

Variation of Magnesium, One of the Macronutrients, in Some Trees Based on Organs and Species

Ramazan Erdem¹, İsmail Koç², Hatice Çobanoğlu³, Hakan Şevik⁴

¹Department of Forestry, Kastamonu University, Arac Rafet Vergili Vocational School, Kastamonu, Türkiye

²Düzce University Forestry Vocational School, Düzce, Türkiye

³Department of Forest Engineering, Düzce University Institute of Graduate Education Institute, Düzce, Türkiye

⁴Department of Environmental Engineering, Kastamonu University Faculty of Engineering and Architecture, Kastamonu, Türkiye

ABSTRACT

Plants' ability to perform the expected functions depends on their ability to grow and develop healthily. Environmental factors shape plant growth, and nutrients are one of the most main features affecting plant development. Magnesium, one of the macronutrients for plants, is necessary for plant growth and development. It is also one of the essential heavy metals, and it is critical to watch the change in its concentration in the air regarding human and environmental health. This study aimed to reach information about the change of magnesium concentration in some trees based on species and organs as well as its transfer after it is taken into the plant. In addition, it is aimed to observe the variation of magnesium contamination in the air and to determine the species that can be used to reduce pollution. For this purpose, log samples from *Cedrus atlantica*, *Pinus pinaster*, *Picea orientalis*, *Cupressus arizonica*, and *Pseudotsuga menziesii* trees were used. As a result, it has been shown that the transfer of magnesium concentration in the wood of the studied species is limited. While the highest magnesium accumulation was obtained in *Cupressus arizonica* species, the highest concentrations were obtained in the outer bark and the lowest in the inner bark as the plant organ. In addition, it has been determined that the magnesium concentration in the air is related to the traffic density.

Keywords: Biomonitor, heavy metal, Mg, nutrient element

Introduction

Plants, which form the basis of the food source, form the origin of all living things in the world due to their economic and ecological functions (Özel et al., 2022). The ability of plants to perform all the functions they provide depends primarily on their healthy and adequate development (Erdem et al., 2023). The development of plants is shaped by the mutual interaction of their genetic structures (Kurz et al., 2023) and environmental factors (Varol et al., 2022; Tandogan et al., 2023). The most important environmental factors in plant development are climatic factors, such as temperature and precipitation (Koç, 2022; Dogan et al., 2023), and edaphic factors, such as nutrient status, soil depth, and pH (Cetin et al., 2022).

Soil is one of the most vital parameters affecting plant development, and the nutrients that plants take from the soil with their roots play a vital role in plant development. While nine of the 16 nutrients required for plant nutrition are macronutrients (C, H, O, N, P, K, Ca, Mg, S), seven are classified as micronutrients (Fe, Zn, Mn, Cu, B, Mo, Cl). Nutrients participate in various metabolic processes, from main and subordinate metabolism to cell protection and signal transduction to gene regulation, hormone perception, and energy metabolism (Aygün et al., 2018).

Magnesium (Mg), one of the essential macronutrients for plants, is the eighth most abundant element on planet. Magnesium is the fundamental element for plant development. A typical Mg deficiency symptom causes interveinal chlorosis in leaves (Gransee and Fühns, 2013; Tian et al., 2021). In higher plants, it affects numerous perilous biochemical and physiological processes, and its deficiency inhibits plant development (Xie et al., 2021). Since Mg acts as the chlorophyll molecule's central atom, chlorosis development requires predegradation of chlorophyll. Because Mg is firmly adhered to this molecule, chlorosis is a late reply to Mg deficiency. In plants well fed with Mg, only around 20% of the total Mg is adhered to chlorophyll, while the remaining roughly 80% is in more mobile forms (Gransee and Fühns, 2013).

Cite this article as:

Erdem, R., Koç, İ., Çobanoğlu, H., & Şevik, H. (2024). Variation of magnesium, one of the macronutrients, in some trees based on organs and species. *Forestist*, 74(1), 84-93.

Corresponding Author:

Ramazan Erdem

e-mail:

rerdem@kastamonu.edu.tr

Received: June 9, 2023

Revision Requested: July 03, 2023

Accepted: August 17, 2023

Publication Date: January 17, 2024



Content of this journal is licensed under a Creative Commons Attribution-NonCommercial 4.0 International License.

