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Examination of Heavy Metal Content and Phytoremediation Capacities of Poaceae Forage Plant Species Spreading Around Iron Mine: The Case of Bingöl-Avnik (Türkiye)*

Demir Madeni Çevresinde Yayılış Gösteren Buğdaygil Yem Bitkisi Türlerinin Ağır Metal İçeriklerinin ve Fitoremediasyon Kapasitelerinin İncelenmesi: Bingöl-Avnik Örneği (Türkiye)

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Abstract: This study aimed to investigate the heavy metal contents and evaluate the phytoremediation capacity of forage grasses distributed in the natural areas surrounding the Avnik iron mine in the Genç district of Bingöl province. Five different species of the Poaceae family (*Poa bulbosa* L., *Bromus tectorum* L., *Aegilops neglecta*, *Calamagrostis pseudophragmites*, *Stipa capensis*) were collected. Aluminum (Al), cobalt (Co), chromium (Cr), copper (Cu), iron (Fe), nickel (Ni), manganese (Mn) and zinc (Zn) contents were determined in roots, leaves, stems, and generative parts of the plants. Translocation Factor (TF) and Bioconcentration factor (BCF) were calculated. $TF_{Cr,\ Mn,\ Ni}$>1 were observed in *B. tectorum*; TF_{Cu}>1 was observed in *P. bulbosa* and *S. capensis*; and TF_{Mn}>1 was observed in *A. neglecta* and *C. pseudophragmites*, which may suggest a potential role in phytoextraction. Especially, BCFroot >15 was determined in *P. bulbosa*, *A. neglecta*, and *S. capensis*, supporting their suitability for phytostabilization of Cr. Although the TF and BCF values>1 of these Poaceae species collected from the area around the mining facility are thought to be promising in terms of phytoremediation for these metals, more clear information will be obtained in pot trials to be carried out at different doses. In addition, even though it is thought that there is no hazardous pollution in the soils sampled around the mine site, animal grazing should be cautious in these areas due to the high concentrations in the above-ground organs of some species.

Keywords: Phytoremediation, Poaceae, Forage plants, BCF

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Öz: Bu çalışmada Bingöl ili, Genç ilçesinde bulunan Avnik demir madeninin çevresindeki doğal alanlarda yayılış gösteren buğdaygil yem bitkileri türlerinin ağır metal içeriklerinin araştırılması ve fitoremediasyon kapasitelerinin değerlendirilmesi amaçlanmıştır. Bu doğrultuda buğdaygiller familyasına ait (*Poa bulbosa* L., *Bromus tectorum* L., *Aegilops neglecta*, *Calamagrostis pseudophragmites*, *Stipa capensis*) 5 farklı tür toplanmıştır. Bitkilerin kök, gövde, yaprak ve generatif kısımlarında alüminyum (Al), kobalt (Co), krom (Cr), bakır (Cu), demir (Fe), nikel (Ni), mangan (Mn) ve çinko (Zn) içerikleri belirlenmiştir. Translokasyon Faktörü (TF) ve Biyokonsantrasyon faktörü (BCF) hesaplanmıştır. *B. tectorum*'da $TF_{Cr,\ Mn,\ Ni}$>1, *P. bulbosa* ve *S. capensis*'te TF_{Cu}>1, *A. neglecta* ve *C. pseudophragmites*'te TF_{Mn}>1 olarak belirlenmesinden dolayı bu türlerin fitoekstraksiyonda potansiyel bir rolü olabileceği düşünülmektedir. Özellikle Cr metalinde, *P. bulbosa*, *A. neglecta* ve *S. capensis* için $BCF_{kök}$>15 olduğundan bu türlerin fitostabilizasyonda (Cr) kullanılma durumları güçlenmektedir. Maden işletmesi çevresinden toplanan bu buğdaygil türlerinden TF ve BCF değerlerinin>1 olması bu metaller için fitoremediasyon açısından umut verici olduğu düşünülmekle birlikte farklı dozlarda yapılacak saksı denemelerinde daha net bilgiler elde edilecektir. Ayrıca maden alanı çevresinde örneklenen topraklarda tehlikeli bir kirliliğin söz konusu olmadığı düşünülmekle birlikte bazı türlerin toprak üstü organlarındaki yüksek konsantrasyonlar sebebi ile bu alanlarda hayvan otlatmalarına dikkat edilmelidir.

Anahtar Kelimeler: Fitoremediasyon, Buğdaygil, Yem bitkisi, BCF

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INTRODUCTION

The term "heavy metal" (e.g. Fe, Mn, Cu, Ni, Co, Cd, Zn; Ghori et al., 2019) is generally used for metals with a concentration greater than 5 g cm^{-3} (Sharma and Agrawal, 2005). The uptake and accumulation of health-threatening toxic metals by plants is a potential route of entry into humans and their animal diets. Heavy metals are continuously introduced into the biosphere through natural processes, such as volcanic activity and precipitation, as well as human activities including mining and the combustion of fossil fuels (Ertekin et al., 2020).

Today, the role of the mining industry is becoming more and more important in order to reach the standards of modern and developed countries. Mining activities, which date back to ancient times, are one of the largest industries today. However, regardless of the method followed during the operation of the mine, there is a possibility that it may cause long-term and irreversible environmental pollution (Gökdere et al., 2025). Soil remediation includes physical methods (soil exchange, thermal desorption, membrane filtration) and chemical methods (precipitation, leaching, fixation and immobilization) (Karn et al., 2021). However, these methods are often costly, and can lead to secondary contamination of soil (Salas-Moreno and Marrugo-Negrete, 2020; Chamba-Eras et al., 2022).

Phytoremediation is a type of bioremediation that uses plants to reduce the toxic effects of heavy metals in the environment (Ashraf et al., 2019). In phytoremediation, phytostabilization and phytoextraction are two important points and phytostabilization helps to keep metals underground, while phytoextraction is more effective in removing metals from the soil (Yan et al., 2020). Plants that can accumulate metals with high biomass production, known as hyperaccumulator plants, are preferred for phytoremediation (Chamba-Eras et al., 2022).The bioconcentration factor (BCF) is used to evaluate the metal accumulation efficiency in plants and the translocation factor (TF) is used to evaluate the capacity of the plant to translocate metals from the roots to the upper organs (Sürmen et al., 2019). Plants with BCF and TF values>1 were classified as "phytoextractors" and plants with TF<1 and BCF>1 were classified as "phytostabilizers" (Yang et al., 2014). Monitoring of natural plant species in mine sites may help to identify suitable plants for phytoremediation approaches. No prior studies have been reported on the phytoremediation potential of Poaceae species in the Avnik. This study was carried out to investigate the heavy metal contents of Poaceae forage plant species naturally distributed around Avnik iron mine, which has been in existence for about 15 years in Genç district of Bingöl province, and to evaluate their phytoremediation capacities.

MATERIAL AND METHOD

This study was carried out in April-June 2024 to collect and determine the heavy metal contents of the forage plant species of Poaceae distributed in the natural areas around the Avnik Iron mine (Şahin, 2025). The coordinates (38° 39′ 1″ N- 40° 18′ 13″ E) and map of the site (around 4 ha) are shown in Figure 1.

