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(RESEARCH ARTICLE)

Variation in potassium concentration in *Cedrus atlantica* by organ, direction, and period

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Abstract

Potassium (K), one of the essential macronutrients for plants, is also one of the most common heavy metals. Therefore, determining potassium accumulation in the woody part, which is the largest organ of trees with long lifespans and large biomass, is important. This study examined the variation of potassium in the trunk organs of cedar (*Cedrus atlantica*), which is widely used in landscaping, based on organ, direction, and period. The results showed that K concentrations in the outer bark were much higher than those in the inner bark and wood. The highest values in the outer bark were obtained in the north, where urbanization and traffic are intense. It was determined that K concentrations in wood can vary greatly between neighboring cell groups. These results can be interpreted as indicating that atmospheric K pollution is likely caused by urban areas and traffic, and that *Cedrus atlantica* is a suitable biomonitor for tracking changes in atmospheric K pollution.

Keywords: Cedar; *Cedrus Atlantica*; Potassium; Biomonitor

1. Introduction

Since plants form the basis of the food supply, all life on Earth depends on plants. In addition, plants perform many economic, ecological, and social functions (Yigit et al., 2021). Plants used in urban green spaces play an important role in providing essential ecosystem services, including carbon sequestration, stormwater management, and habitat conservation, beyond their aesthetic contributions (Kalayci et al., 2025). The ability of plants to perform all their functions depends primarily on their ability to develop healthily and sufficiently (Erdem et al., 2023a,b). Plant development is shaped by the interaction between their genetic structure (Sevik et al., 2012; Kurz et al., 2023) and environmental factors (Tandogan et al., 2023; Sevik et al., 2025a). The most important environmental factors in plant development are climatic factors such as temperature and precipitation (Zeren Cetin et al., 2025a,b; Canturk et al., 2025) and edaphic factors such as nutrient status, soil depth, and pH (Kravkaz Kuscu et al., 2028).

Soil is one of the most important factors affecting plant development, and the nutrients that plants absorb from the soil through their roots play a vital role in plant development. Sixteen essential nutrients are required for plant nutrition, nine of which are classified as macronutrients (C, H, O, N, P, K, Ca, Mg, S) and seven as micronutrients (Fe, Zn, Mn, Cu, B, Mo, Cl). Nutrient elements participate in a wide variety of metabolic processes, from primary and secondary metabolism to cell defense and signal transmission to gene regulation, energy metabolism, and hormone perception (Erdem et al., 2024).

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Potassium (K) is an essential element for plant growth and development (Pramanik et al., 2019). As a vital macronutrient, K plays important roles in plants, including osmoregulation, membrane potential regulation, sugar transport, stress adaptation, and growth. Its deficiency or excess causes the disruption of many functions in plants (Johnson et al., 2022). As a dominant osmolite, K+, which accumulates in guard cells, is involved in regulating stoma morphology and function. Therefore, it affects stoma transmission. Considering that K+ plays vital roles in maintaining chloroplast osmoregulation and pH stability, its deficiency can reduce Rubisco enzyme activity and content and lead to chlorophyll degeneration (Xie et al., 2021).

Nutrient elements in plants grown in agricultural areas can be supplemented through fertilization. However, fertilization is often neglected in trees grown in urban areas, which can cause problems for the plants. Therefore, it is important to determine the levels and transfer of nutrient elements in which organs of plants grown in urban areas. In particular, elements accumulated in wood, the largest organ of the plant, remain out of the nutrient cycle for decades or even centuries. Therefore, it is important to determine the accumulation and transfer of nutrient elements within the wood of trees. This is because potassium is also an important heavy metal, and studies have shown that even essential heavy metals, when present in high amounts, can be harmful to living organisms (Key et al., 2023; Koc et al., 2024). It is stated that heavy metals are extremely harmful to living organisms, especially humans, when inhaled from the air (Ghoma et al., 2023). For this reason, the change in K concentration in individuals of cedar, which is widely used in landscaping not only in our country but also in many regions of the world, based on organ, direction, and period, has been evaluated in areas with high levels of heavy metal pollution.

2. Material and methods

The aim of this study was to obtain information on the accumulation and transfer of K concentration in the main trunk of cedar (*Cedrus atlantica*). Furthermore, K is one of the important and widespread heavy metals. Since the results of the study were expected to provide information on heavy metal accumulation and transfer in cedar trees, it was deemed appropriate to select sample trees grown in areas with high heavy metal pollution. Therefore, materials obtained from trees growing in the city center of Düzce were used in the study. According to the World Air Pollution Report 2021, Düzce is one of the five cities with the most polluted air in Europe (Koc et al., 2024), and numerous studies conducted in the region have determined that trees growing in this region have extremely high levels of heavy metal accumulation, such as Pb, As, Pd, Al, and Fe, which are extremely harmful to human health (Koç et al., 2025a,b; Isinkaralar et al., 2025a, b; Yaşar Ismail et al., 2025).

