Spatial and Organ-Based Variations of Potassium (K) and Phosphorus (P) Concentrations in Woody Plant Species and Soils in Kastamonu, Hanönü

Kastamonu, Hanönü'nde Odunsu Bitki Türleri ve Topraklarda Potasyum (K) ve Fosfor (P) Konsantrasyonlarının Mekânsal ve Organa Dayalı Değişimleri

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SPATIAL AND ORGAN-BASED VARIATIONS OF POTASSIUM (K) AND PHOSPHORUS (P) CONCENTRATIONS IN WOODY PLANT SPECIES AND SOILS IN KASTAMONU, HANÖNÜ

ABSTRACT

Understanding nutrient dynamics between plants and soils is crucial for sustainable forest management, particularly in areas where fertilization is not commonly practiced. This study investigates the distribution and accumulation patterns of two essential macronutrients, potassium (K) and phosphorus (P), in different plant organs and soil depths within a forested area in Kastamonu, Hanönü. Four tree species—Pinus nigra Arnold (black pine), Pinus sylvestris L. (Scots pine), Fagus orientalis Libsky (Oriental beech), and Abies nordmanniana subsp. bornmülleriana Mattf. (Turkish fir)—were examined. Samples were collected from five plant organs (needle/leaf, bark, cone, wood, root) and from three soil depths (0–5 cm, 20–30 cm, and 50–60 cm). Elemental analyses were performed using ICP-OES following microwave digestion. The results indicated significant differences ($p < 0.05$) in K and P concentrations among species and organs. The highest K concentrations were found in leaves, while wood consistently exhibited the lowest values. Fo species showed high K accumulation in wood, potentially leading to soil depletion due to wood harvesting. Conversely, Ab species exhibited significant P accumulation in cones and leaves, contributing to P enrichment in topsoil through litter decomposition. Soil nutrient concentrations also varied significantly by depth but were less influenced by species. These findings highlight the role of species-specific nutrient uptake and organ distribution in shaping soil nutrient dynamics. Incorporating these patterns into forest management strategies—such as species rotation—can help maintain soil fertility and promote long-term ecosystem sustainability.

Keywords: Potassium (K), Phosphorus (P), Soil Depth, Species Rotation.

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KASTAMONU, HANÖNÜ'NDE ODUNSU BİTKİ TÜRLERİ VE TOPRAKLARDA POTASYUM (K) VE FOSFOR (P) KONSANTRASYONLARININ MEKÂNSAL VE ORGANA DAYALI DEĞİŞİMLERİ

ÖZ

Bitkiler ile toprak arasındaki besin döngüsünün anlaşılması, özellikle gübrelemenin yaygın olarak uygulanmadığı bölgelerde, sürdürülebilir orman yönetimi açısından büyük önem taşımaktadır. Bu çalışma, Kastamonu'nun Hanönü

ilçesindeki ormanlık bir alanda, iki temel makro besin elementi olan potasyum (K) ve fosforun (P) farklı bitki organları ve toprak derinliklerindeki dağılım ve birikim desenlerini incelemektedir. Dört ağaç türü — Pinus nigra Arnold (karaçam), Pinus sylvestris L. (sarıçam), Fagus orientalis Libsky (doğu kayını) ve Abies nordmanniana subsp. bornmülleriana Mattf. (Uludağ göknarı) — araştırmaya dâhil edilmiştir. Örnekler beş bitki organından (iğne/yaprak, kabuk, kozalak, odun, kök) ve üç farklı toprak derinliğinden (0–5 cm, 20–30 cm, 50–60 cm) toplanmıştır. Element analizleri, mikrodalga sindirimi sonrası ICP-OES yöntemiyle gerçekleştirilmiştir. Sonuçlar, türler ve organlar arasında K ve P konsantrasyonları açısından anlamlı farklılıklar ($p < 0.05$) olduğunu göstermiştir. En yüksek K konsantrasyonları yapraklarda bulunurken, en düşük değerler odun dokusunda saptanmıştır. Fo türleri, odun dokusunda yüksek K birikimi göstermiş ve bu durum, odun hasadı nedeniyle toprakta besin kaybına yol açma potansiyeli taşımaktadır. Buna karşılık, Ab türleri kozalak ve yapraklarda belirgin P birikimi göstermiş, bu da döküntülerin ayrışması yoluyla yüzey toprağında P zenginleşmesine katkıda bulunmuştur. Toprak besin konsantrasyonları derinliğe göre anlamlı biçimde değişmekle birlikte, tür etkisi daha sınırlı bulunmuştur. Bu bulgular, türlere özgü besin alımı ve organlar arasındaki dağılımın toprak besin dinamiklerinin şekillenmesinde önemli bir rol oynadığını göstermektedir. Bu desenlerin orman yönetimi stratejilerine — örneğin tür rotasyonu uygulamalarına — dâhil edilmesi, toprak verimliliğinin korunmasına ve uzun vadeli ekosistem sürdürülebilirliğinin desteklenmesine katkı sağlayabilir.