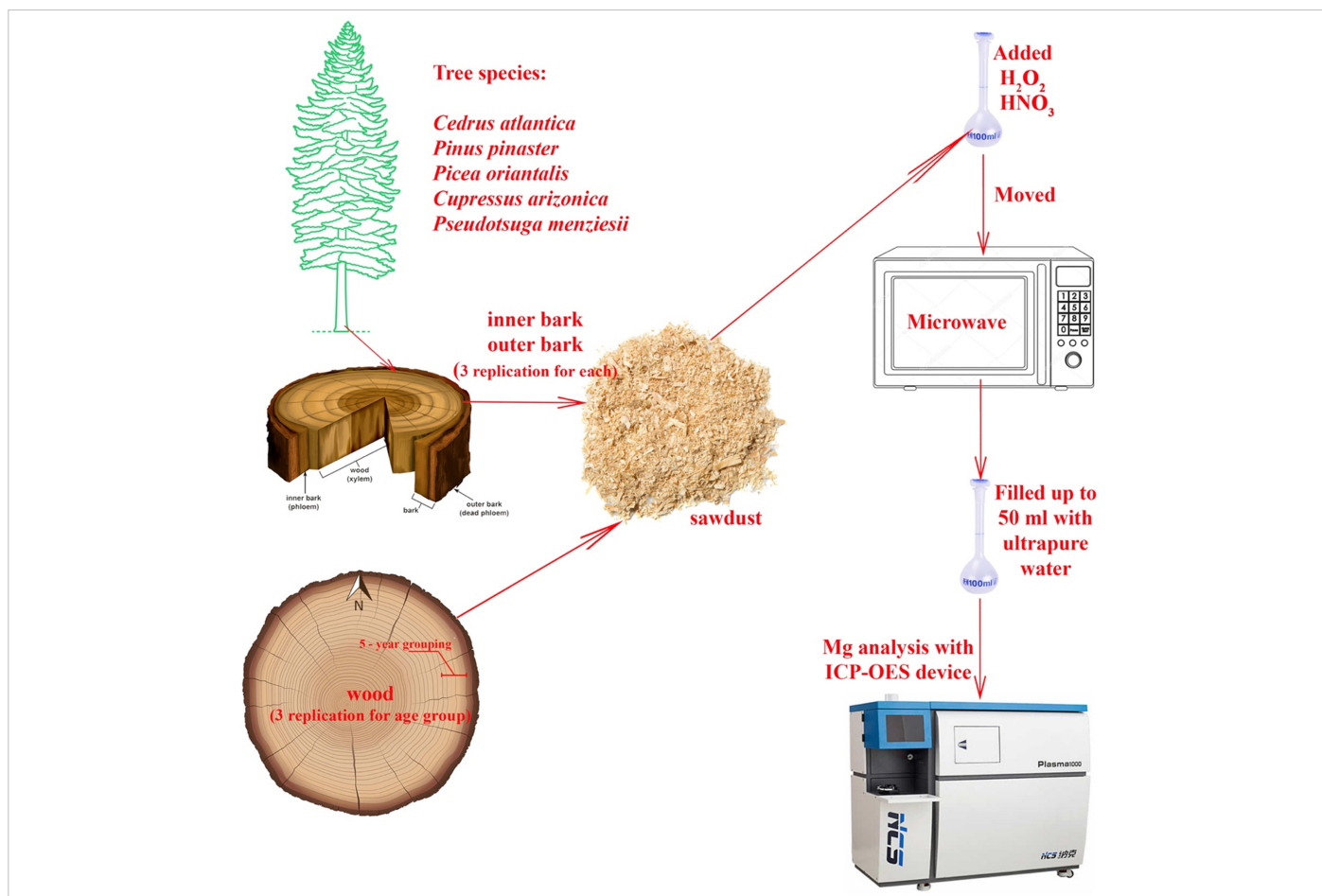


Figure 1.
Method Flow Chart. ICP-OES inductively coupled plasma–optical emission spectrometry; Mg magnesium.

Although Mg is one of the essential nutrients involved in various enzyme activities and structural stabilization of organs, its importance as a macronutrient ion has been neglected in recent years by botanists and agriculturalists, who do not consider Mg deficiency in plants as a severe health disorder (Guo et al., 2016). It is one of the essential macronutrients for plants and plays a crucial role in various biochemical activities, especially in photosynthesis as the key atom in chlorophyll (Wang et al., 2020). Mg, as both a regulatory feature and a structural component, assists plants succeed greater nitrogen utilization, photosynthetic efficiency, and stress resistance. Plants require a particular concentration of Mg for their development, and various key genes responsible for Mg accumulation, translocation, and detoxification have been identified. Despite its functional significance, basic research on Mg nutrition is still inadequate (Tian et al., 2021). In addition, information on its transfer, especially in higher plants, is limited.

In addition, Mg is one of the critical heavy metals. While some heavy metals such as Pb, Hg, As, V, and Cr can be toxic and deadly for living organisms even in small amount (Key et al., 2022; Isinkaralar et al., 2022), it is stated that even those that are necessary as nutrients for plants are harmful at high concentrations or when they exceed certain threshold values (Elajail et al., 2022; Istanbulu et al., 2023). It is also known that inhaling heavy metals from the air into the human body can be much more harmful and deadly (Ghoma et al., 2022; Sulhan et al., 2022). Therefore, it is crucial to carry out comprehensive studies on heavy metals.

This study aimed to reach information on the change of Mg concentration in some high-structured woody plants based on species and organs and on its transfer after being taken into the plant body. In addition, it is aimed to observe the variation of Mg pollution in the air and to determine the species that can be used to reduce pollution.

Material and Methods

Within the scope of this research, log samples were obtained from *Cedrus atlantica* (Endl.) Manetti ex Carr. (Atlas cedar), *Pinus pinaster* Aiton. (Maritime pine), *Picea orientalis* (L.) Peterm. (Caucasian spruce), *Cupressus arizonica* Greene (Arizona cypress), and *Pseudotsuga menziesii* (Mirb.) Franco (Douglas fir). These trees are frequently grown in Europe and used in landscape studies. The log samples of the mentioned species were obtained and preserved during the cutting in February 2022, provided that their directions are marked on the logs, and their coordinates are noted. After determining the age range groups on the wood surface (a five-year grouping was made considering the annual ring widths), samples were obtained from the outer and inner barks and wood of every age range with the help of a steel-tipped drill and put in glass petri dishes. The wood specimens were ground and turned into sawdust.

The samples placed into glass petri dishes were reserved in the laboratory with their caps open until they became room-dry, and the samples that became room-dry were taken to a drying oven and dried at 45°C for

2 weeks. Of them, 0.5 g of the dried samples were taken, and 6 mL of 65% HNO₃ and 2 mL of 30% H₂O₂ were added and placed in the microwave oven. The microwave device is set to rise to 200C in 15 minutes and stay at 200C for 15 minutes. After the specimens were burned in the microwave oven, the samples in solution form were taken into flasks and filled up to 50 mL with ultrapure water, and elemental analyses were made with the inductively coupled plasma–optical emission spectrometry device. The method flow chart is shown in Figure 1.

The analysis results were multiplied by 100 (dilution factor) because 0.5 g of samples was taken and made up to 50 g with water. According to the analysis results that did not fall into the calibration graph, different calibration graphs were created at the ppm level, and rereading was performed. Variance analysis was applied to the obtained data using the Statistical Package for the Social Sciences Statistics software 21.0 package program; the Duncan test was applied for the factors found to have statistically significant differences at 95% CI (*p* .05) according to the results of analysis of variance (ANOVA). Hence, the variation of Mg element concentration based on plant species, organ, direction, and year period was decided and assessed separately.

Ethics committee approval is not required for this study, because animal and human tissues and organs have not been studied. Only plant organs were used in this study.

Results

The results of the ANOVA regarding the variation of Mg concentration based on species and direction in the species subject to the study and the average values are given in Table 1. According to the ANOVA results, the difference of Mg concentration based on species in all directions is statistically significant (*p* .05). While the highest Mg concentration in the north side was obtained in the *Cupressus arizonica*, the highest Mg concentration in the east direction was obtained in the *Picea orientalis*. The highest Mg value was seen in the *Cupressus arizonica* in the south and west sides. Again, according to the average values, the highest value was obtained in the *Cupressus arizonica*.

The variation of Mg concentration by species and organ is given in Table 2. The variation of Mg concentration by species and organ is given in Table 2. When the results in the table were examined, the change in Mg concentration was significant (*p* .05) in all organs based on species. The highest Mg concentration in the outer and inner barks was

Species	East	West	North	South	Average
<i>Pinus pinaster</i>	325.0 a	173.1 a	447.4 a	262.0 a	301.9 a
<i>Cupressus arizonica</i>	333.5 a	316.2 b	900.8 b	457.5 b	502.0 b
<i>Picea orientalis</i>	530.3 b	184.7 a	309.5 a	307.1 ab	332.9 a
<i>Cedrus atlantica</i>	252.4 a	153.3 a	402.6 a	183.2 a	247.9 a
<i>Pseudotsuga menziesii</i>	383.6 ab	178.8 a	233.5 a	146.5 a	235.6 a
F-value	3.0*	2.4*	4.7**	4.0**	7.2***

Note: According to the results of the Duncan's test, numbers followed by the different letters (a and b) indicate significant differences among species within each direction.
**p* .05.
***p* .01.
****p* .001.