Samples were taken from the main trunk at the end of the 2022 growing season, with the north direction determined. Logs cut approximately 50 cm above the ground were brought to the laboratory, cleaned, and grouped into 5-year annual rings. Studies show that annual rings are grouped into 3, 5, or 10-year groups depending on the purpose of the study and the structure of the rings (Cobanoglu et al., 2023; Şevik et al., 2024; Isinkaralar et al., 2024). Samples were taken from each group of wood, inner bark, and outer bark from four directions using a steel drill. The samples were left to dry at room temperature for two weeks, then placed in glass Petri dishes and dried in an oven at 45 °C for two weeks, followed by a pre-combustion process in a specially designed microwave oven. K concentrations were determined using an ICP-OES device. The method used in this study has been widely used in related studies in recent years (Key et al., 2023; Yaşar Ismail et al., 2025). Variance analysis and Duncan's test were applied to the obtained data using the SPSS 22.0 package program.

3. Results and Discussion

Mean values and statistical analysis results for the variation of K concentration in *Cedrus atlantica* by organ and direction are given in Table 1.

Table 1 Variation of K concentration in linden by organ and direction

Organ	North	East	South	West	F Value	Average
OB	2694.8 Dc	369.6 Ac	2181.0 Bc	2377.5 Cc	18698.8***	1905.7 b
IB	610.5 Cb	165.3 Bb	92.7 Aa	150.1 Ba	1755.6***	254.6 a
Wood	256.2 Ba	69.1 Aa	333.9 Bb	463.4 Cb	16.9***	276.6 a
F Value	202.1***	110.4***	231.8***	180.3***		97.2***

Average	535.5 B	118.7 A	563.3 B	663.5 B	3.4*	

According to the values in the table, the change in K concentration is statistically significant in all organs based on direction and in all directions based on organ. For the north and east directions, the sequence is wood<inner bark<outer bark, while for the south and west directions, the sequence is inner bark<wood<outer bark. For the outer bark, it is possible to establish the sequence east<south<west<north. In the inner bark, the highest value was obtained in the north direction and the lowest value in the south direction. The highest value in the wood was observed in the west direction, and the lowest value was observed in the east direction. According to the average, the highest value was observed in the north, south, and west directions, while the lowest value was obtained in the east direction. The change in K concentration in cedar based on period and direction is given in Table 2.

Table 2 Variation of K concentration in cedar by period and direction

Period	**North**	**East**	**South**	**West**	**F Value**
2018-2022	573.1 Cf	54.2 Abc	533.8 Bd	642.4 De	5511.1***
2013-2017	431.9 Cd	56.8 Ac	351.2 Bb	483.2 Db	2321.0***
2008-2012	112.1 Bb	41.9 Aa	381.6 Cc	540.7 Dc	1481.1***
2003-2007	133.3 Bc	48.7 Ab	347.2 Cb	471.8 Db	2658.2***
1998-2002	118.3 Bb	146.5 Ce	55.8 Aa	567.3 Dd	5644.7***
1993-1997	557.4 e	UnderLimit	UnderLimit	UnderLimit	-
1988-1992	62.0 a	UnderLimit	UnderLimit	75.3 a	3.0 ns
1983-1987	61.6 a	66.9 d	UnderLimit	UnderLimit	0.4 ns
F Value	2086.9***	399.5***	1918.3***	1106.7***	

The change in K concentration in cedar wood was found to be statistically significant in all periods except for the 1983-1987 and 1988-1992 periods, both direction-based and period-based in all directions. The highest values in the north, south, and west directions were observed after 2018, while the highest value in the east direction was observed in the 1998-2002 period. According to the average values, the highest value was obtained in the 1993-1997 period. Again, looking at the average values, the lowest value was obtained in the east direction, while the highest value was calculated in the north, south, and west directions. Apart from this, in the east direction in the 1988-1992 and 1993-1997 periods; in the south direction in the 1983-1987, 1988-1992, and 1993-1997 periods, and in the west direction in the 1983-1987 and 1993-1997 periods.