Anahtar Kelimeler: Potasyum (K), Fosfor (P), Toprak Derinliği, Tür Rotasyonu.

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INTRODUCTION

Plants represent the essential foundation of the food pyramid, supporting nearly all forms of life on Earth either directly or indirectly (Rondanelli et al., 2022). In addition to their ecological significance, plants play crucial roles in economic and social systems. They provide multiple ecosystem services, including air filtration, climate regulation, erosion control, habitat formation for wildlife, and recreational opportunities for communities (Ertugrul et al., 2021; Cao et al., 2022).

The capacity of plants to deliver these services depends on their healthy growth and physiological development, which result from complex interactions between genetic traits (Hrivnak et al., 2017; Koç et al., 2021) and environmental conditions (Güney et al., 2021; Ghoma et al., 2022). Among the environmental determinants, soil characteristics—particularly the availability of nutrients—play a decisive role in regulating plant development (Kravkaz Kuscu et al., 2018; Mehmood et al.,

2021; Zhao et al., 2021). The concentration and balance of essential nutrients in the soil directly influence plant vitality, highlighting the critical link between nutrient availability and plant growth dynamics.

Once absorbed from the soil, nutrients are distributed and stored within different plant organs at varying levels. This nutrient partitioning and speciation within tissues are fundamental for understanding plant growth processes. Exploring how nutrients function in plant development and how they are transported among organs is key to gaining a comprehensive picture of internal nutrient dynamics (Erdem, 2021; Verma et al., 2021; Bhantana et al., 2021). Consequently, a wide range of studies has examined variations in nutrient distribution across plant organs and species, considering factors such as organ type and species-specific characteristics (Karacocuk et al., 2022; Isinkaralar, 2022).

Despite these investigations, a notable gap persists regarding the extent to which nutrient accumulation in plants corresponds to their concentrations in the surrounding soil and atmosphere. Uncertainties remain about the variation of nutrient content among plant organs after uptake, the chemical forms these nutrients assume within tissues, and the degree of nutrient transfer between organs (Shahid et al., 2017; Cetin et al., 2022). Bridging this knowledge gap is essential to deepen our understanding of nutrient behavior within plants and its implications for growth and development.

Accordingly, this study seeks to address part of this deficiency by examining phosphorus (P) and potassium (K) accumulation levels in different organs of various plant species and evaluating their relationship with corresponding nutrient levels in the soil. The research was conducted in Kastamonu, Hanonu, aiming to contribute new insights into plant–soil nutrient interactions.

MATERIAL AND METHOD

This research was conducted to examine the variations in phosphorus (P) and potassium (K) concentrations among different organs of selected woody plant species. To minimize the influence of external factors and ensure environmental consistency, the study was carried out within a confined area characterized by homogeneous soil structure and climatic conditions. The species investigated were Pinus nigra Arnold (black pine), Pinus sylvestris L. (Scots pine), Fagus orientalis Libsky (Oriental beech), and Abies nordmanniana subsp. bornmülleriana Mattf. (Turkish fir). These tree species were grown on flat terrain in Kastamonu, Hanonu, which provided a controlled setting for comparing nutrient distribution across plant organs.