Table 2.
Variation of Magnesium Concentration (ppm) by Species and Organ

Species	Wood	Outer Bark	Inner Bark	Average
<i>Pinus pinaster</i>	242.2 c	800.5 a	280.8 a	242.2 c
<i>Cupressus arizonica</i>	194.7 b	1623.4 b	1838.5 b	194.7 b
<i>Picea orientalis</i>	220.6 bc	812.4 a	751.5 a	220.6 bc
<i>Cedrus atlantica</i>	159.3 a	885.6 a	318.8 a	159.3 a
<i>Pseudotsuga menziesii</i>	157.8 a	705.4 a	388.2 a	157.8 a
F-value	9.4***	3.9**	15.8***	9.4***

Note: According to the results of the Duncan's test, numbers followed by the different letters (a and b) indicate significant differences among species within each direction.
***p* .01.
****p* .001.

observed in the *Cupressus arizonica*, while the lowest was in *Pinus pinaster*, *Picea orientalis*, *Cedrus atlantica*, and *Pseudotsuga menziesii* species. The highest value was obtained in wood in *Pinus pinaster*, while the lowest value was observed in *Cedrus atlantica*, and *Pseudotsuga menziesii*. It is possible to sort wood inner bark outer bark according to average values.

The variation of Mg concentration by period and direction is presented in Table 3. Considering values, the difference in Mg concentration was significant (*p* .05) in all periods based on direction. In all directions except east and west, the variation in Mg concentration was not significant (*p* .05) based on the period. Notably, the highest Mg value in the west side is seen in the periods 2008–2012, 2013–2017, and 2018–2022, while the highest Mg concentration in the east direction is seen after 2018. The lowest Mg value in the east side was obtained in 1988–1992, and the lowest concentration in the west was obtained in 1993–1997. According to the average values, the highest value was seen after 2018.

The variation of Mg concentration by organ and direction is presented in Table 4. When the results are examined, the difference in Mg concentration based on the direction in all organs and organs in all directions except the inner bark is statistically significant (*p* .05). We can sort wood inner bark outer bark for north and east directions. In the south and west directions, the highest Mg concentration was observed in the outer and inner barks, while the lowest concentration was obtained in wood. The highest Mg concentration in the outer bark was observed in the north direction, and the lowest value in the west side. In contrast, the highest value in the wood was obtained in the north and east sides, and the lowest Mg was in the west direction. According to the average values, it was determined that the highest Mg concentration was in the north and the lowest one was in the west direction.

The variation of Mg concentration in *Pinus pinaster* by organ and direction is given in Table 5. According to the ANOVA results, the variation in Mg concentration in *Pinus pinaster* was statistically significant based on the direction in all organs and organs in all directions except the east. In the north and south directions, the highest value was observed in the outer bark, while the lowest was obtained in the inner bark and wood. When the table is examined in the west direction, it is possible to sort wood outer bark inner bark. According to the average values, the outer bark had the highest Mg value. We can sort the outer bark as west east south north. For the inner bark, this order is north south east west. Considering the average values, the lowest Mg

Table 3.
Variation of Magnesium Concentration (ppm) by Period and Direction

Age Category	East	West	North	South	F-Value	Average
2018–2022	405.5 Bc	140.3 Ab	326.2 B	179.3 A	10.9***	262.8 c
2013–2017	250.2 Bb	140.3 Ab	232.1 B	153.9 A	6.1**	194.1 b
2008–2012	235.7 Bb	140.2 Ab	279.2 B	151.5 A	10.5***	201.7 b
2003–2007	214.5 Bab	112.1 Aab	209.8 B	152.0 A	9.0***	172.1 ab
1998–2002	262.6 Bb	118.1 Aab	240.7 B	151.5 A	5.9**	193.2 b
1993–1997	255.4 BCb	95.7 Aa	275.0 C	161.6 AB	5.0**	196.9 b
1988–1992	124.0 Aa	119.7 Aab	196.3 B	136.2 A	4.7**	144.1 a
1983–1987	248.7 Bb	103.7 Aab	248.6 B	177.0 AB	6.8**	194.5 b
F-value	5.0***	2.3*	1.3 ns	0.8 ns		4.6***

Note: According to the results of the Duncan's test, numbers followed by the different letters (A, B, C, a, b, and c) indicate significant differences among each period within each direction. Lowercase letters illustrate vertical directions, while capital letters indicate horizontal directions.
ns not significant.
*p .05.
**p .01.
***p .001.

value was found in the west, while the highest Mg value was obtained in the north.

The variation of Mg concentration in *Pinus pinaster* wood by period and direction is presented in Table 6. The variation of Mg concentration in all woods was statistically significant in all periods based on direction and in all directions based on period. The highest Mg concentration in the north side was observed in the 1998–2002 period, the highest Mg in the east and south directions was observed in the 1993–1997 period, and the highest Mg value in the west side was observed after 2018. According to the average values, the highest value was obtained in 1993–1997 and 1998–2002. The lowest Mg concentration was observed in the west side, while the highest was in the north and east sides.

The variation of Mg concentration in *Cupressus arizonica* by organ and direction is presented in Table 7. Considering the results, the alteration in Mg concentration in *Cupressus arizonica* is statistically significant in all organs based on direction and based on organs in all directions. We can sort as east west south north for outer and inner barks. The highest Mg concentration in wood was observed in the north and east sides, while the lowest value was obtained in the west. According to

the average values, the highest Mg concentration was obtained in the north, while the lowest was obtained in the east, south, and west sides. For north, south, and west directions, wood outer bark inner bark can be sorted. In the east direction, this order is in the form of wood inner bark outer bark.

The variation of Mg concentration in *Cupressus arizonica* wood by period and direction is present in Table 8. According to the ANOVA results, the difference of Mg concentration in *Cupressus arizonica* woods was statistically significant in all periods based on direction and in all directions based on period. The highest Mg concentration in the north side was observed in 2008–2012, while the highest Mg concentration in the east side was obtained in 2013–2017. The highest Mg concentration in the south side was obtained after 2018, while the highest concentration in the west direction was observed in 2003–2007. According to the mean values, there is no statistically significant difference (p .05) between the periods.