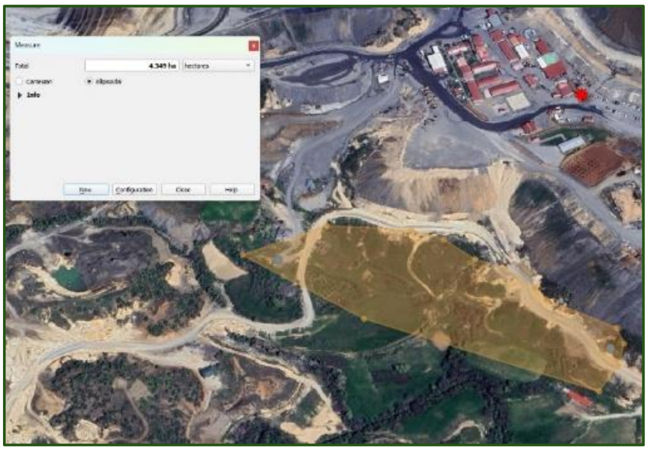

Figure 1. Showing the coordinates of the study area on the map.
Şekil 1. Çalışma alanının koordinatlarının harita üzerinde gösterilmesi.

The plants were taken from the field as much as possible without damaging the roots, identified, separated into organs including roots, stem, leaves and generative parts and washed. Plant parts were dried at 70 °C for 48 hours, then ground in a hand mill and prepared for analysis.

Soil samples were taken from the places where plant samples were taken (3 different points for 4 ha area), bags were brought to the laboratory and sieved with the help of a 2 mm sieve and prepared for analysis. Soil samples were analyzed for texture according to the method reported by Gee and Bouder (1986), pH by Thomas (1996), EC by (Rhoades, 1996), organic matter by Nelson and Sommers (1996) and lime by Allison and Moodie (1965). Some properties of the soils sampled from the study area are presented in Table 1.

Table 1. Some properties of soils sampled from the study area.
Çizelge 1. Çalışma alanından örneklenen topraklara ait bazı özellikler.

Texture	**pH**	**EC (µs cm^{-1})**	**O.M. (%)**	**Lime (%)**
Loamy	6.60	403.10	0.41	2.58
		Total Element concentrations (mg kg^{-1})		
Al	**Cd**	**Co**	**Cr**	**Cu**
21832.8	-	6.5	1.5	1.7
Fe	**Mn**	**Ni**	**Pb**	**Zn**
9821.5	117.2	7.6	2.3	5.2

When the average values of the soils in the study area are examined, pH is in the "neutral" class according to Sağlam (2012), in the "slightly salty" class according to Dellavalle (1992), in the "very low" organic matter class according to Ülgen and Yurtsver (1974), and in the "calcareous" class according to Evliya (1964). Limit values of toxic metals permitted in plants and soils set by WHO: 5 mg kg^{-1} Cr, 40 mg kg^{-1} Cu, 450 mg kg^{-1} Fe, 500 mg kg^{-1} Mn, 67 mg kg^{-1} Ni, 60 mg kg^{-1} Zn in plants and 150 mg kg^{-1} Cr, 140 mg kg^{-1} Cu, 50000 mg kg^{-1} Fe, 80 mg kg^{-1} Mn, 50 mg kg^{-1} Ni, 300 mg kg^{-1} Zn in soil (WHO/FAO, 2007; Sönmez and Kılıç, 2021).

When the element contents of the soils of the study area were analyzed according to the permissible metal limits in soils determined by WHO no limit value was shown for Al and Co, Cd element was not detected in the study soils, Cr, Cu, Fe, Ni, Pb and Zn did not exceed the permissible limit values, only Mn content was measured higher than the permissible limits.

Plant Species Collected from the Poaceae Family

The prevailing 5 Poaceae forage plant species distributed around the mining area were collected (for each species, no fewer than 15 plants were randomly selected from the site. Elemental determinations were performed in 3 replicates, each consisting of five plants) and identified according to the 11-volume Flora of Turkey and the East Aegean Islands (Davis, 1965-1985). The average altitude of the area where the samples were collected was 1240 m and the coordinates were 38° 39' 1" N- 40° 18' 13" E , the general view of the area was photographed, together with the general view of the plant and the habitat area. The scientific names of the taxa were checked from the current List of Plants of Turkey (Güner et al., 2012) and the identified plant species are given in Table 2.

Table 2. List of identified species of the Poaceae family.
Çizelge 2. Buğdaygil ailesine ait teşhis edilen bitki türlerinin listesi.

	Species	**Family**	**Species name**
1	*Poa bulbosa* L.	Poaceae	Bulbous bluegrass
2	*Bromus tectorum* L.	Poaceae	Cheatgrass, Downy brome
3	*Aegilops neglecta* Req. Ex Bertol.	Poaceae	Three-awn goat grass
4	*Calamagrostis pseudophragmites* (Haller) Koeler	Poaceae	Common reed bent-grass
5	*Stipa capensis* Thunb.	Poaceae	Mediterranean needle-grass

The generative parts of the species are the panicles. Images of the species belonging to the Poaceae family are presented in Figure 2.

Figure 2. Views of species belonging to the Poaceae family. In the on-site images of the species belonging to the Poaceae family in Figure 2, a) *Poa bulbosa* L., b) *Bromus tectorum* L., c) *Aegilops neglecta* Req. Ex Bertol., d) *Calamagrostis pseudophragmites* (Haller) Koeler, e) *Stipa capensis* Thunb.

Şekil 2. Buğdaygil familyasına ait türlerin görselleri. Poaceae familyasına ait türlerin Şekil 2'de sahadaki görsellerinde a) Poa bulbosa L., b) Bromus tectorum L., c) Aegilops neglecta Req. Ex Bertol., d) Calamagrostis pseudophragmites (Haller) Koeler, e) Stipa capensis Thunb. türlerini belirtmektedir.

Plant and Soil Analysis

Determination of Element Concentrations (Al, Co, Cr, Cu, Fe, Mn, Ni and Zn)

Plant and soil analyses were carried out at Bingöl University Central Laboratory. Microwave incineration of the ground parts of the plants was carried out by adapting the method reported by Miller (1998). In the next step, necessary dilution and filtration processes were carried out. The elemental concentrations of the samples were read and recorded by ICP-MS (Inductively Coupled Plasma Mass Spectrometry).

Although Cd and Pb metals were also included in the elemental readings of the plants, they were not detected in the plant samples and therefore not included in the findings. Total elemental analyses of soil samples were carried out by adapting the method reported by Kacar (2009) and readings were made with ICP-MS device.

Calculation of Translocation Factor (TF)

This value is the ratio of the heavy metal concentration in the shoot of the plant to the heavy metal concentration in the root and indicates the ability of heavy metals to be transported from the root to other organs of the plant. If the TF values of plants are greater than 1, they can be used as bioaccumulators in phytoremediation (Sürmen et al., 2019). It was calculated using the formula below (Alaribe and Agamuthu, 2015; Ortakcı, 2020).

$$TF = \frac{Element\ concentration\ in\ the\ shoot}{Element\ concentration\ in\ the\ root} \quad (1)$$

Calculation of the Bioconcentration Factor (BCF)

The magnitude of metal uptake by plants is expressed as the Bioconcentration factor (BCF). This factor is calculated by dividing the metal concentration in the plant (root or shoot) by the metal concentration in the soil (Ladislas et al., 2012; Sürmen et al., 2019).

$$BCF = \frac{Plant\ metal\ conc.(root\ or\ shoot)}{Metal\ conc.in\ soil} \quad (2)$$

Statistical Analysis

The data obtained were subjected to both two-factor (species*organ inetraction) analysis of variance (ANOVA) and one-factor (accumulation in a single organ) analysis of variance (ANOVA) with the JMP statistical program and significant ($p<0.05$) parameters were compared with Tukey test (JMP, 2018). Species*organ interactions are presented in tables and elemental contents of species in single organ are presented in graphs.