Sampling involved the collection of needles, bark, wood, cones, and roots from each species, using non-metallic tools to prevent contamination. Due to its lack of

cones, Fagus orientalis Libsky was excluded from the cone analysis. Soil samples were also taken from beneath each tree at three depth intervals: 0–5 cm (surface), 20–30 cm (intermediate), and 50–60 cm (deep). All soil samples were air-dried in the laboratory for two weeks and then sieved. Subsequently, both soil and plant materials were oven-dried at 45 °C for two weeks to standardize moisture levels and ensure reliable elemental analysis.

For the determination of P and K concentrations, 0.5 g of each dried sample was digested with a mixture of 6 ml of 65% HNO_3 and 2 ml of 30% H_2O_2 using a microwave digestion system. The resulting solutions were transferred to volumetric flasks and diluted with ultrapure water to a final volume of 50 ml. Elemental concentrations of phosphorus and potassium were quantified using Inductively Coupled Plasma–Optical Emission Spectrometry (ICP-OES), a widely applied technique for trace element analysis in recent studies (Cesur et al., 2021; Isinkaralar et al., 2022).

The obtained data were analyzed using SPSS 22.0 statistical software. Analysis of Variance (ANOVA) was applied to identify statistically significant differences among factors at a 95% confidence level ($P < 0.05$). Duncan's multiple range test was then employed to classify the variables into statistically homogeneous groups. The results were systematically tabulated, simplified, and interpreted to enable a clear and comprehensive evaluation of nutrient distribution patterns.

RESULTS

The variations in potassium (K) concentrations across species and plant organs, along with the outcomes of the statistical analyses, are summarized in Table 1.

Table 1. Variation in K concentration in plants by species and organ – Kastamonu, Hanönü

Species	Organ	Leaf	Bark	Cone	Wood	Root	F Values	Average
Ab		6815.20 Bb	5680.30 Bb	8555.66 Bb	380.62 Aa	5505.22 Bb	8.86***	5387.40 b
Pn		4100.37 Ca	1394.20 Aba	993.00 Aa	900.80 Ac	2292.11 Ba	17.47***	1936.09 a
Ps		4976.75 Da	2966.02 Ca	1582.42 Ba	727.51 Ab	4811.31 Db	65.71***	3012.80 a
Fo		4503.64 Ba	2538.44 Aa	-	1671.11 Ad	2184.60 Aa	16.22***	2724.44 a
F Values		15.20***	4.21*	24.12***	111.11***	18.24***		16.00***
Average		5098.99 C	3144.74 B	3710.36 B	920.01 A	3698.31 B	13.89***	

The ANOVA results demonstrated statistically significant differences in K concentrations between species and among different plant organs ($p < 0.05$). The lowest potassium levels were consistently detected in wood samples, whereas the highest concentrations appeared in leaves, with some species exhibiting nearly 18-fold differences between these two organs. Based on mean values and Duncan's multiple range test, organ concentrations were classified into three groups: wood in the first group, bark/cones/roots in the second, and leaves in the third group.

Species-wise, the Ab species displayed the highest K concentrations in all organs except wood. According to the mean grouping, Ab was placed in the second group, while the other species were assigned to the first group. The variations in phosphorus (P) concentrations among species and organs are shown in Table 2.

Table 2. Variation in P concentration in plants by species and organ – Kastamonu, Hanönü

Species	Organ	Leaf	Bark	Cone	Wood	Root	F Values	Average
Ab		457.05 BCc	392.71 Bb	654.90 Cb	16.32 Aa	146.93 Aa	11.65***	333.58 b
Pn		347.53 Cb	125.32 Aa	76.76 Aa	47.41 Ab	217.76 Bab	15.87***	162.96 a
Ps		438.88 Dc	222.18 Bab	40.15 Aa	55.12 Ab	329.65 Cb	142.22***	217.20 a
Fo		221.70 Ba	184.42 Aba	-	116.50 Ac	224.05 Bab	3.33*	186.66 a
F Values		29.91***	3.34*	28.57***	78.54***	3.90*		6.53***
Average		366.29 C	231.16 B	257.27 B	58.83 A	229.60 B	12.92***	

The analysis revealed significant variations in P concentrations across both organs and species ($p < 0.05$). Generally, leaves exhibited the highest P levels, followed by bark, cones, and roots, with wood showing the lowest values. Similar to K distribution, the P concentrations were grouped into three categories: wood (lowest), bark/cones/roots (middle), and leaves (highest). According to Duncan's test, the Ab species belonged to the second group, while the remaining species were placed in the first group for most organs, except wood and roots.