The variation of Mg concentration in *Picea orientalis* by organ and direction is presented in Table 9. Considering the results, the difference in Mg concentration in *Picea orientalis* is statistically significant in all organs based on direction and based on organs in all directions. The highest Mg concentration was observed in the outer and inner barks in the north side, while the lowest was obtained in the wood. We can sort wood inner bark outer bark in the east direction. The order for the south and west directions is wood outer bark inner bark. According to the average values, the highest Mg concentration was obtained in the outer and inner barks, while the lowest was observed in wood. It is possible to rank west south north east for the outer bark and north west east south for the inner bark.

The variation of Mg concentration in *Picea orientalis* wood by period and direction is presented in Table 10. According to the Mg concentration, the variation of Mg concentration in *Picea orientalis* woods was statistically significant in all periods based on direction and in all directions based on period. The lowest Mg concentration in the north side was seen after 2018, while the lowest Mg concentration in the east side was obtained in 2013–2017. The highest Mg concentration in the south

Table 4.
Variation of Magnesium Concentration by Organ and Direction

Organ	East	West	North	South	F-Value
Outer bark	1023.4 Bc	491.0 Ab	1604.9 Cc	742.6 ABb	9.6***
Inner bark	629.8 b	550.9 b	974.6 b	706.9 b	0.7 ns
Wood	249.6 Ca	121.3 Aa	251.0 Ca	157.9 Ba	43.2***
F-value	90.0***	67.5***	50.9***	61.9***	
Average	365.0 BC	201.2 A	458.7 C	271.2 AB	10.0***

Note According to the results of the Duncan's test, numbers followed by the different letters (A, B, C, a, b, and c) specify differences among organs within each direction. Lowercase letters illustrate vertical directions, while capital letters indicate horizontal directions.
ns not significant.
***p .001.

Table 5.
Variation of Magnesium Concentration in *Pinus pinaster* by Organ and Direction

Organ	East	West	North	South	F-Value	Average
Outer bark	460.8 Ba	313.8 Ab	1764.7 Db	662.8 Cb	29817.0***	800.5 b
Inner bark	346.8 Ca	355.1 Dc	203.6 Aa	217.5 Ba	4956.4***	280.8 a
Wood	305.3 Ca	132.8 Aa	313.2 Ca	217.5 Ba	16.1***	242.2 a
F-value	1.7 ns	313.2***	204.5***	103.3***		35.6***

Note: According to the results of the Duncan's test, numbers followed by the different letters (A, B, C, D, a, b, and c) specify significant differences among organs within each direction. Lowercase letters illustrate vertical directions, while capital letters indicate horizontal directions.
ns not significant.
*** p .001.

side was obtained in 1983–1987, while the highest Mg concentration in the west side was observed in 1988–1992 and 1993–1997. It is remarkable that the highest value according to the average values is seen after 2018. Again, according to the average values, it was determined that the highest Mg concentration was in the north and east sides, and the lowest value was in the south and west directions.

The variation of Mg concentration in *Cedrus atlantica* by organ and direction is presented in Table 11. The variation in Mg concentration is statistically significant (p .05) in all organs based on direction and in all directions based on organs. It is possible to sort as wood inner bark outer bark for the east, south, and west sides. In the north direction, the highest Mg concentration was observed in the outer bark and

the lowest concentration was observed in the inner bark and wood. According to the average values, the highest Mg concentration was obtained in the outer bark and the lowest in the wood. The Mg concentration in the outer bark and wood was observed in the north direction and the lowest was observed in the west side. The inner bark is ordered as west south east north is valid. The highest Mg concentration was found in the north side according to the average values.

The variation of Mg concentration in *Cedrus atlantica* wood by period and direction is presented in Table 12. According to the ANOVA results, the difference of Mg concentration in *Cedrus atlantica* woods was statistically significant (p .05) in all periods based on direction and in all directions based on period. The highest Mg concentration in the north

Table 6.
Variation of Magnesium Concentration (ppm) in *Pinus pinaster* Woods by Period and Direction

Age Category	East	West	North	South	F-Value	Average
2018–2022	358.9 De	162.4 Af	308.8 Ce	234.0 Be	1082.7***	266.0 bc
2013–2017	161.9 Bb	113.0 Ab	260.2 Dd	189.7 Cc	1856.9***	181.2 ab
2008–2012	223.7 Bc	147.8 Ae	221.7 Bb	150.6 Aa	404.3***	186.0 ab
2003–2007	287.9 Dd	150.0 Ae	238.6 Cc	207.3 Bd	1098.4***	221.0 ab
1998–2002	459.0 Cg	138.0 Ad	568.0 Dg	204.7 Bd	15788.6***	342.4 c
1993–1997	521.5 Dh	113.3 Ab	452.2 Cf	317.2 Bg	11145.9***	351.0 c
1988–1992	47.0 Aa	108.4 Ba	306.9 De	156.7 Cb	6334.3***	154.8 a
1983–1987	382.7 Df	129.2 Ac	149.5 Ba	279.8 Cf	1527.7***	235.3 ab
F-value	3781.6***	434.7***	2839.4***	1261.3***		5.3***

Note: According to the results of the Duncan's test, numbers followed by the different letters (A, B, a, and b) specify significant differences among period within each direction. Lowercase letters illustrate vertical directions, while capital letters indicate horizontal directions.
*** p .001.

Table 7.
Variation of Magnesium Concentration (ppm) in *Cupressus arizonica* by Organ and Direction

Organ	East	West	North	South	F-Value	Average
Outer bark	788.1 Ac	961.2 Bb	3132.8 Db	1611.3 Cb	35169.5***	1623.4 b
Inner bark	584.3 Ab	1380.2 Bc	3654.5 Dc	1735.0 Cc	35471.6***	1838.5 b
Wood	245.3 Ca	102.5 Aa	377.5 Ca	153.5 Ba	29.5***	194.7 a
F-value	139.7***	8272.9***	1679.9***	23107.2***		100.7***

Note: According to the results of the Duncan's test, numbers followed by the different letters (A, B, a, and b) specify significant differences among organs within each direction. Lowercase letters illustrate vertical directions, while capital letters indicate horizontal directions.
*** p .001.

side was obtained in 1993–1997, the highest Mg value in the east side was obtained in 2008–2012, the highest concentration in the south side was obtained after 2018, and the highest Mg concentration in the west side was obtained in the 1988–1992, 1998–2002. According to the average values, the highest Mg concentration was seen in the north direction, while the lowest was found in the east, west, and south directions.

According to the mean values, there is no statistically significant ($p .05$) difference between the periods.