RESULTS AND DISCUSSION

Aluminum (Al) Concentration in Poaceae Species

Aluminum concentration among the species, Al concentration among the organs and species*organ interactions were found to be statistically significant ($p<0.01$) and the mean groups are given in Table 3.

Table 3. Averages of Al concentration in Poaceae species and their organs.
Çizelge 3. Buğdaygil türleri ve türlerin organlarında bulunan Al konsantrasyonuna ait ortalamalar.

Al Concentration (mg kg^{-1})					
Species	Organs				Means
	Root	Stem	Leaf	Generative part	
P. bulbosa	981.84a**	260.61def	260.61def	185.67efg	422.18A**
B. tectorum	596.23c	320.43d	320.43d	108.58g	336.42BC
A. neglecta	877.25ab	85.66g	85.66g	180.10fg	307.17C
C. pseudophragmites	659.84c	84.92g	334.02d	175.34fg	313.53C
S. capensis	818.42b	299.93de	299.93de	83.77g	375.51B
Means	786.71A**	210.31C	260.13B	146.69D	

**: $p<0.01$ significant. Uppercase letters indicate mean groups, lowercase letters indicate interaction groups.

Among the organs, the highest Al content was determined in the roots with 786.71 mg kg^{-1} and the lowest in the stem with 210.3180 mg kg^{-1}. Among species, the highest Al content was determined in *P. bulbosa* with 422.18 mg kg^{-1} and the lowest in *A. neglecta* and *C. pseudophragmites* with 307.17 mg kg^{-1} and 313.53 mg kg^{-1}, respectively. In the species*organ interaction, the highest Al content (981.84 mg kg^{-1}) was determined in the roots of *P. bulbosa*.

Al concentrations of the species by organ (generative part, leaves, stems and roots) were visualized graphically and presented in Figure 3.

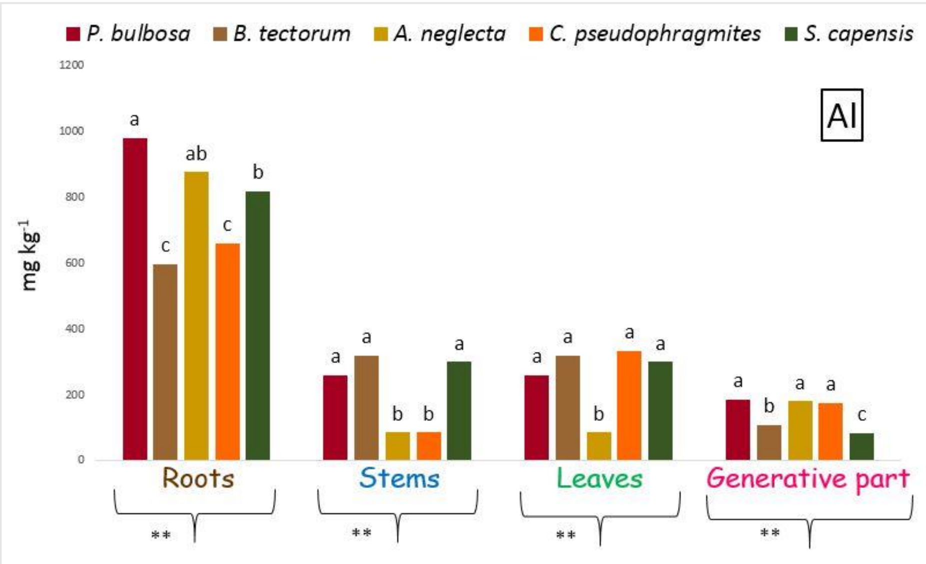

Figure 3. Al content of organs in Poaceae species.
Şekil 3. Poaceae türlerinde organlarının Al içerikleri.

P. bulbosa accumulated the most aluminum in its roots, while *P. bulbosa*, *B. Tectorum* and *S. Capensis* contained the most Al in their stems. Compared to *A. neglacta*, the other 4 grass species contained more Al in their leaves. Looking at the Al content of the generative parts of the plants, *B. Tectorum* and *S. Capensis* species contained less Al than the other 3 grass species (Figure 3). The roots of *B. tectorum* accumulated about 2-fold more Al than the shoots, and Andersson and Brunet (1993) measured about 6-fold more Al accumulation in the roots of *Bromus benekenii* than in the shoots. The Al content of *C. epigejos* plants collected from hearth ash heaps varied and ranged from 8.68 to 1500 mg kg^{-1} (Antonkiewicz, 2010). The average Al content (313.53 mg kg^{-1}) determined in the tissues of *C. pseudophragmites* in this study is within the concentration range determined by the researchers. Iron mine waste may contain potentially toxic elements such as Al, As, Ba, Cr, Cd, Cu, Fe, Mn, Ni, Pb, V, and Zn (Carmo et al., 2017).

Cobalt (Co) Concentration in Poaceae Species

Cobalt concentration among the species, Co concentration among the organs and species*organ interactions were found to be statistically significant ($p<0.01$) and the mean groups are given in Table 4.

Table 4. Averages of Co concentration in Poaceae species and their organs.
Çizelge 4. Buğdaygil türleri ve türlerin organlarında bulunan Cokonsantrasyonuna ait ortalamalar.

Species	Co Concentration (mg kg^{-1})				
	Organs				Mean
	Root	Stem	Leaf	Generative part	
P. bulbosa	0.61b**	0.20e	0.20e	0.15ef	0.29B**
B. tectorum	0.45c	0.20e	0.20e	0.08f	0.23C
A. neglecta	0.71a	0.08f	0.08f	0.33d	0.30B
C.pseudophragmites	0.30d	0.12ef	0.18e	0.08f	0.17D
S. capensis	0.62ab	0.33d	0.33d	0.12ef	0.35A
Mean	0.54A**	0.19B	0.20B	0.15C	

**: p<0.01 significant. Uppercase letters indicate mean groups, lowercase letters indicate interaction groups.

Among the organs, the highest Co content was determined in the roots with 0.54 mg kg^{-1} and the lowest in the generative parts with 0.15 mg kg^{-1}. Among species, the highest Co was determined in *S. capensis* plants with 0.35 mg kg^{-1} and the lowest in *C. pseudophragmites* plants with 0.17 mg kg^{-1}. In the species*organ interaction, the highest Co content was determined in the roots of *A. neglecta* with 0.71 mg kg^{-1}.

Co concentrations of the species by organ (generative part, leaves, stems and roots) were visualized graphically and presented in Figure 4.

