quality, as well as for monitoring air quality. The purpose of this study is to determine the variation of different heavy metal concentrations, depending on the traffic density, in some landscape plants sampled from areas with different levels of traffic density. Our results show that heavy metal accumulation differs according to both plant species and traffic density. In traffic-dense areas we measured the greatest amounts of Cu, Ni, and Fe in *Prunus cerasifera*; of Ca, Mg, and Mn in *Ailanthus altissima*; of Cr and Zn in *Elaeagnus angustifolia*; and of Pb and Cd in *Tilia tomentosa*.

Keywords: heavy metal, traffic density, plants

Introduction

Millions of people worldwide die from air pollution every year. Because of the intensification of air pollution in urban centers, it poses a great risk – especially for people with various health problems [1-8]. Heavy metals hold a special place among the components of the air pollution. They cannot be destroyed or degraded in nature. They also tend to bioaccumulate in organisms. Thus, determining heavy metal concentration is of paramount importance for the identification of risk areas and levels [9]. A great volume of research has proven the significant effects of atmospheric heavy metal pollution on human health. A recent study has revealed that in 1952, 4,000 people died from heavy metal-induced damage to respiratory systems and reported high levels of heavy metals in their lungs, including Pb, Zn, and Fe [10].

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Plants are often used as biomonitors in monitoring heavy metal concentrations. The species used as biomonitors of traffic-induced air pollution include *Aesculus hippocastanum*, *Betula pendula*, *Platanus orientalis*, *Fraxinus excelsior*, *Tilia tomentosa*, and *Elaeagnus angustifolia* [11-14].

Plants used as biomonitors, especially in urban centers with heavy traffic, have also several other benefits such as adding an aesthetic value to their space [15], producing a positive effect on human psychology [16-20], preventing erosion, reducing wind speed and rain rate to allow rainwater to penetrate the soil, providing food and shelter to animals, and performing crucial functions within the ecological system [20-22].

In addition to such functions, plants reduce all kinds of air pollution [15, 21, 23-26]. However, not all plants have the same effect on the removal of heavy metals from the air. Previous studies have shown that different plants have different levels of potential for accumulating different heavy metals. Thus, the effective use of plants both as biomonitors and for the removal of heavy metals from the air is achieved only by determining the heavy metals that different plants tend to accumulate in their bodies.

The purpose of this study is to determine the variation of different heavy metal concentrations, depending on the traffic density, in some landscape plants sampled from areas with different levels of traffic density.

Material and Methods

Our study was carried out on materials collected from the city center of Ankara. The samples were taken from *Tilia tomentosa*, *Elaeagnus angustifolia*, *Prunus*, and *Ailanthus altissima* that are frequently used in landscaping. As the leaf samples were collected at the end of the vegetation season, heavy metal accumulation in the leaves occurred in a one-year vegetation cycle. At the end of the vegetation season, the leaves were collected from areas with dense traffic (dense), less dense traffic (less dense), and no vehicle access within a radius of at least 50 m (no traffic). Leaf specimens used in the work are collected from trees determined according to the traffic density at the end of the vegetation season. Approximately one kg of leaf ornate is collected and brought to the laboratories in open boxes. The leaves classified in the laboratory were first room-dried for 15 days. From the air-dried samples, 150-200 gr were taken and left in a drying oven at 50ºC for another 15 days. For analysis, 2 g dry leaf samples were used for each repetition.

The leaves classified in the laboratory were first room-dried for 15 days and then left in a drying oven at 50ºC for another 15 days. 2 g of the dried samples were placed in 10 ml of concentrated HNO_3 at room temperature for one day and then boiled at 180ºC for one hour. 20 ml of distilled water was added to the solution that was later filtered through a filter paper of 45 μm. The filtered solutions were analyzed for heavy metal concentrations of Pb, Cu, Ca, Mg, Cd, Cr, Ni, Fe, MN, and Zn using GBC Integra XL–SDS-270 ICP-OES. The range of detection limits (DL) of the device used in the study is: Pb>0.377 ppb, Cu>0.639 ppb, Ca>0.00208 ppm, Mg>0.00758 ppm, Cd>0.063 ppb, Cr>0.311 ppb, Ni>0.171 ppb, Fe>0.00068 ppm, Mn>0.00015 ppm, Zn>0.00634 ppm. The data were analyzed using analysis of variance (ANOVA) and Duncan's Multiple Range Test in SPSS software.