The variation of Mg concentration in *Pseudotsuga menziesii* by organ and direction is presented in Table 13. Considering the results, the difference in Mg concentration in *Pseudotsuga menziesii* is statistically

Table 8.
Variation of Magnesium Concentration (ppm) in Cupressus arizonica Wood by Period and Direction

Age Category	East	West	North	South	F-Value	Average
2018–2022	309.4 De	117.0 Ae	219.0 Ce	182.7 Bf	3423.8***	207.0
2013–2017	333.0 Df	93.0 Ac	200.5 Cd	137.6 Ba	3210.4***	191.0
2008–2012	138.0 Ba	98.3 Ad	516.3 Dh	148.1 Cc	24437.6***	225.2
2003–2007	202.7 Cb	147.7 Bf	377.3 Df	136.6 Aa	10921.3***	216.1
1998–2002	242.6 Dd	99.5 Ad	188.6 Cc	161.8 Bd	1069.7***	173.1
1993–1997	224.3 Cc	88.4 Aab	145.1 Ba	147.6 Bc	516.5***	151.3
1988–1992	200.9 Db	91.2 Abc	178.2 Cb	172.0 Be	1245.1***	160.6
1983–1987	311.5 Ce	85.0 Aa	395.3 Dg	142.0 Bb	5053.2***	233.5
F-value	1167.2***	272.5***	4147.4***	155.9***		1.1 ns

Note: According to the results of the Duncan's test, numbers followed by the different letters (A, B, a, and b) specify significant differences among periods within each direction. Lowercase letters illustrate vertical directions, while capital letters indicate horizontal directions.
*** $p .001$.

Table 9.
Variation of Magnesium Concentration in Picea orientalis by Organ and Direction

Organ	East	West	North	South	F-Value	Average
Outer bark	1954.2 Dc	278.7 Ab	560.1 Cb	456.6 Bb	3156.6***	812.4 b
Inner bark	810.7 Cb	650.4 Bc	417.1 Aab	1127.8 Dc	3941.0***	751.5 b
Wood	317.3 Ba	114.8 Aa	264.7 Ba	185.8 Aa	11.2***	220.6 a
F-value	113.9***	664.1***	6.1**	465.3***		42.9***

Note: According to the results of the Duncan's test, numbers followed by the different letters (A, B, a, and b) specify significant differences among organs within each direction. Lowercase letters illustrate vertical directions, while capital letters indicate horizontal directions.
** $p .01$.
*** $p .001$.

Table 10.
Variation of Magnesium Concentration (ppm) in Picea orientalis Wood by Period and Direction

Age category	East	West	North	South	F-Value	Average
2018–2022	772.5 Dg	110.2 Ac	600.0 Cf	144.6 Bb	18030.4***	406.8 c
2013–2017	65.8 Aa	110.1 Bc	213.8 Dc	190.3 Cd	2225.2***	145.0 a
2008–2012	349.4 Df	117.0 Ad	157.0 Cb	144.6 Bb	3310.4***	192.0 ab
2003–2007	249.8 Dc	64.6 Aa	156.2 Cb	135.8 Ba	1166.2***	151.6 a
1998–2002	284.5 Cd	98.0 Ab	150.8 Bab	151.2 Bc	2080.3***	171.1 ab
1993–1997	341.7 De	150.7 Be	146.6 Aa	207.6 Cf	10880.6***	211.6 ab
1988–1992	222.0 Cb	147.8 Ae	248.2 Dd	201.3 Bd	588.9***	204.8 ab
1983–1987	252.8 Bc	119.8 Ad	444.8 De	311.0 Cg	1234.5***	282.1 b
F-value	8051.3***	221.0***	3735.3***	1127.5***		5.3***

Note: According to the results of the Duncan's test, numbers followed by the different letters (A, B, a, and b) specify significant differences among periods within each direction. Lowercase letters illustrate vertical directions, while capital letters indicate horizontal directions.
*** $p .001$.

Table 11.
Variation of Magnesium Concentration (ppm) in Cedrus atlantica by Organ and Direction

Organ	East	West	North	South	F-Value	Average
Outer bark	818.9 Bc	508.8 Ac	1733.3 Cb	481.6 Ac	3952.7***	885.6 c
Inner bark	380.2 Cb	208.5 Ab	405.7 Da	281.0 Bb	1016.7***	318.8 b
Wood	165.7 Ba	102.0 Aa	235.9 Ca	133.7 ABa	12.6***	159.3 a
F-value	308.1***	117.4***	191.2***	93.0***		83.8***

Note: According to the results of the Duncan's test, numbers followed by the different letters (A, B, a, and b) specify significant differences among organs within each direction. Lowercase letters illustrate vertical directions, while capital letters indicate horizontal directions.
***p .001.

Table 12.
Variation of Mg Concentration (ppm) in Cedrus atlantica Wood by Period and Direction

Age category	East	West	North	South	F-Value	Average
2018–2022	185.1 Cc	72.2 Ab	145.8 Ba	185.9 Cf	761.4***	147.2
2013–2017	201.6 Dd	134.6 Be	184.2 Cc	118.3 Ac	1756.0***	159.7
2008–2012	215.4 Ce	84.5 Ad	236.2 De	179.2 Be	740.0***	178.8
2003–2007	200.0 Cd	82.4 Ad	198.7 Cd	170.4 Bd	1879.5***	162.9
1998–2002	196.0 Cd	168.5 Af	239.2 De	174.2 Bd	429.5***	194.5
1993–1997	95.0 Ca	29.2 Aa	574.7 Df	71.8 Ba	11223.9***	192.7
1988–1992	96.6 Ba	167.2 Df	158.7 Cb	69.7 Aa	1141.7***	123.0
1983–1987	135.7 Cb	77.2 Ac	149.7 Da	99.7 Bb	766.6***	115.6
F-value	559.9***	893.5***	7478.3***	1080.9***		1.2 ns

Note: According to the results of the Duncan's test, numbers followed by the different letters (A, B, a, and b) specify significant differences among periods within each direction. Lowercase letters illustrate vertical directions, while capital letters indicate horizontal directions.
***p .001.

Table 13.
Variation of Mg Concentration (ppm) in Pseudotsuga menziesii by Organ and Direction

Organ	East	West	North	South	F-Value	Average
Outer bark	1095.0 Db	392.6 Ab	833.4 Cb	500.6 Bc	6025.5***	705.4 c
Inner bark	1027.1 Db	160.3 Aa	192.2 Ca	173.4 Bb	27247.8***	388.2 b
Wood	214.3 Ba	154.4 Aba	163.6 Aba	98.9 Aa	4.2**	157.8 a
F-value	68.2***	15.9***	51.0***	194.6***		52.9***

Note: According to the results of the Duncan's test, numbers followed by the different letters (A, B, a, and b) specify significant differences among organs within each direction. Lowercase letters illustrate vertical directions, while capital letters indicate horizontal directions.
**p .01.
***p .001.

significant ($p .05$) in all organs based on direction and based on organs in all directions. The highest Mg concentration in the north and west directions was obtained in the outer bark, and the highest concentration in the east direction was obtained in the outer and inner barks. In the south side, it can be sorted as wood inner bark outer bark. For the outer and inner barks, wood can be sorted as west south north east. In wood, the highest concentration was found in the east direction.

