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Soil chemistry in apricot cultivation: evaluation of C and N dynamics by PCA and correlation analysis

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Abstract

This study uses statistical methods to analyze soil carbon (C) and nitrogen (N) dynamics in four different apricot growing regions (Battalgazi, Akçadağ, Doğanşehir and Hekimhan) in Malatya. Correlation analysis, hierarchical clustering (HCA) and Principal Component Analysis (PCA) were applied to examine the relationships between soil organic matter (OM), soluble carbon (Soluble C), biomass nitrogen (Biomass N), total nitrogen (N) and other soil chemical parameters. According to the results obtained, a strong positive correlation ($r = 0.67$) was found between organic matter (OM) and total nitrogen (N), indicating that the organic matter content in the soil contributes directly to the nitrogen mineralization process. Positive correlations were found between soluble carbon (Soluble C) and biomass carbon (Biomass C) and N, indicating that microbial activity and carbon cycling in soil are directly related to nitrogen dynamics. In PCA analysis, the first two principal components (PC1 and PC2) explained 82.1% of the total variance. The PC1 axis is related to soil macronutrients (C, N, K, P) and organic matter content, while the PC2 axis is related to lime ($CaCO_3$), pH and micronutrients (Fe, Mn, Zn). When the regional distribution is analyzed, Battalgazi and Doğanşehir show similar chemical characteristics, while Hekimhan is differentiated by high pH and lime content. Hierarchical cluster analysis (HCA) shows that Battalgazi and Doğanşehir have similar soil characteristics, but Akçadağ and especially Hekimhan have different soil composition. Hekimhan's high $CaCO_3$ content and alkaline pH level may negatively affect productivity by suppressing organic matter and nitrogen levels. The results of this study can contribute to the development of soil management strategies in apricot farming in Malatya. In particular, organic matter management, pH regulation strategies and optimization of macro/micro nutrient balance are needed. A detailed study of C and N cycles is a critical step for sustainable soil management and improving the productivity of apricot production.

Keywords: Apricot, Carbon, Nitrogen, PCA, Correlation Soil

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INTRODUCTION

Apricot (Prunus armeniaca L.) cultivation is one of the most important agricultural activities in Turkey, covering a wide area from the southeast to the western regions of the country. In apricot cultivation, balanced management of soil carbon (C) and nitrogen (N) cycles directly affects plant nutrition and soil fertility. Apricot has a great economic, cultural and social importance especially in Malatya province. Malatya is the largest apricot producer in Turkey and accounts for 85% of Turkey's total dried apricot production (Öztürk and Karakaş, 2017; Ercisli and Güleryüz, 2001). Apricot is one of the key elements of agricultural development in the region and also stands out as an important agricultural product that strengthens the local economy (Duru et al., 2022).

The optimal growth and productivity of apricot trees are closely influenced by soil characteristics. Specifically, well-drained soils with high organic matter content promote robust root development and enhance nutrient uptake efficiency in apricot plants. Studies indicate that maintaining soil pH within the range of 6.0 to 7.5 is essential for achieving maximum yield potential in apricot cultivation (Eriş, 1995). Furthermore, key factors such as soil fertility, organic matter dynamics, and the management of soil carbon processes play a pivotal role in ensuring sustainable and efficient agricultural production systems (Montanaro et al., 2012; Gerke, 2022).

In addition, soil nutrients also play a decisive role in the quality of apricot. Potassium improves fruit quality, while nitrogen promotes overall plant growth (Xu et al., 2020). In addition, adequate amounts of calcium and magnesium in the soil increase the resistance of apricot trees to diseases and promote fruit set. Soil diversity in different regions is an important factor in apricot farming; therefore, conducting local soil analysis helps farmers to determine the most appropriate farming practices (Zhao et al., 2018).

In apricot cultivation, effective management of soil carbon (C) and nitrogen (N) cycles is essential, as these directly influence plant nutrition and soil fertility. The cycling of carbon and nitrogen is intricately linked to microbial activity, organic matter content, and nutrient dynamics within the rhizosphere (Lal, 2015). Mineralization of organic matter enhances soil fertility by converting nitrogen into plant-available forms, while carbon sequestration contributes to improved soil structure and increased water-holding capacity. However, certain soil characteristics, particularly alkaline pH and elevated calcium carbonate levels, may restrict the efficiency of carbon and nitrogen turnover processes (Marschner, 2012). Notably, in calcareous soils, the bioavailability of micronutrients such as iron, zinc, and manganese is often reduced, potentially leading to nutritional imbalances and physiological disorders in plants.