The differences in soil K concentrations by species and depth are summarized in Table 3.

Table 3. Variation in K concentration in soils by species and depth – Kastamonu, Hanönü

Species	Soil Depth	Upper	Middle	Deep	F Values	Average
Ab		9229.09 b	8450.76 b	9082.90 c	0.78 ns	8920.91 c
Pn		8545.70 b	6199.03 a	7424.34 b	1.55 ns	7389.69 b
Ps		13441.03 c	12330.51 bc	10564.48 c	3.48 ns	12112.01 d
Fo		4838.37 a	5660.34 a	5523.20 a	1.25 ns	5340.64 a
F Values		11.41***	57.07***	14.58***		43.37***
Average		9013.55	8160.16	8148.73	0.99 ns	

The statistical analysis indicated no significant differences in soil K concentrations among species ($p > 0.05$), while the effect of soil depth was significant ($p < 0.001$). The lowest K values at all depths were associated with Fo, whereas the highest were found in Ps. Table 4.

Table 4. Variation in P concentration in soils by species and depth – Kastamonu, Hanönü

Species	Soil Depth	Upper	Middle	Deep	F Values	Average
Ab		138.12 a	132.20 a	139.36	0.33 ns	136.56 a
Pn		211.82 Bb	155.04 Aab	167.55 A	10.70**	178.14 b
Ps		182.81 Bb	120.46 Aa	127.69 A	9.94**	143.65 a
Fo		201.83 b	176.60 b	171.63	1.03 ns	183.35 b
F Values		7.84**	4.10*	2.81 ns		9.06***
Average		183.65 B	146.07 A	151.56 A	8.20**	

For soil P, variations with depth were not statistically significant for Ab and Fo, but Pn and Ps displayed clear declines with increasing depth. Inter-species differences were significant in the upper and middle layers ($p < 0.05$), but not in the deeper soils. Duncan's test revealed that Ab belonged to the first group in the upper and middle layers, whereas Fo was consistently in the last group. Overall, P concentrations varied depending on the plant species, reflecting differences in litterfall and nutrient cycling. Among the studied species, Fo contributed the most to increasing soil P concentrations, while Ab showed the lowest enrichment.

DISCUSSION

In this study, potassium (K) concentrations did not exhibit statistically significant variation with respect to soil depth. However, notable differences were observed among species and their associated environmental settings. Across all soil layers, Fo species displayed the lowest K values, whereas Ps showed the highest (Table 3). When examining plant organs, Fo had the highest K concentration in wood samples, but the lowest in other tissues, suggesting that Fo tends to sequester K primarily in its trunk. This pattern is reflected in the lower soil K concentrations found in areas where Fo is cultivated. Conversely, Ps species exhibited relatively low K concentrations in leaves and cones, ranking in the first group according to Duncan's test. Interestingly, the soils where Ps grew had the highest K concentrations, implying that Ps uses potassium less efficiently than other species. For Ab, both soil and plant organ K concentrations were high. The leaf tissue of Ab in particular contained the greatest K levels among species (except for wood), indicating intensive uptake and utilization in leaves. The subsequent decomposition of leaf litter likely contributes to the re-enrichment of K in the soil.

Potassium is an essential macronutrient involved in multiple physiological and biochemical functions, including stomatal regulation, carbohydrate transport through the phloem, enzyme activation, osmoregulation, cation–anion balance, and overall plant stress adaptation (Denizhan et al., 2021; Xie et al., 2021; Isinkaralar & Erdem, 2022; Erdem, 2021). It plays a critical role in maintaining plant water relations and enabling tolerance to biotic and abiotic stressors such as drought, salinity, pests, diseases, frost, and flooding. Previous research has consistently shown significant differences in K concentration depending on species and plant organ, aligning with the findings of this study.