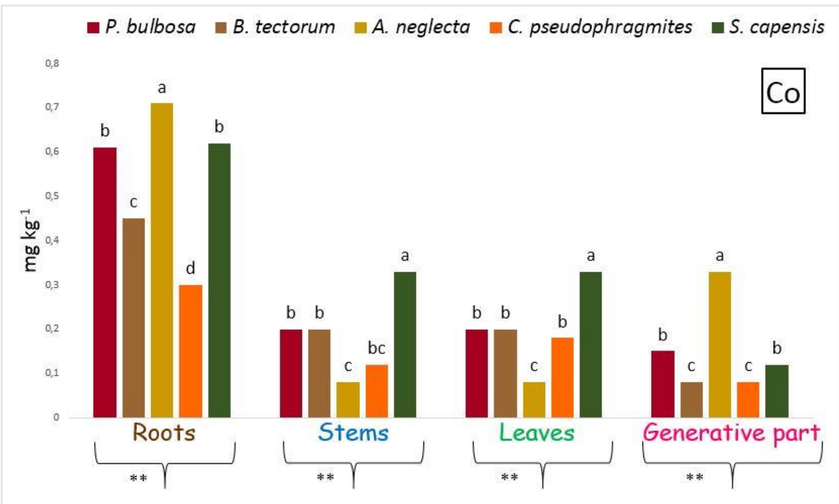

Figure 4. Co content of organs in Poaceae species.
Şekil 4. Poaceae türlerinde organlarının Co içerikleri.

A. neglecta was the species with the highest Co in roots and generative parts, while *S. capensis* was the species with the highest Co in stems and leaves. Compared to the other species, *C. pseudophragmites* contained the least Co in the roots, *A. neglecta* contained the least in the stems and leaves, and *B. tectorum* and *C. pseudophragmites* contained the least in the generative parts (Figure 4). The Co in shoots of *P. bulbosa* was much lower than the Co of *P. pratensis* plants collected by Banowetz et al. (2009). Although the most important factor in the uptake of metals by plants is the metal concentration in the soil, soil pH, and plant species also play a role (Annan et al., 2013). The average Co determined in the tissues of *C. pseudophragmites* in this study is in a similar range with the Co determined by Antonkiewicz (2010) in *C. epigejos*.

Chromium (Cr) Concentration in Poaceae Species

Chromium concentration among the species, Cr concentration among the organs and species*organ interactions were found to be statistically significant (p<0.01) and the mean groups are given in Table 5.

Table 5. Averages of Cr concentration in Poaceae species and their organs.
Çizelge 5. Buğdaygil türleri ve türlerin organlarında bulunan Cr konsantrasyonuna ait ortalamalar.

Cr concentration (mg kg^{-1})					
Species	**Organs**				**Mean**
	Root	**Stem**	**Leaf**	**Generative part**	
P. bulbosa	26.70b**	11.51cd	11.51cd	3.76e	13.37C**
B. tectorum	5.19de	8.96cde	8.96cde	3.57e	6.67D
A. neglecta	34.30a	4.06e	4.06e	28.98ab	17.85B
C.pseudophragmites	9.45cde	5.33de	14.77c	4.34e	8.47D
S. capensis	31.96ab	25.06b	25.06b	9.47cde	22.89A
Mean	21.52A**	10.98BC	12.87B	10.02C	

**: p<0.01 significant. Uppercase letters indicate mean groups, lowercase letters indicate interaction groups.

Among the organs, the highest Cr content was determined in the roots with 21.52 mg kg^{-1} and the lowest in the generative part and stem with 10.02 mg kg^{-1} and 10.98 mg kg^{-1}. Among the species, the highest Cr content was determined in *S. capensis* with 22.89 mg kg^{-1} and the lowest in *B. tectorum* and *C. pseudophragmites* with 6.67 mg kg^{-1} and 8.47 mg kg^{-1}, respectively. In the species*organ interaction, the highest Cr content was determined in the roots of *A. neglecta* with 34.30 mg kg^{-1}.

The Cr concentrations of the species by organ (generative part, leaves, stems and roots) were visualized graphically and presented in Figure 5.

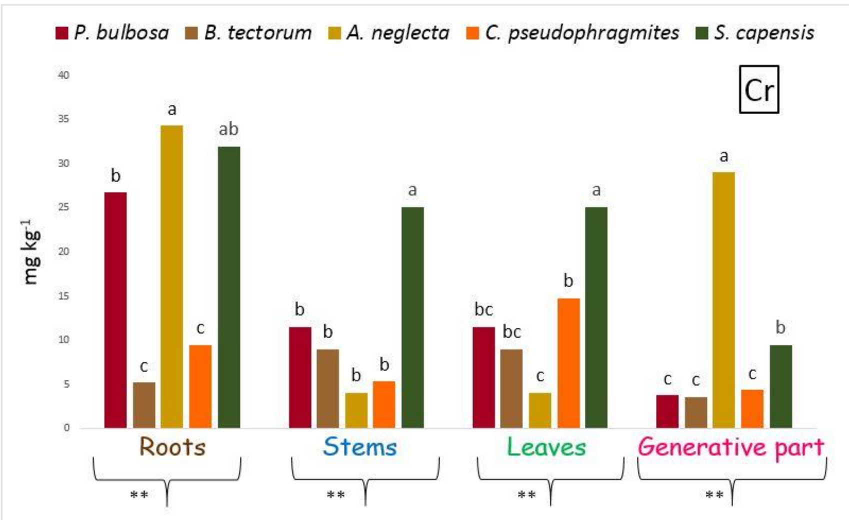

Figure 5. Cr content of organs in Poaceae species.
Şekil 5. Poaceae türlerinde organlarının Cr içerikleri.

The species with the highest Cr content in roots and generative parts was *A. neglecta*, while the species with the highest Cr content in stems and leaves was *S. capensis*. Compared to other species, *B. tectorum* and *C. pseudophragmites* contained the least chromium in their roots (Figure 5). The Cr content in the shoots of *P. bulbosa* was higher than the Cr content of *P. annua* examined by Salinitro et al. (2019). Plants reflect the element concentration of the soil etc. in which they grow (Marschner, 1995).

Copper (Cu) Concentration in Poaceae Species

Copper concentration among the species, Cu concentration among the organs and species*organ interactions were found to be statistically significant (p<0.01) and the mean groups are given in Table 6.

Table 6. Averages of Cu concentration in Poaceae species and their organs.
Çizelge 6. Buğdaygil türleri ve türlerin organlarında bulunan Cu konsantrasyonuna ait ortalamalar.

Cu concentration (mg kg^{-1})					
Spesies	**Organs**				**Mean**
	Root	**Stem**	**Leaf**	**Generative part**	
P. bulbosa	2.10e-h**	2.26efg	2.26efg	2.60ef	2.30C**
B. tectorum	2.88e	1.95fgh	1.95fgh	2.59ef	2.34BC
A. neglecta	1.68gh	1.24h	1.24h	1.83fgh	1.50D
C.pseudophragmites	10.90a	9.94b	6.64c	5.72d	8.30A
S. capensis	2.48efg	2.56efg	2.56efg	2.97e	2.64B
Mean	4.01A**	3.59B	2.93C	3.14C	

**: p<0.01 significant. Uppercase letters indicate mean groups, lowercase letters indicate interaction groups.

Among the organs, the highest Cu content was determined in roots with 4.01 mg kg^{-1} and the lowest in leaves and generative parts with 2.93 mg kg^{-1} and 3.14 mg kg^{-1}. Among the species, the highest Cu content was determined in *C. pseudophragmites* with 22.89 mg kg^{-1} and the lowest in *A. neglecta* with 1.50 mg kg^{-1}. In the species*organ interaction, the highest Cu content was determined in the roots of *C. pseudophragmites* with 10.90 mg kg^{-1} and the lowest in the stems and leaves of *A. neglecta* with 1.24 mg kg^{-1}.