The variation of Mg concentration in *Pseudotsuga menziesii* wood by period and direction is presented in Table 14. When the average values were examined, the difference in Mg concentration was statistically significant in all periods based on direction (except for the

2018–2022 period) and based on periods in all directions. The highest Mg concentration in the north side was seen after 2018, while the highest Mg concentration in the east side was obtained in 2013–2017. Notably, the highest Mg concentration in the west side was obtained in the 2008–2012 and 2013–2017 periods, while the highest concentration in the south side was observed after 2018.

Discussion and Conclusion

As a result, it was found that Mg accumulated within the determinable limits in all samples. This situation indicates that the species subject to the study have a high Mg accumulation potential. The most critical

Table 14.
Variation of Magnesium Concentration (ppm) in *Pseudotsuga menziesii* Wood by Period and Direction

Age Category	East	West	North	South	F-Value	Average
2018–2022	401.5 Abc	239.6 Ae	357.4 Ag	149.2 Af	1.7 ns	286.9 b
2013–2017	488.9 Dc	251.0 Bf	301.6 Cf	133.4 Ae	8671.4***	293.7 b
2008–2012	251.9 Bab	253.6 Bf	264.7 Ce	135.2 Ae	1279.5***	226.3 b
2003–2007	132.0 Da	115.8 Cd	78.4 Ab	110.1 Bd	527.8***	109.1 a
1998–2002	131.2 Da	86.5 Ca	57.1 Aa	65.4 Bb	749.7***	85.0 a
1993–1997	94.3 Ca	97.0 Cb	56.4 Aa	63.8 Bb	370.9***	77.9 a
1988–1992	53.6 Aa	84.0 Ba	89.7 Cc	81.2 Bc	103.3***	77.1 a
1983–1987	161.0 Da	107.6 Cc	103.6 Bd	52.8 Aa	1734.7***	106.2 a
F-value	6.5**	2420.9***	14940.3***	635.2***		16.8***

Note: According to the results of the Duncan's test, numbers followed by the different letters (A, B, a, and b) specify significant differences among periods within each direction. Lowercase letters illustrate vertical directions, while capital letters indicate horizontal directions.
 **p .01.
 ***p .001.

feature sought in the species that can be used to determine heavy metal pollution is the ability of the species to accumulate heavy metals in its body (Savas et al., 2021).

The study's first aim is to determine the variation of Mg concentration on the basis of species and organs. The study results show that the highest Mg concentration was obtained in *Cupressus arizonica* as a species. Magnesium concentration based on the organ is listed as wood inner bark outer bark. Studies show that each species has a different potential to accumulate different heavy metals (Karacocuk et al., 2022).

As a result, there was a significant difference between the Mg concentrations in the woods of different directions formed in the same period. For example, the Mg concentration, measured as 78.4 ppm in the woods formed in 2003–2007 in the north direction in *Pseudotsuga menziesii*, was measured as 264.7 ppm in the woods formed in 2008–2012 in the same direction. These results could be interpreted as the limited transfer of Mg in wood. Different researchers obtained similar results, revealing that the transfer of some elements in wood is higher, while some elements are more limited (Cesur et al., 2021; Cobanoglu et al., 2023).

As a result, Mg concentration was ordered as north east south west according to the average values. Ankara–istanbul highway, one of the busiest highways in Türkiye, passes through the northeast of the study area. According to these outcomes, it could be said that Mg concentrations rise drastically depending on traffic density. Studies on heavy metals indicate that traffic density is one of the main heavy metal sources (Arıcak et al., 2020). Studies also show that the concentration of Mg in the air rises depending on the traffic density (Ozel et al., 2021).

The study results also point out that the concentration of Mg in the air increases due to traffic. The fact that the concentrations obtained in the north and east sides in the outer bark are much higher supports this result. Studies show that heavy metals in the air adhere to particulate matter in areas close to the source of pollution and contaminate particulate matter with heavy metals, and these particulate substances settle on plant organs and increase heavy metal concentrations in these organs (Sevik et al., 2020; Kuzmina et al., 2023). Since the outer bark has

a rough surface structure, particulate matter can easily adhere here. Thus, heavy metal concentrations are at high levels, especially in the barks in the side of heavy traffic (Yayla et al., 2022).

The study results show that Mg varies significantly based on plant species and organs. Elements can enter the plant body through roots from the soil, leaves from the air, or stem parts (Chen et al., 2021). Magnesium uptake by plants is highly dependent on the concentration, amount, and activity of Mg in the soil solution and the soil's capacity to regenerate Mg in the soil solution. The availability of Mg depends on the activity or ratio of Mg relative to the exchangeable and soluble amounts of K, Al, Ca, Na, and Mn (Mayland and Wilkinson, 1989). Magnesium uptake from the soil into stem cells is generally unidirectional (Wang et al., 2020). Magnesium can be diffused or transported passively by plant roots by Mg-specific transporters (Li et al., 2001; Gebert et al., 2009) or Mg²⁺ by water flow in the apoplast of the root cortex. Mg²⁺ absorbed by the roots from the soil solution is transported to the airborne biomass by the water transpiration flow moving along the xylem veins. Magnesium is a phloem mobile element and can easily migrate to fruits, seeds, and tubers (Hermans et al., 2013). Second, an active transport pathway consumes energy and requires Mg to bind to membrane proteins before it can enter stem cells (Wang et al., 2020).

However, Mg in the soil and Mg in the air should not be considered in the same category, because the number of studies on the damage that Mg inhaled in the air can cause in the human body is limited. Studies have shown that the Mg concentration in the air increases with traffic density (Ozel et al., 2021) and that heavy metals inhaled from the air can be highly harmful and deadly for humans (Ghoma et al., 2022). Therefore, it is crucial for human and environmental health to monitor the change of Mg pollution in the air and to take measures to reduce it when necessary.

In future studies, it is recommended to investigate the effects of sub-species, forms, varieties, and even different genotypes of the same species as well as plant species. Like all phenotypic traits, plant development is shaped under the mutual interaction of genetic structure (Koç and Nzokou, 2022) and environmental conditions (Koç et al., 2022). In addition, plant habitus and development also affect the element uptake and accumulation of the plant (Cesur et al., 2022). All factors

affecting the plant habitus also affect the entry and accumulation of elements into the plant. Therefore, the plant habitus is shaped under the mutual interaction of many factors that affect each other, such as genetic structure (Koç and Nzokou, 2022), edaphic (Shults et al., 2020), climatic factors (Varol et al., 2022; Cetin et al., 2023), and stress factors (Koç and Nzokou, 2023). Consequently, many of these factors, directly and indirectly, affect plants' element uptake and accumulation potential, and the information about this complex mechanism is still limited (Isinkaralar et al., 2022).