Phosphorus (P) concentrations varied significantly among both species and plant organs (Table 2). While variations in deep soil P levels were not statistically significant, significant differences emerged in the middle and upper soil layers. According to Duncan's test, Fo organs (except wood) predominantly belonged to the first group, whereas Ab exhibited the highest concentrations in cones and bark. These results indicate that Ab species utilize phosphorus more intensively, while Fo makes relatively lower use of it. When averaged across species, leaves contained the highest P concentrations, followed by bark, cones, and roots, with wood consistently exhibiting the lowest values. This pattern suggests that leaf tissues act as primary P sinks, and the decomposition of fallen leaves contributes to P enrichment in the upper soil horizons.

Phosphorus is indispensable for plant development, particularly in root formation and flowering (Kaya et al., 2019). Numerous studies have demons-

trated its importance for agricultural productivity and the positive impact of phosphatic fertilizers on plant growth (Tibbett et al., 2020; Shi et al., 2020; Mardamootoo et al., 2021).

Overall, the study results confirm that elemental concentrations in plant tissues differ significantly between species and organs, a finding that aligns with previous research (Karacocuk et al., 2022). Elemental accumulation is strongly influenced by both the morphological and physiological traits of species (Key & Kulaç, 2022), as well as the interaction between genetic makeup (Strable, 2021) and environmental factors (Yoshida et al., 2021). Because elemental uptake occurs primarily through the root system (Shahid et al., 2017), soil properties are a decisive factor. In the Kastamonu, Hanönü study area, where soils are relatively uniform and forestry practices involve no fertilization, plant species emerge as the dominant driver of variability in elemental concentrations.

The data further demonstrate that species identity influences soil K and P levels. Modern studies highlight the critical role of micro-environmental factors in shaping plant growth and nutrient dynamics (Yigit et al., 2021; Dong & Lin, 2021). Plants not only respond to soil composition but also modify it through their physiological activities and litter input, creating a dynamic feedback loop that remains only partially understood (Sevik et al., 2019).

CONCLUSION

The central aim of this research was to examine the spatial variation of potassium (K) and phosphorus (P) concentrations within soils and different plant organs in Kastamonu, Hanönü. These two macronutrients are vital for healthy plant growth, and their deficiencies can significantly constrain physiological development and productivity. In forested landscapes where fertilization practices are not applied—unlike in agricultural systems—understanding nutrient dynamics and species-specific uptake patterns is crucial for sustainable forest management and planning.

The study demonstrated that Fo species exhibited pronounced potassium accumulation in wood tissues. Unlike leaves, bark, and cones—which generally remain in the field post-harvest—wood is typically extracted. This selective removal indicates that long-term cultivation of Fo may gradually lead to potassium depletion in the soil, as the nutrient stock contained in harvested wood is continuously exported from the system.

Similarly, significant phosphorus accumulation was detected in the leaves and cones of Ab species. As these tissues eventually fall and decompose, they contribute to phosphorus enrichment in the topsoil, potentially improving soil ferti-

lity in areas dominated by Ab stands. This natural nutrient cycling mechanism is particularly relevant for forest systems that aim to maintain soil health without external fertilization.

Over time, uneven nutrient uptake among different species can result in the progressive depletion of specific elements. To mitigate this risk, adopting a species rotation strategy—similar to crop rotation in agriculture—is recommended. Such a strategy can help balance nutrient extraction and replenishment, support long-term soil fertility, and promote overall ecosystem sustainability within forested landscapes.

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Author Contribution Rates

Design of Study:

Data Acquisition:

Data Analysis:

Writing Up:

Submission and Revision:

Availability of Data and Materials

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

Conflict of interest

All authors certify that they have no affiliations with or involvement in any organization or entity with any financial interest or non-financial interest in the subject matter or materials discussed in this manuscript.

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