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Original Article

The Change of the Concentrations of Boron and Sodium in Some Forest Soils Depending on Plant Species

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ABSTRACT

Plant growth is largely related to soil structure, nutrients, and climatic factors. In agricultural soils, the amount of nutrients in the soil can be changed significantly by fertilization, whereas the bedrock's characteristics largely shape soil nutrient content in forested areas. Therefore, the accumulation level of each element in different organs of the plants is different, and the nutrient content in the soil differs according to the plant species. The organ samples (leaf, bark, wood, cone, and root) were taken from the relevant trees, and soil samples from the surface (0–5 cm), moderate (20–30 cm), and deep (50–60 cm) depths under the trees. The dried samples were combusted in special microwave ovens and turned into a solution. Then, using the ICP-OES device, the boron (B) and sodium (Na) element analyses were conducted. By using Statistical Package for the Social Sciences 22.0 package software, the data were subjected to variance analysis and Duncan's test. The data were then simplified and interpreted by tabularizing. In this study, the concentrations of B and Na in the leaves, bark, wood, roots, and cones of black pine, scotch pine, oriental beech, and Turkish fir trees grown in a limited area in a similar land structure were determined. These concentrations were compared with the concentrations at different depth levels of the soil. It was to determine how the B and Na concentrations changed depending on the species, organ, and soil depth.

Keywords: Boron, nutrient, soil, sodium

Introduction

Plants photosynthesize by making use of the sunlight, and thus, they produce the essential nutrient elements, which all living organisms need, by synthesizing the organic compounds (Koç, 2019; Koç & Nzokou, 2022; Yigit et al., 2021). Hence, plants constitute the foundation of life on earth (Aricak et al., 2020; Yucedag et al., 2019). In addition, green plants also fulfill many other functions during photosynthesis. Plants reduce the air pollution in their environment (Alaquori et al., 2020; Koç et al., 2022a), reduce the noise (Elsunousi et al., 2021), positively affect humans from a psychological aspect (Cetin, 2015), prevent erosion (Turna & Guney, 2009), and provide many living organisms with food and shelter (Ozkazanc et al., 2019).

Moreover, plants are among the most important economic resources (Sevik et al., 2012). Especially forests are essential resources, which host many species and a high number of plants and animals and are of significant economic importance for many countries (Ertugrul et al., 2019). Woody plants, especially forest trees, which constitute the main components of forests, are the primary wood sources that are the raw materials for many products we use daily (Cesur et al., 2021).

Healthy and sufficient development plays a determinant role in forests' capacity to fulfill all their functions properly. The development of organisms is shaped by the interaction between their genetic structures (Hrivnak et al., 2017) and environmental factors (Cetin et al., 2018a,b). In plant development, however, the most important environmental factors include climatic factors such as temperature and precipitation (Ertugrul et al., 2021; Key et al., 2022; Koç, 2021a,b) and edaphic factors such as nutrient availability (Shults et al., 2020), soil depth, and pH (Kravkaz Kuscu et al., 2018a,b). Plants alter the nutrient content in the soil during their development either by taking them from the soil via their roots or as a result of the disintegration of falling organs. Although the depreciating amount of nutrients in agricultural lands can be supported through fertilizers, it is not possible for forest lands since no fertilization is performed. For this reason, for the forest to continue developing healthily, it is critical to determine how the forest trees shape the nutrient content in the soil. Boron (B) is found in the

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earth's crust, sedimentary rocks, oceans, coal, and some soils in oxidized form as borax and colemanite. Boron is a critical element for humans, plants, and animals. It is found in the soil in concentrations ranging from 10 to 300 mg kg^{-1}, depending on the amount of precipitation, soil type, and the amount of organic matter. It is released into the environment from various industrial activities (geothermal steam, burning of agricultural wastes and firewood, electric generators (oil/coal burning), chemical plants, and boron products) (Ozturk et al., 2010). Sodium (Na), one of the most abundant (seventh) elements in the earth's crust, is a key and essential element for decomposers and animals (Kaspari, 2020). However, Na is essential for most plants (Kaspari, 2020), and its requirements differ between organisms, and organismal activities affect Na intake (Santiago-Rosario et al., 2021). Within the scope of this study, it was aimed to determine to what extent the B and Na concentrations, among the important nutrients in the soil, accumulate in which organs of different forest trees and the relationship between these accumulations and nutrient elements in the soil.