Peer-review: Externally peer-reviewed.

Author Contributions: Concept – H.S., R.E.; Design – H.S., R.E., İ.K.; Supervision – R.E.; Resources – H.C., İ.K.; Materials – H.S.; Data Collection and/or Processing – H.S., R.E.; Analysis and/or Interpretation – H.C., İ.K.; Literature Search – İ.K., H.S.; Writing Manuscript – H.C., H.S., İ.K.; Critical Review – H.C., H.S., İ.K.; Other – R.E., İ.K., H.C., H.S.

Acknowledgments: We thank the Kastamonu University Scientific Research Studies Project Management Coordination.

Declaration of Interests: The authors have no conflict of interest to declare.

Funding: This study is supported by the Kastamonu University Scientific Research Projects Coordination Unit (Project number is KUBAP01/2022-2).

References

- Aricak, B., Cetin, M., Erdem, R., Sevik, H., & Cometen, H. (2020). The usability of Scotch pine (*Pinus sylvestris*) as a biomonitor for traffic-originated heavy metal concentrations in Turkey. *Polish Journal of Environmental Studies*, 29(2), 1051–1057. [\[CrossRef\]](#)
- Aygün, C., Kara, ., Oral, H. H., Erdodu, ., Atalay, A. K., & Sever, A. L. (2018). Bazı çalı bitkilerinin sezonluk (ilkbahar, yaz, sonbahar) yaprak örneklerindeki Makro ve mikro besin elementleri içerikleri. *Bahri Dağdaş Bitkisel Araştırma Dergisi*, 7(1), 51–65.
- Cesur, A., Zeren Cetin, I., Abo Aisha, A. E. S., Alrabiti, O. B. M., Aljama, A. M. O., Jawed, A. A., Cetin, M., Sevik, H., & Ozel, H. B. (2021). The usability of *Cupressus arizonica* annual rings in monitoring the changes in heavy metal concentration in air. *Environmental Science and Pollution Research International*, 28(27), 35642–35648. [\[CrossRef\]](#)
- Cesur, A., Zeren Cetin, I., Cetin, M., Sevik, H., & Ozel, H. B. (2022). The use of *Cupressus arizonica* as a biomonitor of Li, Fe, and Cr pollution in Kastamonu. *Water, Air, and Soil Pollution*, 233(6), 193. [\[CrossRef\]](#)
- Cetin, M., Aljama, A. M. O., Alrabiti, O. B. M., Adiguzel, F., Sevik, H., & Zeren Cetin, I. (2022). Determination and mapping of regional change of Pb and Cr pollution in Ankara City Center. *Water, Air, and Soil Pollution*, 233(5), 1–10. [\[CrossRef\]](#)
- Cetin, M., Sevik, H., Koc, I., & Zeren Cetin, I. Z. (2023). The change in biocomfort zones in the area of Mula province in near future due to the global climate change scenarios. *Journal of Thermal Biology*, 112, 103434. [\[CrossRef\]](#)
- Chen, S., Yao, Q., Chen, X., Liu, J., Chen, D., Ou, T., Liu, J., Dong, Z., Zheng, Z., & Fang, K. (2021). Tree-ring recorded variations of 10 heavy metal elements over the past 168 years in southeastern China. *Elementa: Science of the Anthropocene*, 9(1). [\[CrossRef\]](#)
- Cobanoğlu, H., Sevik, H., & Koç, İ. (2023). Do annual rings really reveal Cd, Ni, and Zn pollution in the air related to traffic density? An example of the Cedar tree. *Water, Air, and Soil Pollution*, 234(2), 65. [\[CrossRef\]](#)
- Dogan, S., Kilicoglu, C., Akinci, H., Sevik, H., & Cetin, M. (2023). Determining the suitable settlement areas in Alanya with GISbased site selection analyses. *Environmental Science and Pollution Research International*, 30(11), 29180–29189. [\[CrossRef\]](#)
- Elajail, I. S. I., Sevik, H., Ozel, H. B., & Isik, B. (2022). Examining the chemical compositions of mineral concrete agents in terms of their environmental effects. *Feb-fresenius environmental bulletin*, 31(9), 9784–9790.
- Erdem, R., Cetin, M., Aricak, B., & Sevik, H. (2023). The change of the concentrations of Boron and Sodium in some forest soils depending on plant species. *Forestist*, 7(3), 207–212
- Gebert, M., Meschenmoser, K., Svidová, S., Weghuber, J., Schweyen, R., Eifler, K., Lenz, H., Weyand, K., & Knoop, V. (2009). A root-expressed magnesium transporter of the MRS2/MGT gene family in Arabidopsis thaliana allows for growth in low-Mg²⁺ environments. *Plant Cell*, 21(12), 4018–4030. [\[CrossRef\]](#)
- Ghoma, W. E. O., Sevik, H., & Isinkaralar, K. (2022). Using indoor plants as biomonitors for detection of toxic metals by tobacco smoke. *Air Quality, Atmosphere and Health*, 15(3), 415–424. [\[CrossRef\]](#)
- Granssee, A., & Führs, H. (2013). Magnesium mobility in soils as a challenge for soil and plant analysis, magnesium fertilization and root uptake under adverse growth conditions. *Plant and Soil*, 368(1–2), 5–21. [\[CrossRef\]](#)
- Guo, W., Nazim, H., Liang, Z., & Yang, D. (2016). Magnesium deficiency in plants: An urgent problem. *Crop Journal*, 4(2), 83–91. [\[CrossRef\]](#)
- Hermans, C., Conn, S. J., Chen, J., Xiao, Q., & Verbruggen, N. (2013). An update on magnesium homeostasis mechanisms in plants. *Metallomics*, 5(9), 1170–1183. [\[CrossRef\]](#)
- Isinkaralar, K., Koç, ., Kuzmina, N. A., Menshchikov, S. L., Erdem, R., & Aricak, B. (2022). Determination of heavy metal levels using Betula pendula Roth. under various soil contamination in Southern Urals, Russia. *International Journal of Environmental Science and Technology*, 19(12), 12593–12604. [\[CrossRef\]](#)
- Istanbullu, S. N., Sevik, H., Isinkaralar, K., & Isinkaralar, O. (2023). Spatial distribution of heavy metal contamination in road dust samples from an urban environment in Samsun, Türkiye. *Bulletin of Environmental Contamination and Toxicology*, 110(4), 78. [\[CrossRef\]](#)
- Karacocuk, T., Sevik, H., Isinkaralar, K., Turkyilmaz, A., & Cetin, M. (2022). The change of Cr and Mn concentrations in selected plants in Samsun city center depending on traffic density. *Landscape and Ecological Engineering*, 18(1), 75–83. [\[CrossRef\]](#)
- Key, K., Kulaç, ., Koç, ., & Sevik, H. (2022). Determining the 180-year change of Cd, Fe, and Al concentrations in the air by using annual rings of *Corylus colurna* L. *Water, Air, and Soil Pollution*, 233(7), 244. [\[CrossRef\]](#)
- Koç, İ. (2022). Determining the near-future biocomfort zones in Samsun Province by the global climate change scenarios. *Kastamonu Üniversitesi Orman Fakültesi Dergisi*, 22(2), 181–192. [\[CrossRef\]](#)
- Koç, İ., & Nzokou, P. (2022). Do various conifers respond differently to water stress. A comparative study of white pine, concolor and balsam fir. *Kastamonu Üniversitesi Orman Fakültesi Dergisi*, 22(1), 1–16. [\[CrossRef\]](#)
- Koç, İ., & Nzokou, P. (2023). Combined effects of water stress and fertilization on the morphology and gas exchange parameters of 3-year-old *Abies fraseri* (Pursh) Poir. *Acta Physiologiae Plantarum*, 45(3), 49. [\[CrossRef\]](#)
- Koç, İ., Nzokou, P., & Cregg, B. (2022). Biomass allocation and nutrient use efficiency in response to water stress: Insight from experimental manipulation of balsam fir, concolor fir and white pine transplants. *New Forests*, 53(5), 915–933. [\[CrossRef\]](#)
- Kurz, M., Kölz, A., Gorges, J., Pablo Carmona, B., Brang, P., Vitasse, Y., Kohler, M., Rezzonico, F., Smits, T. H. M., Bauhus, J., Rudow, A., Kim Hansen, O., Vatanparast, M., Sevik, H., Zhelev, P., Gömöry, D., Paule, L., Sperisen, C., & Csilléry, K. (2023). Tracing the origin of Oriental beech stands across Western Europe and reporting hybridization with European beech—Implications for assisted gene flow. *Forest Ecology and Management*, 531, 120801. [\[CrossRef\]](#)
- Kuzmina, N., Menshchikov, S., Mohnachev, P., Zavyalov, K., Petrova, I., Ozel, H. B., Aricak, B., Onat, S. M., & Sevik, H. (2023). Change of aluminum concentrations in specific plants by species, organ, washing, and traffic density. *BioResources*, 18(1), 792–803. [\[CrossRef\]](#)
- Li, L., Tutone, A. F., Drummond, R. S., Gardner, R. C., & Luan, S. (2001). A novel family of magnesium transport genes in Arabidopsis. *Plant Cell*, 13(12), 2761–2775. [\[CrossRef\]](#)
- Mayland, H. F., & Wilkinson, S. R. (1989). Soil factors affecting magnesium availability in plant-animal systems: A review. *Journal of Animal Science*, 67(12), 3437–3444. [\[CrossRef\]](#)
- Özel, H. B., evik, H., Onat, S. M., & Yiit, N. (2022). The effect of geographic location and seed storage time on the content of fatty acids in Stone Pine (*Pinus pinea* L.) Seeds. *BioResources*, 17(3), 5038–5048. [\[CrossRef\]](#)
- Ozel, H. B., Varol, H. N., & Sevik, H. (2021). Change of Mg concentration in several plants depending on plant species, washing status, and traffic density. *World Journal of Advanced Research and Reviews*, 12(1), 447–453. [\[CrossRef\]](#)
- Savas, D. S., Sevik, H., Isinkaralar, K., Turkyilmaz, A., & Cetin, M. (2021). The potential of using *Cedrus atlantica* as a biomonitor in the concentrations of Cr and Mn. *Environmental Science and Pollution Research International*, 28(39), 55446–55453. [\[CrossRef\]](#)
- Sevik, H., Cetin, M., Ozel, H. B., Akarsu, H., & Zeren Cetin, I. Z. (2020). Analyzing of usability of tree-rings as biomonitors for monitoring heavy metal