Results and Discussion

The amount of heavy metal accumulation in each plant species was calculated and the data was analyzed using ANOVA and Duncan's test. Table 1 shows the analysis results.

Given the data in Table 1, there is a statistically significant difference of at least 95% confidence level between the plant species with respect to all the studied heavy metals other than Mn. The greatest amounts of Pb, Cd, and Cr were found in *Tilia tomentosa*; the greatest amount of Mn and Zn in *Elaeagnus angustifolia*; the greatest amount of Cu, Ni, and Fe in *Prunus cerasifera*; and the greatest amount of Ca and Mg in *Ailanthus altissima*. Table 2 presents the mean value of heavy metal amounts depending on the traffic density and the results of ANOVA and Duncan's test.

As seen in Table 2, there is a statistically significant difference of at least 95% confidence level in the accumulation of all the studied heavy metals other than Cu and Cd. The greatest amount of all the heavy metals was found in areas with dense traffic. Table 3 shows the amount of heavy metal accumulation in the studied plant species depending on the traffic density and the results of ANOVA and Duncan's test.

In the areas with dense traffic, the greatest amount of Cu, Ni, and Fe was found in *Prunus cerasifera*, the greatest amount of Ca, Mg, and Mn in *Ailanthus altissima*, the greatest amount of Cr and Zn in *Elaeagnus angustifolia,* and the greatest amount of Pb and Cd in *Tilia tomentosa*. Considering the amount of heavy metal accumulation, *Tilia tomentosa* significantly differs in Pb accumulation from other species. The amount of Pb measured (17.106 ppb) in *Tilia tomentosa* that grows in areas with less dense traffic is even greater than the amount of Pb measured in other species growing in areas with dense traffic. The same case is true for the amount of Cd in *Tilia tomentosa*, and the amount of Cu and Ni in *Prunus cerasifera*. Another remarkable fact is the great amount of Cu accumulation in *Prunus cerasifera* compared to other plant species. The amount of Cu measured in *Prunus cerasifera* was 148.253 ppb in the no-traffic areas and 127.593 ppb in the dense-traffic areas. Among the other plant species, *Ailanthus altissima* is the species with the greatest

Table 1. Variation of heavy metal amounts depending on plant species.

Metals	Species				F Value
	Tilia tomentosa	*Eleagnus angustifolia*	*Prunus cerasifera*	*Ailanthus altissima*	
Pb (ppb)	**16.322 b**	8.468 a	7.511 a	14.502 b	13.733***
Cu (ppb)	32.824 a	54.764 ab	**169.475 c**	77.806 b	44.482***
Ca (ppm)	2.234 ab	1.532 a	2.901 b	**2.892 b**	4.473**
Mg (ppm)	0.380 ab	0.314 a	0.585 b	**0.610 b**	3.211*
Cd (ppb)	**14.780 b**	5.884 a	3.957 a	3.431 a	10.081***
Cr (ppb)	**27.668 b**	24.360 b	16.431 a	16.504 a	9.447***
Ni (ppb)	4.571 a	4.746 a	**13.413 b**	5.224 a	8.691***
Fe (ppm)	15.151 bc	10.813 ab	**16.446 c**	9.368 a	3.497*
Mn (ppm)	4.864 a	**7.315 a**	4.824 a	6.855 a	1.892ns
Zn (ppm)	5.113 b	**6.037 b**	2.386 a	2.482 a	9.717***

*significant at 0.05 level; **significant at 0.01 level; ***significant at 0.001 level; ns not significant. The letters a, b, c, etc. means according to Duncan test results; show that the group is located. It is statistically different from the values contained in different groups, starting with the letter a numerical value grows.

amount of Cu (102.660 ppb) in the dense-traffic areas. The same is true for Ni accumulation.