Methods

The present study was carried out in a limited area with similar environmental factors but different forest trees. The area was a land, which is located on a single bedrock, there was no soil transportation through erosion, and the main factor altering the soil composition is thought to be the plants. The field that fits the purpose of this study is located within the borders of Araç district of Kastamonu province. The analyses were performed on (Ab) *Abies nordmanniana* subsp. *bornmülleriana* Mattf. (Turkish fir), (Pn) *Pinus nigra* Arnold. (black pine), (Ps) *Pinus sylvestris* L. (Scotch pine), and (Fo) *Fagus orientalis* Libsky. (Oriental beech) species, which grow very closely in this field. Within the scope of this study, the organ samples (leaf, bark, wood, cone, and root) were taken from the relevant trees and soil samples from the surface (0–5 cm), moderate (20–30 cm), and deep (50–60 cm) depths under the trees. The samples were taken to the laboratory by labeling them. Plant samples were shredded without using metal instruments and kept on cardboard for 2 weeks. During the same period, the soil samples were kept and then sieved. The sieved soil and shredded plant samples were dried in a drying oven at 45°C for 2 weeks. The dried samples were combusted in special microwave ovens and turned into a solution. Then, using the ICP-OES device (GBC Scientific Equipment Pty Ltd., Melbourne, Australia), the B and Na element analyses were conducted. This method is among the ones used widely for elemental analyses in recent studies (Cesur et al., 2022; Isinkaralar et al., 2022). By using Statistical Package for the Social Sciences 22.0 package software, the data were subjected to variance analysis and Duncan's test. The data were then simplified and interpreted by tabularizing.

Results

The change of B concentration by species and organs is presented in Table 1, whereas the change in the soil is presented in Table 2.

Table 1.
Changes in Boron Concentration in Plants by Species and Organs

	Organ						
Species	Leaf	Bark	Cone	Wood	Root	F Values	Average
Ab	4069.9 Aa	1577.6 Aa	2738.13 A	UL	52,590.86 B	4.05*	18,619.84
Pn	UL	UL	UL	UL	30,374.26	-	30,374.26
Ps	5558.2 Ba	4321.0 Ab	UL	UL	18,807.66 C	32.57***	9607.59
Fo	16,775.4 Bb	5091.5 Ac	UL	UL	44,480.79 C	378.6***	18,346.98
F values	116.000***	13.3***	–	–	1.26 ns		1.25 ns
Average	8801.1 a	3663.3 a	2738.13 a	–	36,275.3 b	11.272***	

Note: Ab = *Abies nordmanniana* subsp. *bornmülleriana* Mattf.; Fo = *Fagus orientalis* Libsky.; ns = not significant; Pn = *Pinus nigra* Arnold.; Ps = *Pinus sylvestris* L.; UL = under limit.
According to Duncan's test results, the letters a, b, etc., represent the statistical differences between organs.
*Significant at 0.05 level; **Significant at 0.01 level; ***Significant at 0.001 level.

Table 2.
Changes in Boron Concentration in Soils by Species and Depth

	Soil Depth				
Species	Upper	Medium	Lower	*F* Values	Average
Ab	51.52 Aab	53.46 Aab	72.39 Bb	6.48**	59.12 ab
Pn	61.82 Ab	48.52 Aa	55.66 Aa	1.00 ns	55.33 a
Ps	62.26 Ab	70.74 Bc	67.37 Abab	3.47*	66.79 b
Fo	40.11 Aa	58.88 Bb	58.50 Bab	6.60**	52.50 a
F values	2.94*	15.01***	2.71 ns		4.40**
Average	53.92 A	57.90 AB	63.48 B	3.36*	

Note: Ab = *Abies nordmanniana* subsp. *bornmülleriana* Mattf.; Fo = *Fagus orientalis* Libsky.; ns = not significant; Pn = *Pinus nigra* Arnold.; Ps = *Pinus sylvestris* L.
According to Duncan's test results, the letters a, b, etc., represent the statistical differences between organs.
*Significant at 0.05 level; **Significant at 0.01 level; ***Significant at 0.001 level.