The Cu concentrations of the species by organ (generative part, leaves, stems and roots) were visualized graphically and presented in Figure 6.

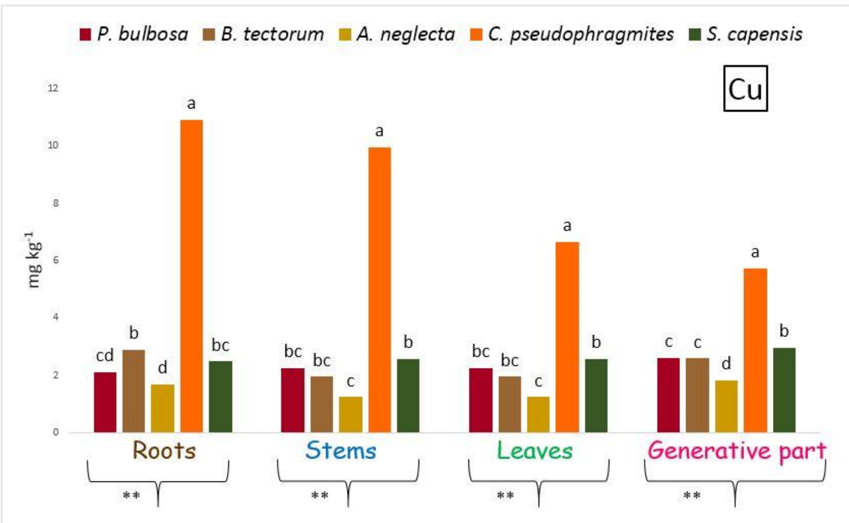

Figure 6. Cu content of organs in Poaceae species.
Şekil 6. Poaceae türlerinde organlarının Cu içerikleri.

Calamagrostis pseudophragmites had the highest Cu content in roots, stems, leaves and generative parts, while *A. neglecta* had the lowest Cu content in all organs (generative part, leaves, stems and roots) (Figure 6). The average Cu concentration in the tissues of *Poa bulbosa* (2.30 mg kg^{-1}) is within the range of the concentration found by Salinitro et al. (2019) for Cu content of *Poa annua* plants (1.80-20.2 mg kg^{-1}). Mitrović et al. (2008) found that the average above-ground concentrations of Cu in *Calamagrostis epigejos* plants obtained from different areas were lower than the below-ground concentrations. In this study, the above-ground Cu concentration of *Calamagrostis pseudophragmites* plants was lower than the below-ground Cu concentration.

Iron (Fe) Concentration in Poaceae Species

Iron concentration among the species, Fe concentration among the organs and species*organ interactions were found to be statistically significant (p<0.01) and the mean groups are given in Table 7.

Table 7. Averages of Fe concentration in Poaceae species and their organs.
Çizelge 7. Buğdaygil türleri ve türlerin organlarında bulunan Fe konsantrasyonuna ait ortalamalar.

Species	Fe concentration (mg kg^{-1})				
	Organs				Mean
	Root	Stem	Leaf	Generative part	
P. bulbosa	740.22b**	208.55ef	208.55ef	91.00gh	312.08B**
B. tectorum	369.92cd	284.74de	284.74de	65.82h	251.30C
A. neglecta	922.49a	88.40g	88.40g	250.83ef	337.53B
C.pseudophragmites	257.92ef	61.97h	253.58ef	170.69fg	186.04D
S. capensis	805.64b	389.37c	389.37c	76.36gh	415.19A
Mean	619.24A**	206.60C	244.93B	130.94D	

**: p<0.01 significant. Uppercase letters indicate mean groups, lowercase letters indicate interaction groups.

Among the organs, the highest Fe content was determined in the roots with 619.24 mg kg^{-1} and the lowest in the generative parts with 130.94 mg kg^{-1}. Among species, the highest Fe content was determined in *S. capensis* with 415.19 mg kg^{-1} and the lowest in *C. pseudophragmites* with 186.04 mg kg^{-1}. In the species*organ interaction, the highest Fe content was determined in the roots of *A. neglecta* with 922.49 mg kg^{-1} and the lowest in the stems of *C. pseudophragmites* and generative parts of *B. tectorum* with 61.97 mg kg^{-1} and 65.82 mg kg^{-1}, respectively.

The Fe concentrations of the species by organ (generative part, leaves, stems and roots) were visualized graphically and presented in Figure 7.

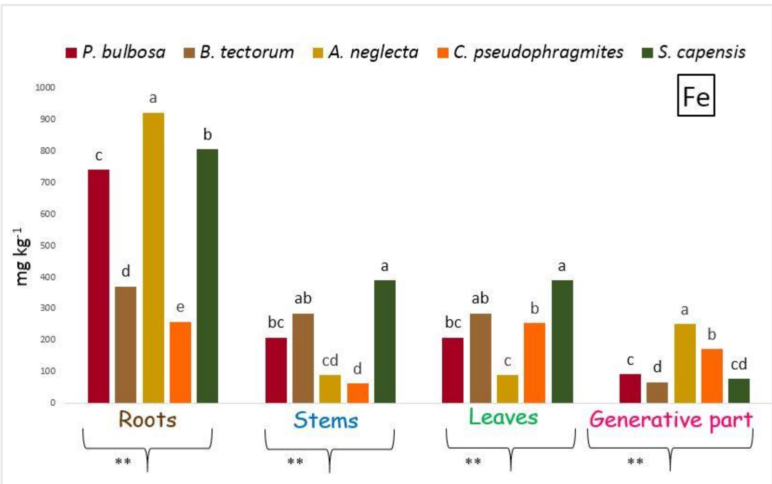

Figure 7. Fe content of organs in Poaceae species.
Şekil 7. Poaceae türlerinde organlarının Fe içerikleri.

A. neglecta accumulated the most Fe in the root zone and generative parts, while *S. capensis* accumulated the most Fe in the stems and leaves. *C. pseudophragmites* contained the least Fe in its roots and stems compared to the roots and stems of other grass species. *A. neglecta* had less Fe in the leaves than the others, while *B. tectorum* had less Fe in the generative parts (Figure 7). The Fe content in shoots of *P. bulbosa* was lower than the Fe content of *P. pratensis* plants collected by Banowetz et al. (2009). Khan et al. (2019) reported that the Fe concentration in the pre-flowering stage of *B. catharticus* was 700 mg kg^{-1}. In this study, the average Fe content in shoots of mature plants was lower (284.74 mg kg^{-1}). In *A. neglecta*, Fe content was much higher in roots than in above-ground organs. Karatassiou et al. (2021) also found that Fe concentration of *A. triuncialis* was much higher in roots than in stems and leaves.

Manganese (Mn) Concentration in Poaceae Species

Manganese concent among the species, Mn concentration among the organs and species*organ interactions were found to be statistically significant ($p<0.01$) and the mean groups are given in Table 8.

Table 8. Averages of Mn concentration in Poaceae species and their organs.
Çizelge 8. Buğdaygil türleri ve türlerin organlarında bulunan Mn konsantrasyonuna ait ortalamalar.