Research has shown that heavy metal accumulation differs according to both plant species and traffic density. This result concurs with that of several previous studies. Ozturk and Bozdogan [14] measured heavy metal accumulation in deciduous plants and reported the greatest amount of Zn accumulation in *Betula pendula,* that of Cd accumulation in *Elaeagnus angustifolia,* that of Cu accumulation in *Catalpa bignonioides*, and that of Ni and Pi in *Acer campestre.* Similar results have been put forward in many studies [27-28].

Many plants serve as biomonitors of traffic-borne pollutants. Different plant species accumulate different heavy metals at different levels [12, 29]. Distinct parts of a single plant species also accumulate different levels of heavy metals [30-31]. Heavy metal accumulation in plants can also change seasonally [16-19, 32].

According to research results, in dense-traffic areas the greatest amounts of Cu, Ni, and Fe were measured in *Prunus cerasifera*, those of Ca, Mg, and Mn in *Ailanthus altissima*, Cr and Zn in *Elaeagnus angustifolia*, and Pb and Cd in *Tilia tomentosa*. It is an expected fact that heavy metal accumulation differs according to plant species. This result is also supported by previous studies [14, 33].

Metals can actually accumulate in plant leaves through foliar transfer after the deposition of

Table 2. Variation of heavy metal amounts depending on traffic density.

Metals	Traffic Density			F Val
	No	Middle	Dense	
Pb (ppb)	8.821 a	11.523 ab	14.758 b	4.979*
Cu (ppb)	69.615 a	71.096 a	110.441 a	1.969ns
Ca (ppm)	1.594 a	2.186 a	3.390 b	17.752***
Mg (ppm)	0.322 a	0.425 a	0.669 b	7.095**
Cd (ppb)	4.806 a	5.838 a	10.395 a	2.615ns
Cr (ppb)	16.595 a	23.411 b	23.716 b	4.391*
Ni (ppb)	4.381 a	5.840 a	10.745 b	5.233*
Fe (ppm)	8.361 a	11.100 a	19.373 b	27.847***
Mn (ppm)	4.436 a	4.465 a	8.993 b	19.265***
Zn (ppm)	2.388 a	3.561 a	6.065 b	12.721***

*significant at 0.05 level; **significant at 0.01 level; ***significant at 0.001 level; ns not significant. The letters a, b, c, etc. means according to Duncan test results; show that the group is located. It is statistically different from the values contained in different groups, starting with the letter a numerical value grows.

Table 3. Variation of heavy metal amounts depending on plant species and traffic density.