Table 3.
Changes in Sodium Concentrations by Species and Organ in Plants

	Organ						
Species	Leaf	Bark	Cone	Wood	Root	F Values	Average
Ab	46.95 Ab	44.57 A	31.73 A	79.37 A	265.62 Bb	5.16**	93.65 b
Pn	28.57 Aa	35.02 A	37.75 A	56.60 B	64.06 Ba	6.34***	44.40 a
Ps	30.64 a	70.44	33.37	67.51	66.93 a	1.95 ns	53.78 a
Fo	45.26 b	76.17	–	77.75	85.17 a	1.35 ns	71.09 ab
F values	6.08**	2.33 ns	2.88 ns	0.24 ns	4.31*		2.94*
Average	37.86 A	56.55 A	34.28 A	70.31 A	120.45 B	6.33***	

Note: Ab = *Abies nordmanniana* subsp. *bornmülleriana* Mattf.; Fo = *Fagus orientalis* Libsky.; ns = not significant; Pn = *Pinus nigra* Arnold.; Ps = *Pinus sylvestris* L.
According to Duncan's test results, the letters a, b, etc., represent the statistical differences between organs.
*Significant at 0.05 level; **Significant at 0.01 level; ***Significant at 0.001 level.

Given the changes of B concentration by organs of plants, it can be seen that it remained below the detectable limits in wood for all species, in cones for all species other than Ab, and in all organs of Pn. Besides that, it was also determined that the B concentrations detected in roots were much higher when compared to the other organs, and the concentrations can be sorted by organs as wood < cone < bark < leaf < root in all species. The sorting by species is (for leaves and barks) Pn < Ab < Ps < Fo. The change of B concentration by species in roots and mean concentrations were found to be statistically insignificant.

The change in B concentration by species in belowground soils and the change by soil depth in soils where Pn grows were statistically insignificant ($p < .05$). When mean values are examined, it can be seen that B concentration increased with increasing soil depth. When the change by species are examined, it can be seen that the lowest concentrations were obtained from Pn and Fo, whereas the highest ones were obtained from Ps.

The change of Na concentrations by species and organs is presented in Table 3, whereas the change in the soil by species and depth is presented in Table 4.

As a result of the variance analysis, it was determined that the change in Na concentration by organs in Ab and Pn species and the changes in leaves and roots by species were found to be statistically significant ($p < .05$). The highest Na concentrations in leaves were found in Ab and Fo, and the highest concentrations in roots were found in Ab. While the highest Na concentrations were found in roots in Ab and Pn species, the values found in all organs other than the root in Ab and the values found in all organs other than wood and roots in Pn were in the first group in the Duncan test. Considering the mean values, the values obtained from the roots were in the second group, whereas those obtained from the other organs were in the first group. By the species, the lowest values were found in the pines and the highest ones in Ab.

In Table 4, showing the changes in Na concentration in soils, it can be seen that the change of Na concentration in soils by depth was not statistically significant in species other than Ps ($p > .05$). In Ps, the Na concentration was found to decrease with increasing soil depth. It was also determined that the change in Na concentration by species was statistically significant for all the soil depths ($p < .05$). Given the results of the Duncan test, the highest Na concentrations were obtained from Ps species in all soil depths, whereas the values obtained from all the soils where Pn and Fo grow were in the second group.

Discussion, Conclusion and Recommendations

It can be seen that Pn does not use the B element at a remarkable level; thus, the concentration of B in soils where Pn grows did not change by the soil depth. Especially in soils where Ab and Fo grow, B concentration on the surface is relatively low, and these species have shallow roots. The highest B concentrations were found in the roots of all the species,

Table 4.
Changes in Sodium Concentration in Soils by Species and Depth

	Soil Depth				
Species	Upper	Medium	Lower	*F* Values	Average
Ab	591.80 Aa	444.63 Ab	439.13 Aab	2.70 ns	491.86 b
Pn	416.05 Aa	357.61 Aa	340.41 Aa	0.61 ns	371.36 a
Ps	800.41 Bb	560.88 Ac	540.75 Ab	7.71**	634.01 c
Fo	411.02 Aa	370.50 Aab	379.44 Aa	0.82 ns	386.99 a
F values	7.97***	10.87***	5.44***		17.13***
Average	554.28 B	433.40 A	424.93 A	6.21**	

Note: Ab = *Abies nordmanniana* subsp. *bornmülleriana* Mattf.; Fo = *Fagus orientalis* Libsky.; ns = not significant; Pn = *Pinus nigra* Arnold.; Ps = *Pinus sylvestris* L.
According to Duncan's test results, the letters a, b, etc., represent the statistical differences between organs.
*Significant at 0.05 level; **Significant at 0.01 level; ***Significant at 0.001 level.

and the values found in roots were much higher than in the other organs. This can be interpreted to suggest that B element is intensely used in the roots and B concentration in the near-surface soils reduces in the shallow-rooted species.