Mn concentration (mg kg^{-1})					
Species	**Organs**				**Mean**
	Root	**Stem**	**Leaf**	**Generative part**	
P. bulbosa	28.66fg**	27.22fgh	27.22fgh	28.96fg	28.01D**
B. tectorum	33.83ef	46.46d	46.46d	25.00fgh	37.94C
A. neglecta	45.18d	61.52c	61.52c	23.23gh	47.86B
C. pseudophragmites	33.36efg	43.34de	197.51a	84.63b	89.71A
S. capensis	31.72fg	34.44ef	34.44ef	17.96h	29.64D
Mean	34.55C**	42.60B	73.43A	35.96C	

**: $p<0.01$ significant. Uppercase letters indicate mean groups, lowercase letters indicate interaction groups.

Among the organs, the highest Mn content was determined in leaves with 73.43 mg kg^{-1} and the lowest in roots and generative parts with 34.55 and 35.96 mg kg^{-1}. Among the species, the highest Mn content was determined in *C. pseudophragmites* with 89.71 mg kg^{-1} and the lowest in *P. bulbosa* and *S. capensis* with 28.01 and 29.64 mg kg^{-1}. In the species*organ interaction, the highest Mn content was determined in the leaves of *C. pseudophragmites* plant with 197.51 mg kg^{-1} and the lowest in the generative parts of *S. capensis* plant with 17.96 mg kg^{-1}.

The Mn concentrations of the species by organ (generative part, leaves, stems and roots) were visualized graphically and presented in Figure 8.

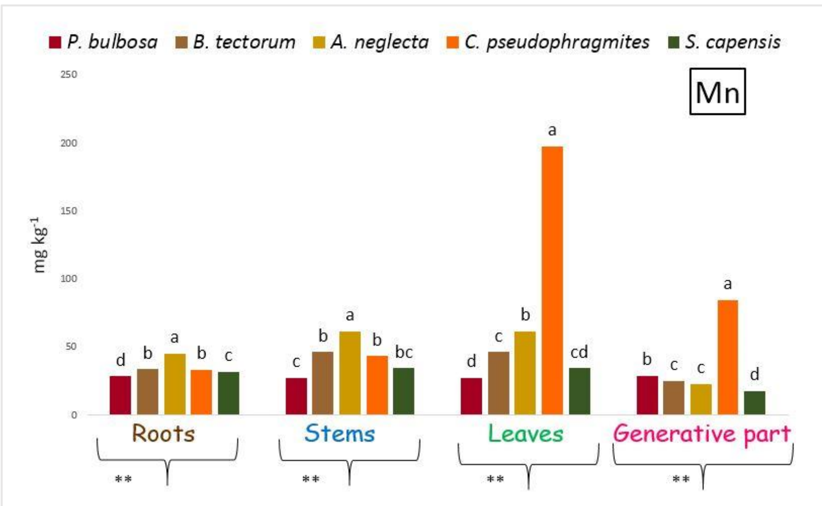

Figure 8. Mn content of organs in Poaceae species.
Şekil 8. Poaceae türlerinde organlarının Mn içerikleri.

The highest Mn accumulation in the roots and stems of the species was measured in *A. Neglecta*, while the highest Mn content in the leaves and generative parts was determined for *C. pseudophragmites*. The lowest Mn content in roots, stems and leaves was determined in *P. bulbosa*, while *S. capensis* had the lowest Mn content in the generative parts (Figure 8). Manganese content in roots and leaves of *P. bulbosa* was 28.66 mg kg^{-1} and 27.22 mg kg^{-1}, respectively. Padmavathiamma and Li (2010) determined Mn content as 390 mg kg^{-1} in the roots and 297 mg kg^{-1} in the leaves of *P. pratensis* at a soil Mn concentration of 215 mg kg^{-1} and a soil pH of 5.4. The lower soil Mn concentration (117.2 mg kg^{-1}) and higher soil pH value were the reasons for the lower Mn content in plant tissues. The Mn concentration determined in the shoots of *B. tectorum* was in parallel with the Mn content determined in the above-ground organs of *B. hordaceus* by Adarve et al. (1998). In *A. neglecta*, Mn content was lower in the roots than in the above-ground organs. In contrast to this study, Karatassiou et al. (2021) found the highest Mn concentration in roots and the lowest in leaves in *A. triuncialis*.

Nickel (Ni) Concentration in Poaceae Species

Nickel concentration among the species, Ni concentration among the organs and species*organ interactions were found to be statistically significant ($p<0.01$) and the mean groups are given in Table 9.

Table 9. Averages of Ni concentration in Poaceae species and their organs.
Çizelge 9. Buğdaygil türleri ve türlerin organlarında bulunan Ni konsantrasyonuna ait ortalamalar.

Ni concentration (mg kg^{-1})					
Species	Organs				Mean
	Root	Stem	Leaf	Generative part	
P. bulbosa	7.14cd**	3.47e-h	3.47e-h	1.89hı	3.99C**
B. tectorum	1.65hı	2.69f-ı	2.69f-ı	0.91ı	1.99D
A. neglecta	10.80a	1.03ı	1.03ı	8.04bc	5.23B
C.pseudophragmites	4.33ef	2.35f-ı	4.01efg	5.20de	3.97C
S. capensis	9.88ab	6.62cd	6.62cd	2.19ghı	6.33A
Mean	6.76A	3.23B	3.57B	3.65B	

**: $p<0.01$ significant. Uppercase letters indicate mean groups, lowercase letters indicate interaction groups.

Among the organs, the highest Ni content was determined in roots with 6.76 mg kg^{-1} and the lowest in stems, leaves and generative parts with 3.23, 3.57 and 3.65 mg kg^{-1}. Among the species, the highest Ni content was determined in *S. capensis* and the lowest in *B. tectorum*. In the species*organ interaction, the highest Ni content was determined in the roots of *A. neglecta* and in the generative parts of *B. tectorum*.

The Ni concentrations of the species by organ (generative part, leaves, stems and roots) were visualized graphically and presented in Figure 9.

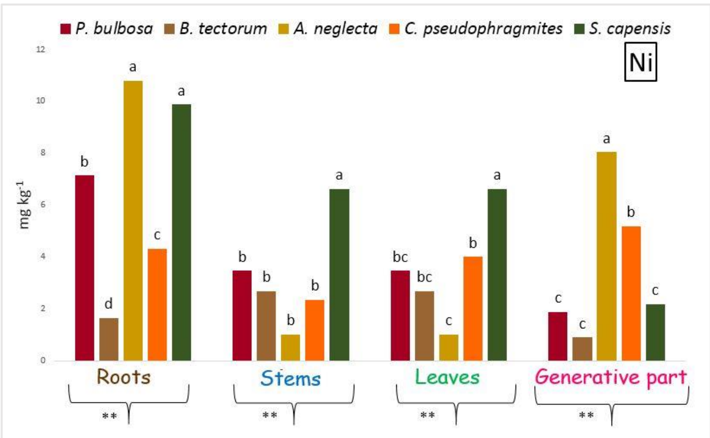

Figure 9. Ni content of organs in Poaceae species.
Şekil 9. Poaceae türlerinde organlarının Ni içerikleri.

A. neglecta and *S. capensis* accumulated nickel more in the roots than the other species, *S. capensis* accumulated more in the stems and leaves, and *A. neglecta* contained the most Ni in the generative parts, while *B. tectorum* contained the least Ni in the roots and generative parts (Figure 9). The average Ni content in the tissues of *P. bulbosa* (3.99 mg kg^{-1}) is in the range of the concentration found by Salinitro et al. (2019) for the Ni content of *P. annua* plants (0.82-17.2 mg kg^{-1}). Sinegani and Dastjerdi (2009) reported Ni concentration in *B. tectorum* in the range of 0<shoot<5 mg kg^{-1}. The Ni concentration in the shoots of *Bromus tectorum* (2.69 mg kg^{-1}) obtained in this study is within the concentration range reported by the researchers. In *A. neglecta*, Ni content was higher in the roots than in the above-ground organs. Karatassiou et al. (2021) also found that Ni concentration of *Aegilops triuncialis* was higher in roots than in stems and leaves.