Metals	Traffic Density	Species			
		Tilia tomentosa	*Eleagnus angustifolia*	*Prunus cerasifera*	*Ailanthus altissima*
Pb (ppb)	No	10.920 a	8.073 a	3.733 a	12.560 a
	Middle	17.106 b	8.133 a	5.733 b	15.120 a
	Dense	20.940 b	9.200 a	13.066 c	15.826 a
	F Val	**15.407****	**0.267 ns**	**146.175*****	**2.465 ns**
Cu (ppb)	No	28.726 a	48.280 a	148.253 b	53.200 a
	Middle	29.046 a	50.186 a	127.593 a	77.560 b
	Dense	40.700 b	65.826 b	232.580 c	102.660 c
	F Val	**6.303***	**179.310*****	**600.178*****	**236.980*****
Ca (ppm)	No	1.068 a	1.044 a	2.628 b	1.638 a
	Middle	2.040 b	1.760 b	2.554 a	2.389 b
	Dense	3.594 c	1.794 c	3.522 c	4.650 c
	F Val	**3835.959*****	**1996.499*****	**6691.754*****	**67168.692*****
Mg (ppm)	No	0.373 a	0.178 a	0.586 b	0.153 a
	Middle	0.377 a	0.320 b	0.533 a	0.459 b
	Dense	0.390 a	0.445 c	0.636 c	1.219 c
	F Val	**0.619 ns**	**32.578****	**37.235*****	**1741.304*****
Cd (ppb)	No	11.800 a	1.553 a	2.353 a	3.120a
	Middle	12.200 a	5.820 ab	2.433 a	3.300 a
	Dense	20.340 a	10.280 b	7.086 b	3.873 a
	F Val	**0.926 ns**	**9.272***	**15.844****	**1.168 ns**
Cr (ppb)	No	23.546 a	20.246 a	10.566 a	12.020 a
	Middle	34.860 a	28.213 a	14.800 b	15.773 b
	Dense	24.600 a	24.620 a	23.926 c	21.720 c
	F Val	**4.356 ns**	**4.943 ns**	**149.530*****	**115.651*****
Ni (ppb)	No	3.553 a	2.953 a	8.046 a	2.973 a
	Middle	6.280 b	3.380 a	8.846 a	4.853 a
	Dense	3.880 a	7.906 b	23.346 b	7.846 a
	F Val	**5.648***	**67.524*****	**58.816*****	**2.796ns**
Fe (ppm)	No	8.373 a	6.480 a	13.346 b	5.246 a
	Middle	17.373 b	8.626 b	10.493 a	7.906 b
	Dense	19.706 c	17.333 c	25.500 c	14.953 c
	F Val	**2024.707*****	**6539.155*****	**4256.958*****	**1650.333*****
Mn (ppm)	No	2.560 a	5.713 a	4.813 b	4.660 b
	Middle	5.960 b	5.513 a	3.440 a	2.946 a
	Dense	6.073 b	10.720 b	6.220 c	12.960 c
	F Val	**226.863*****	**2025.624*****	**1196.541*****	**7934.586*****

Table 3. Continued.

Zn (ppm)	No	2.773 a	3.560 a	1,813 a	1.406 a
	Middle	5.246 b	5.300 b	1.853 a	1.846 b
	Dense	7.320 c	9.253 c	3.493 b	4.193 c
	F Val	**357.976*** **	**1720.189*** **	**169.475*** **	**247.536*** **

*significant at 0.05 level; **significant at 0.01 level; ***significant at 0.001 level; ns not significant. The letters a, b, c, etc. means according to Duncan test results; show that the group is located. It is statistically different from the values contained in different groups, starting with the letter a numerical value grows.

atmospheric particles on leaf surfaces [34]. As stomata in plant leaves regulate the entry of CO_2 and water vapor into plants, they show the maximum potential for the detection of heavy metal accumulation in leaves [35]. The size and density of stomata are significantly influenced by environmental conditions. Additionally, there is an inverse proportion between the size and number of stomata [36-38]. Among the plant species studied in this paper, *Tilia tomentosa* and *Prunus cerasifera* have similar stomata sizes; however, the stomatal opening is larger and the number of stomata is greater in *Tilia tomentosa* [5, 7, 39].

Leaf anatomy can be a significant factor affecting particle deposition. For example, a small leaf area and a high amount of structural wax (conifers) have been suggested to increase particle deposition on leaf surfaces [40]. Considering the leaf features of the studied plant species, there is a significant difference between their leaf surfaces. *Elaeagnus angustifolia* has the smallest leaf surface and *Ailanthus altissima* has a fairly small leaf surface compared to the larger leaf surfaces of *Prunus cerasifera* and *Tilia tomentosa*. However, leaf anatomy can be a more effective factor than leaf surface with respect to heavy metal accumulation. Kacar et al. [41] suggest that some plant leaves are thicker and thus make less use of light, which has a significant effect on plant metabolism. In a similar vein, Zeren et al. [42] reported a considerable difference in leaf chlorophyll content and measured the amount of chlorophyll in *Prunus ceracifera*, *Ailantus altissima*, *Tilia tomentosa*, and *Elaeagnus angustifolia* as 12.68 cc, 18.58 cc, 35.16 cc, and 75.50 cc, respectively. Among the studies plant species, *Elaeagnus angustifolia* is considerably different from others in terms of both chlorophyll content and leaf thickness.