The study found that the highest values were obtained in the outer bark. The values obtained in the outer bark were much higher than those in the wood, and in some cases were calculated to be more than ten times higher. Studies indicate that heavy metals, after being separated from their source, attach themselves to particulate matter in the air, contaminating it, and that these particulate matter then attach themselves to plant organs. It is much easier for heavy metal-contaminated particulate matter to adhere to the surface of rough organs such as bark. For this reason, heavy metal concentrations in these organs are generally very high (Sevik et al., 2025b; Kulac et al., 2025). Contamination of the bark with heavy metals generally also increases the concentration of heavy metals in the inner bark and wood. This is because heavy metals can enter the plant body directly from the soil through the roots, from the air through the stomata on the leaves, or through the stem sections (Ozturk Pulatoglu et al., 2025). Thus, heavy metals adhering to the bark can migrate to the inner bark and wood over time. However, this situation varies depending on the pathway of entry of the elements into the plant. In this study, the values in the inner bark were higher than those in the wood in the north and east, while the values obtained in the wood were higher than those in the inner bark in the south and west.

The study found that the lowest values in the wood were obtained in the east, while the highest values were obtained in the west. Studies show that many pollution factors are released into nature in large amounts as a result of mining, industry, traffic, urban areas and agricultural activities (Özel et al., 2024; 2025). The most dangerous of these pollutants are heavy metals (Sevik et al., 2019a,b; Kuzmina et al., 2023). While urban areas and highways are located in the north and west of the study area, the south and east are largely surrounded by agricultural areas. K is one of the common

heavy metals and is an essential element for most plants, and K fertilization is frequently practiced in agricultural areas. The fact that the lowest concentrations were obtained in the east, where there are intensive agricultural areas, can be interpreted as meaning that K fertilization is not practiced in these areas or that the element does not reach the trees. In addition, the highest concentrations in the outer bark were obtained in the north, and the highest concentrations in the wood were obtained in the west. This situation can be interpreted as the most important source of K pollution in the air being urban areas and traffic.

As a result of the study, it was determined that Na concentrations in wood tissues varied greatly in neighboring cell groups. For example, while a value of 567.3 ppm was obtained in the west during the 1998-2002 period, a value of 55.8 ppm was obtained in the neighboring south. Similarly, during the 1993-1997 period, the K concentration remained below detectable limits. This indicates that the transfer of the K element within the wood is limited. Studies conducted to date have determined that the transfer of many elements between the wood tissues of different tree species can vary depending on the species and element. For example, it has been determined that Pb and Zn can be transferred in *Cedrus deodora* wood, As, Sr, Pd, V, Ag, Se, Sb, and Tl in *Pinus nigra* wood, Co in *Cedrus atlantica* wood, and Bi, Li, and Cr in *Cupressus arizonica* wood. In contrast, it has been noted that the transfer of Cu in *Cedrus deodora*, Tl in *Picea orientalis*, Ni, Cr, and Mn in *Cedrus atlantica*, Cd, Ni, Cr, Tl, Fe, and Zn in *Cupressus arizonica*, and Cd, Ni, Zn, Co, Pb, Cr, Mn, and Zn in *Corylus colurna* is more limited in wood tissues (Key et al., 2023; Şevik et al., 2024; Koç, 2025).

The accumulation of elements in species and organs varies depending on many factors. This is because many factors play a simultaneous role in the uptake and accumulation of elements in plants. The entry and movement of elements within the plant depend on various factors, including plant species, organ structure, surface area, interactions between elements and plants, and weather conditions (Yaşar İsmail et al., 2024). In addition, plant habitus and development can also significantly affect heavy metal uptake and accumulation (Erdem et al., 2023a). Therefore, all factors affecting plant habitus also affect the element uptake and accumulation of these plants. Plant habitus is fundamentally shaped by edaphic and climatic environmental factors, subject to genetic structure (Özel et al., 2022; Zeren Cetin et al., 2025a; Can et al., 2025). Furthermore, numerous factors such as external interventions, e.g., stress factors, maintenance, pruning, and hormone applications, also affect this situation (Gültekin et al., 2025). Therefore, many of these factors directly and indirectly affect each other and, consequently, element accumulation in plants. Moreover, knowledge about this complex mechanism is still quite limited (Sahin et al., 2025).

4. Conclusion

The study evaluated potassium concentrations in the bark and wood of *Cedrus atlantica*. Potassium, the subject of the study, is not only one of the common heavy metals but also one of the essential macronutrients for living organisms. The results of the study reveal that K concentrations in wood show significant variation among neighboring cell groups. This situation can be interpreted as indicating that the transfer of potassium between wood tissues is limited. This situation shows that the species studied is a suitable biomonitor that can be used to track changes in K pollution.

The study revealed that K concentrations in cedar bark were much higher than those in the inner bark and wood. Furthermore, the highest values in the outer bark were obtained in the northern direction, i.e., in the direction of urban areas and heavy traffic. This situation can be interpreted as indicating that urban areas and/or traffic are the main sources of K pollution in the air. It is recommended that necessary measures be taken to prevent and reduce pollution.

Compliance with ethical standards

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Disclosure of conflict of interest

The authors declare that they no conflict of interest. The none of the authors have any competing interests in the manuscript.

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