Zinc (Zn) Concentration in Poaceae Species

Zinc concentration among the species, Zn concentration among the organs and species*organ interactions were found to be statistically significant (p<0.01) and the mean groups are given in Table 10.

Table 10. Averages of Zn concentration in Poaceae species and their organs.
Çizelge 10. Buğdaygil türleri ve türlerin organlarında bulunan Zn konsantrasyonuna ait ortalamalar.

Zn concentration (mg kg-1)					
Species	**Organs**				**Mean**
	Root	**Stem**	**Leaf**	**Generative part**	
P. bulbosa	13.45e	2.30j	2.30j	7.20ghı	6.32D**
B. tectorum	16.93d	9.70fg	9.70fg	11.75ef	12.02B
A. neglecta	9.25fgh	4.36ıj	4.36ıj	6.73hı	6.17D
C.pseudophragmites	28.70a	20.84c	9.32fgh	25.62b	21.12A
S. capensis	13.00e	7.82gh	7.82gh	10.01fg	9.66C
Mean	16.27A**	9.01C	6.70D	12.26B	

**: p<0.01 significant. Uppercase letters indicate mean groups, lowercase letters indicate interaction groups.

Among the organs, the highest Zn content was determined in roots with 16.27 mg kg^{-1} and the lowest in leaves with 6.70 mg kg^{-1}. Among species, the highest Zn was determined in *C. pseudophragmites* and the lowest in *A. neglecta* and *B. tectorum*. In the species*organ interaction, the highest Zn was determined in the roots of *C. pseudophragmites* and the lowest in the stems and leaves of *P. bulbosa*.

The Zn concentrations of the species by organ (generative part, leaves, stems and roots) were visualized graphically and presented in Figure 10.

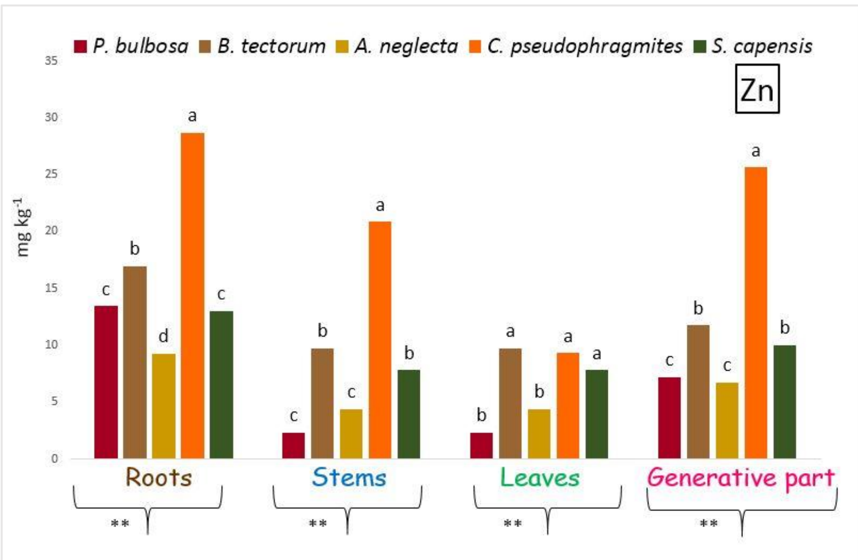

Figure 10. Zn content of organs in Poaceae species.
Şekil 10. Poaceae türlerinde organlarının Zn içerikleri.

Compared to other species, *C.pseudophragmites* had the highest Zn content in all organs while *A.neglecta* had the lowest Zn content (Figure 10). The average Zn content in the tissues of *P. bulbosa* was lower than that reported by Salinitro et al. (2019) for *P. annua* and Banowetz et al. (2009) for *P. pratensis*. The mean Zn in the shoots of *B. tectorum* was lower than the Zn contents reported by Mahdavian et al. (2017) for shoots of *B. tectorum*. Mitrović et al. (2008) found that the average aboveground contents of Zn in *C. epigejos* plants obtained from different areas were lower than the belowground contents. In this study, the above-ground Zn of *C. pseudophragmites* plants were lower than the below-ground Zn.

Evaluation of Phytoremediation Potential of Plants with TF and BCF Values

The ability of a plant to accumulate metals in soil can be estimated using the BCF, defined as the ratio of the metal concentration in the roots to that in the soil. The ability of a plant to transfer metals from roots to shoots is measured using the TF, defined as the ratio of the metal concentration in the shoots to that in the roots. By comparing BCF and TF, the ability of different plants to take up metals from the soil and transfer them to the shoots can be compared. A TF>1 can predict that the plant is suitable for phytoextraction (Chanu and Gupta, 2016). A high BCF (>1) and a low TF (<1) indicate that the plants have phytostabilization potential (Yoon et al., 2006).

TF and $BCF_{root\ and\ shoot}$ values for Al, Co, Cr, Cu, Fe, Mn, Ni and Zn in *Poa bulbosa* are presented in Table 11.

Table 11. TF and BCF values of *Poa bulbosa.*
Çizelge 11. Poa bulbosa bitkisine ait TF ve BCF değerleri.

Species	Elements	TF	BCF_{root}	BCF_{shoot}	Evaluation
Poa bulbosa	Al	0.24	0.04	0.01	Unsuitable
	Co	0.30	0.09	0.03	Unsuitable
	Cr	0.33	17.80	6.00	Phytostabilization
	Cu	1.13	1.27	1.44	Phytoextraction
	Fe	0.23	0.08	0.02	Unsuitable
	Mn	0.97	0.24	0.24	Unsuitable
	Ni	0.41	0.94	0.39	Unsuitable
	Zn	0.29	2.59	0.76	Phytostabilization

In *Poa bulbosa*, TF>1 for Cu, BCF_{root}>1 for Cr, Cu and Zn and BCF_{shoot}>1 for Cr and Cu. Padmavathiamma and Li (2010) reported that the TF value for Mn was 1.16 in *P. pratensis*. The TF_{Mn} calculated for *P. bulbosa* in this study is close to 1.

TF and $BCF_{root\ and\ shoot}$ values for Al, Co, Cr, Cu, Fe, Mn, Ni and Zn in *B. tectorum* are presented in Table 12.

Table 12. TF and BCF values of *Bromus tectorum.*
Çizelge 12. Bromus tectorum bitkisine ait TF ve BCF değerleri.