Heavy metal accumulation in plants is probably associated with their anatomical and physiological features. Heavy metal accumulation on leaf surfaces occurs through stomata, cuticular cracks, lenticels, ectodesmata, and aqueous pores. Heavy metals absorption occurs through ectodesmata between subsidiary cells and guard cells in the cuticular membrane or epidermal cell wall [10]. Shahid et al. [10] note that heavy metal accumulation varies according to the structure of plant canopy, leaf inclination angle, branch density, leaf lamina morphologic anatomical structure, and leaf area. Plants' anatomical and morphological characteristics are influenced by the mutual interaction of genetic and environmental conditions [43]. Thus, there are great differences between species [26]. Likewise, there can also be great differences in the anatomical and morphological structure of subspecies, varieties, forms, and even origins of the same species. Accordingly, these differences cause plants to react differently to external factors [44-46]. This situation is related to plants' genetic structure. A similar situation is inevitably possible for plants' heavy metal accumulation capacity. Thus, in addition to plant species, genetic structure and age seem to affect heavy metal accumulation. Shahid et al. [10] highlight that young leaves accumulate more metal compared to old leaves as their epidermis is less thick.

Another factor affecting anatomical and morphological characteristics is growing conditions, which significantly affect a plant's response to stress factors [47-53]. Environmental conditions also cause significant changes to anatomical and physiological structures. For example, there can be a 2-3-fold difference in the chlorophyll content of leaves growing in shaded conditions and those growing in intense light [5-7, 18-19, 46, 54]. Similar results have been demonstrated for other factors. The structure and density of stomata – among the major factors determining a plant's potential for heavy metal accumulation – can be affected by several environmental factors [55], including drought stress [56-57], light [47-48], and salt stress [58-59]. Air pollution has also been reported to be among the major factors affecting the structure and density of stomata [54].

The prevention and reduction of environmental pollution have now risen to prominence with the growing importance of the quality of urban living. Green spaces are vital constituents of urban ecosystems and thus serve as major devices for reducing airborne pollution and increasing the quality of life. There are various pollutants (industrial, domestic, traffic, etc.) in and around cities. Urban roads that qualify as open green spaces are areas where air pollution is high. Pollutant gases in the air occur 5 to 25 times more and dust condensation and particles occur 10 times more in urban compared to rural areas [14, 39, 60-63]. Traffic-related air pollution has increased in developing cities in Turkey with the gradually growing number of vehicles participating in urban traffic in and around the cities [64]. This situation negatively affects the quality of the environment and illustrates the importance of urban vegetation.

Research on determining air pollution in the city has shown that air pollution varies depending on many factors such as traffic density, climate change, wind direction, and precipitation [7, 39, 60-63, 65-66]. Thus, heavy metal concentration in the air can also vary depending on many parameters. Accordingly, it is of great importance to monitor this variation and to use plants effectively in order to reduce heavy metal concentrations.

Conclusions

Plants' visual qualities are generally foregrounded in the selection of plants used in urban centers, while their functions are neglected. However, the first thing to do for the functional and effective use of plants is to determine which plants best serve the desired function before selecting plant species accordingly.

The present study has indicated that, compared to the other plant spices, *Tilia tomentosa* is more effective in accumulating Pb and Cd and *Prunus cerasifera* is more effective in accumulating Cu and Ni. The use of these species in spaces where these heavy metals pose a problem will lead to a more effective outcome in reducing the amount of heavy metals in the air.

Today, air pollution in urban centers is one of the greatest problems of cities. Thus, future similar studies need to be carried out to determine the most effective species in the removal of heavy metals from the air. Future research should address plant organs (besides plant species) that absorb heavy metals more, and plant species that most accumulate heavy metals depending on weather conditions.

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