As a result of the present study, the highest values, in general, were found in the roots of Ab species, and the highest value among the leaves was found in Ab and Fo species. In the soils where Ps grows, it was found that the Na concentration decreased with increasing depth, and one of the highest values in soils in general and of the lowest values in organs was found in Ps species. Accordingly, it can be concluded that the Na element is not consumed much by the species examined here; hence, its concentrations in the soil were not affected remarkably.

The results suggest that the species examined here utilized the B and Na elements in the soil at different levels. Thus, these plants significantly alter the nutrient content in the soil where they grow. Soil's nutrient content is one of the most important factors influencing plant development (Cetin et al., 2022a,b; Koç et al., 2022b). As with all other organisms, plants' phenotypic character and development are shaped by the effects of their genetic structures (Ghoma et al., 2022) and environmental factors (Sevik et al., 2021; Yayla et al., 2022). Environmental factors include climatic (Kuzmina et al., 2022; Turkyilmaz et al., 2020) and edaphic (Elajail et al., 2022; Koç, 2021c) factors remarkably influencing plant development, as well as temperature (Özel et al., 2022; Yildiz et al. 2014; Zeren Cetin et al., 2022), water deficit (Koç, 2022; Topacoglu et al., 2016), frost (Khaskheli et al., 2021), ultraviolet B (Ozel et al., 2021a,b), pollution (Cetin & Jawed, 2022; Isinkaralar, 2022a,b), and diseases and insects (Khan et al., 2021) causing stress in plants. Among these factors, one of the most influencing plant development is the soil composition, which can also be called nutrient content (Alemneh et al., 2022; Nardi et al., 2021).

In the soils where plants grow, they uptake the nutrient elements for their development, from the soil through their roots and utilize them. As a result, the amount of nutrient elements in the soil decreases, affecting plant development (Shults et al., 2020). In agricultural lands, the decreasing amount of nutrients can be made up by making use of fertilizers (Gworek et al., 2021; Zheng et al., 2021). However, since fertilization cannot be performed in forest lands, the tree species to be planted should be determined considering the nutrient composition of the soil.

However, the number of studies carried out, especially on to what extent the forest trees use which nutrient elements, is very limited. Many studies were carried out on the change of several micronutrients and macronutrients in the species, which were grown in different environments by the species and organs (Cetin et al., 2020; Savas et al., 2021; Sevik et al., 2019). However, the intake of nutrient elements into the body of a plant occurs through the roots and aboveground organs, and there is lacking information about which sources the nutrient elements in plant organs originate from (Karacocuk et al., 2022; Shahid et al., 2017; Sulhan et al., 2022). Hence, the amount of nutrient elements in the plant organs and the amounts in soil should be determined, and comparative analyses should be made. But, the number of studies examining this point is very limited.

It is very important to determine by which species the nutrient elements are utilized to which extent, as well as employ the studies on this subject in the forest management plans in the future. Nowadays, one of the most important problems that our world needs to struggle with and is called irreversible is global climate change (Cantürk and Kulaç, 2021; Varol et al., 2021). It was reported that the group of organisms which will be affected by the global climate most is the plants having no effective movement capacity and that especially the forest will be harmed significantly. The fact that global climate change would be faster than plants could adapt to will necessitate human intervention in the transportation of plants to new locations, which will be more suitable in terms of climatic conditions (Varol et al., 2022a,b). Hence, in this process, the soil factor should be considered in addition to the climatic factors. Consequently, edaphic factors must be examined while deciding which one(s) of the plants would be planted among the species that could adapt to the climate of the region. Because the edaphic factors, together with the climatic ones, are among the most important ones determining the development of plant and limiting its distribution (Yigit et al., 2021).

The results revealed that the B and Na concentrations in the soil significantly varied depending on the species of plants being grown. For instance, it was determined that Pn did not use B element at a high level and B concentration did not decrease in soils where Pn is grown, but Ab and Fo utilized Na intensely in their roots. This finding shows the importance of avoiding monoculture while establishing a forest, as well as the importance of establishing mixed forests.

The results achieved are also important for agroforestry practices. For instance, it was found that Ab did not use B and Na concentration was higher in the upper layer of soils where Ps is grown. Thus, for the agroforestry practices, it can be recommended to utilize the agricultural species with a high B requirement in the lands where Ab is grown and the species with a high Na requirement in soils where Ps is grown.

The findings show that different species need different elements more. However, the number of studies on which elements are needed much by forest trees is very limited. Millions of seedlings are cultivated in forest nurseries annually, but no soil analysis is performed. Through preliminary analysis, determining the effect of fertilization on plant development in forest nurseries and conducting fertilization during seedling cultivation might save time and effort by significantly influencing seedling development.

The datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request.

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