Species	Elements	TF	BCF_{root}	BCF_{shoot}	Evaluation
Bromus tectorum	Al	0.42	0.03	0.01	Unsuitable
	Co	0.36	0.07	0.02	Unsuitable
	Cr	1.38	3.50	4.80	Phytoextraction
	Cu	0.75	1.75	1.31	Phytostabilization
	Fe	0.57	0.04	0.02	Unsuitable
	Mn	1.16	0.29	0.34	Phytoextraction
	Ni	1.27	0.22	0.28	Phytoextraction
	Zn	0.61	3.26	2.00	Phytostabilization

In *Bromus tectorum*, TF>1 for Cr, Mn and Ni, BCF_{root} and BCF_{shoot}>1 for Cr, Cu and Zn. Mahdavian et al. (2017) reported both BCF (unlike this study) and TF (similar to this study) values<1 for Zn in *B. tectorum*. Sinegani and Dastjerdi (2009) reported that TF_{Ni} value for *B. tectorum* was<1. Hassani et al. (2015) calculated TF>1 and BCF<1 for Cr, TF<1 and BCF>1 for Ni, and TF and BCF>1 for Zn in *B. tectorum*. Nouri et al. (2013) determined the TF of *B. hordeaceus* and *B. rubens* plants as 0.63, 0.46, 2.50, 0.44 and 0.10, 0.11 for Cr, Cu and Fe, respectively. The BCF values of *B. hordeaceus* and *B. rubens* were 0.04, 0.04, 0.33, 0.36 and 0.001 for Cr, Cu and Fe, respectively.

TF and $BCF_{root\ and\ shoot}$ values for Al, Co, Cr, Cu, Fe, Mn, Ni and Zn in *A. neglecta* are presented in Table 13.

Table 13. TF and BCF values of *Aegilops neglecta.*
Çizelge 13. Aegilops neglecta bitkisine ait TF ve BCF değerleri.

Species	Elements	TF	BCF_{root}	BCF_{shoot}	Evaluation
Aegilops neglecta	Al	0.13	0.04	0.01	Unsuitable
	Co	0.23	0.11	0.03	Unsuitable
	Cr	0.36	22.9	8.20	Phytostabilization
	Cu	0.86	1.02	0.87	Phytostabilization
	Fe	0.15	0.09	0.01	Unsuitable
	Mn	1.08	0.39	0.42	Phytoextraction
	Ni	0.31	1.42	0.44	Phytostabilization
	Zn	0.56	1.78	0.99	Phytostabilization

In *Aegilops neglecta*, only TF>1 for Mn, BCF_{root} >1 for Cr, Cu, Ni and Zn and BCF_{shoot}>1 for Cr. Hesami et al. (2018) reported the BCF_{shoot} value for Zn element in *A. columnaris* as 0.36 in their study.

TF and BCF values for Al, Co, Cr, Cu, Fe, Mn, Ni and Zn in *C. pseudophragmites* are presented in Table 14.

Table14. TF and BCF values of *Calamagrostis pseudophragmites.*
Çizelge 14. Calamagrostis pseudophragmites bitkisine ait TF ve BCF değerleri.

Species	Elements	TF	BCF_{root}	BCF_{shoot}	Evaluation
Calamagrostis pseudophragmites	Al	0.30	0.03	0.01	Unsuitable
	Co	0.42	0.05	0.02	Unsuitable
	Cr	0.86	6.30	5.40	Phytostabilization
	Cu	0.68	6.61	4.51	Phytostabilization
	Fe	0.63	0.03	0.02	Unsuitable
	Mn	3.25	0.28	0.93	Phytoextraction
	Ni	0.89	0.57	0.51	Unsuitable
	Zn	0.65	5.52	3.58	Phytostabilization

In *Calamagrostis pseudophragmites*, only TF>1 for Mn, BCF_{root} and BCF_{shoot}>1 for Cr, Cu and Zn. Sun et al. (2015) reported TF (similar to this study) and BCF values<1 for Cr, Cu, Ni and Zn in *C. pseudophragmites* plants. Tiodar et al. (2024) calculated BCF>1 for Cu in 40%, BCF>1 for Zn in 33% and BCF>1 for Mn in 13% of *C. epigejos* plants. The TF values of the plants were reported as $TF_{Cu,\ Zn\ and\ Mn}$<1 for all three elements. Ranđelović et al. (2018) calculated BCF values as Fe: 0.05-1, Mn: 0.05-1.61, Zn: 0.24-2.06, Cu: 0.35-0.63 and TF as Fe: 0.16-0.58, Mn: 0.9-1.43, Zn: 0.15-0.26 and Cu: 0.29-0.72 in *C. epigejos* plants.

TF and $BCF_{root\ and\ shoot}$ values for Al, Co, Cr, Cu, Fe, Mn, Ni and Zn in *S. capensis* are presented in Table 15.

Table15. TF and BCF values of *Stipa capensis.*
Çizelge 15. Calamagrostis pseudophragmites bitkisine ait TF ve BCF değerleri.

Species	Elements	TF	BCF_{root}	BCF_{shoot}	Evaluation
	Al	0.28	0.04	0.01	Unsuitable
	Co	0.42	0.10	0.04	Unsuitable
	Cr	0.62	21.3	13.2	Phytostabilization
Stipa capensis	Cu	1.09	1.50	1.63	Phytoextraction
	Fe	0.35	0.08	0.03	Unsuitable
	Mn	0.91	0.27	0.25	Unsuitable
	Ni	0.52	1.30	0.68	Phytostabilization
	Zn	0.66	2.50	1.64	Phytostabilization

In *Stipa capensis*, only TF>1 for Cu, BCF_{root}>1 for Cr, Cu, Ni and Zn and BCF_{shoot}>1 for Cr, Cu and Zn. Hasnaoui et al. (2020) reported BCF 1.55, TF 0.12 for Cu (similar to the result of this study), BCF 0.40, TF 0.59 for Ni (similar to the result of this study) and BCF 0.01, TF 0.50 for Zn (similar to the result of this study) in *S. tenacissima*. In *S. arabica*, TF 2.13, BCF 0.33 for Co, TF 3.34, BCF 0.18 for Cr and TF 1.17, BCF 0.54 for Zn (Hosseinniaee et al., 2022).

CONCLUSION

In this study, heavy metal contents of Poaceae forage plant species spreading in natural areas around Avnik iron mine were investigated and their phytoremediation capacities were evaluated. When the permissible limit values (WHO) of toxic metals in plants and soils were examined for the soils of the study area, no limit value was shown for Al and Co, Cd was not detected in the soils, Cr, Cu, Fe, Ni, Pb and Zn concentrations did not exceed the permissible limit values, only Mn concentration was measured higher than the permissible limit value. When examining the values determined in the above-ground organs of the collected plant species, Cu, Mn, Ni and Zn did not exceed the permitted limit values, only Cr concentrations exceeded the permitted toxic metal concentration in some species. Since TF_{Cu}>1 in *P. bulbosa* and *S. capensis*, $TF_{Cr,Mn,Ni}$>1 in *B. tectorum*, TF_{Mn}>1 in *A. neglecta* and *C. pseudophragmites*, these species are considered to have phytoextraction potential. In particular, BCF_{root} values for Cr were quite high in *P. bulbosa* (17.80), *A. neglecta* (22.9) and *S. capensis* (21.30), strengthening the potential of these species to be used in phytostabilization for Cr. Furthermore, although it is considered that there is no dangerous contamination in the soil sampled around the mining area and in the naturally occurring species of this Poaceae forage plant, grazing of animals in these areas is not recommended due to the high element concentrations in the above-ground organs of some species.

CONFLICT OF INTEREST

The authors have no conflict of interest.

DECLARATION OF AUTHOR CONTRIBUTION

Hava Şeyma İnci: Designing the study, collecting the plants, making the analyses, writing the article. Çağrı Şahin: Collecting the plants, making the analyses, writing the article. The article was co-authored.

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