- accumulation in the atmosphere in urban area: A case study of cedar tree (*Cedrus* sp.). *Environmental Monitoring and Assessment*, 192(1), 23. [\[CrossRef\]](#)
- Shults, P., Nzokou, P., & Koc, I. (2020). Nitrogen contributions of alley cropped *Trifolium pratense* may sustain short rotation woody crop yields on marginal lands. *Nutrient Cycling in Agroecosystems*, 117(2), 261–272. [\[CrossRef\]](#)
 - Sulhan, O. F., Sevik, H., & Isinkaralar, K. (2022). Assessment of Cr and Zn deposition on *Picea pungens* Engelm. in urban air of Ankara, Türkiye. *Environment, Development and Sustainability*, 25(5), 4365–4384.
 - Tandoan, M., Özel, H. B., Gözet, F. T., & evik, H. (2023). Determining the Taxol contents of yew tree populations in western Black Sea and Marmara regions and analyzing some forest stand characteristics. *BioResources*, 18(2), 3496–3508. [\[CrossRef\]](#)
 - Tian, X. Y., He, D. D., Bai, S., Zeng, W. Z., Wang, Z., Wang, M., Wu, L. Q., & Chen, Z. C. (2021). Physiological and molecular advances in magnesium nutrition of plants. *Plant and Soil*, 468(1–2), 1–17. [\[CrossRef\]](#)
 - Varol, T., Canturk, U., Cetin, M., Ozel, H. B., Sevik, H., & Zeren Cetin, I. (2022). Identifying the suitable habitats for Anatolian boxwood (*Buxus sempervirens* L.) for the future regarding the climate change. *Theoretical and Applied Climatology*, 150(1–2), 637–647. [\[CrossRef\]](#)
 - Wang, Y., Wu, B., Berns, A. E., Xing, Y., Kuhn, A. J., & Amelung, W. (2020). Magnesium isotope fractionation reflects plant response to magnesium deficiency in magnesium uptake and allocation: A greenhouse study with wheat. *Plant and Soil*, 455(1–2), 93–105. [\[CrossRef\]](#)
 - Xie, K., Cakmak, I., Wang, S., Zhang, F., & Guo, S. (2021). Synergistic and antagonistic interactions between potassium and magnesium in higher plants. *Crop Journal*, 9(2), 249–256. [\[CrossRef\]](#)
 - Yayla, E. E., Sevik, H., & Isinkaralar, K. (2022). Detection of landscape species as a low-cost biomonitoring study: Cr, Mn, and Zn pollution in an urban air quality. *Environmental Monitoring and Assessment*, 194(10), 687. [\[CrossRef\]](#)