Soil organic matter is at the center of the carbon cycle and is recognized as a component that improves soil health and increases productivity (Schlesinger and Andrews, 2000). Research focusing on apricot cultivation and soil organic carbon (SOC) dynamics is vital for enhancing both soil health and crop productivity. Organic carbon improves soil structure, enhances water retention capacity, and increases the bioavailability of essential nutrients. In particular, soils rich in organic matter significantly promote root development and nutrient uptake in apricot trees (Neguşier et al., 2024). Empirical studies have demonstrated that the application of organic fertilizers can substantially increase SOC levels, thereby boosting apricot yields. For instance, Cai et al. (2020) reported that the integration of compost and manure led to a 15–20% increase in SOC and a corresponding yield improvement in apricot orchards. Moreover, sustainable land management practices—such as cover cropping and reduced tillage—not only support yield stability but also contribute to climate change mitigation by enhancing the soil's carbon sequestration capacity (Smith et al., 2018). Long-term field trials, such as those conducted by Zhang et al. (2022) and Du et al. (2022), have examined the comparative effects of organic versus conventional management on SOC trends in apricot-producing regions, offering specific recommendations to optimize carbon retention in orchard soils.

However, the management of soil organic matter and carbon dynamics in apricot farming regions is of great importance for productive and sustainable agriculture. Studies conducted in Turkey have revealed that soils with high organic matter content increase the growth and productivity of apricot trees (Yang et al., 2021). However, the organic matter content of the soil may vary according to the agricultural techniques used and the climatic characteristics of the region.

Studies on apricot agriculture and soil organic carbon (SOC) dynamics are critical for improving soil health, enhancing crop productivity, and ensuring long-term agricultural sustainability. Organic carbon contributes significantly to soil structure, increases water-holding capacity, and enhances the bioavailability of essential nutrients. In particular, soils with high organic matter content foster optimal root development and facilitate nutrient uptake in apricot trees (Neguşier et al., 2024). Numerous studies have demonstrated that organic fertilizer applications can elevate SOC levels, thereby leading to substantial yield improvements in apricot orchards (Cai et al., 2020). Moreover, sustainable agricultural practices—such as compost application, reduced tillage, and cover cropping—not only enhance soil fertility but also play a pivotal role in climate change mitigation by increasing the soil's carbon sequestration potential (Smith et al., 2018). Long-term field experiments have evaluated the effects of various management strategies on SOC dynamics in apricot cultivation and have provided actionable recommendations to optimize carbon retention and overall soil functionality.

Effective soil analysis and nutrient management are vital components of apricot cultivation, as they directly influence both yield and fruit quality. In this context, conducting comparative soil studies across different agroecological regions is crucial for identifying region-specific nutrient deficiencies and optimizing fertilization strategies tailored to local conditions.

Soil surveys in the region show that soil organic matter and carbon dynamics are related to the productivity of apricot agriculture and these dynamics need to be improved for sustainable production (Yang et al., 2021). Battalgazi, Akçadağ, Hekimhan and Doğanşehir, which are four important districts of Malatya province, are among the regions where apricot production is intensive. The soil properties and organic carbon dynamics of these regions are of great importance for the sustainability of apricot production. Battalgazi, Akçadağ, Hekimhan and Doğanşehir districts show differences in terms of both climatic and soil structure. These differences are important factors affecting the applicability of apricot agriculture and soil management (Keesstra et al., 2016).

In this study, soil C and N dynamics and their interactions with soil pH, $CaCO_3$ content, and micro-macro nutrients were investigated in apricot cultivation in four important agricultural regions of Malatya (Battalgazi, Akçadağ, Doğanşehir, and Hekimhan). The main objective was to identify differences between these regions and to develop appropriate soil management strategies for agricultural production. Three main statistical methods were used in the study. Correlation analysis was applied to determine the relationships between soil carbon, nitrogen, and other nutrients. Principal Component Analysis (PCA) was used to identify the most dominant variables by determining the C and N dynamics of different regions. Hierarchical cluster analysis (HCA) was used to group the soils by identifying the similarities and differences between the regions. This study provides a powerful tool for a detailed study of the interactions between soil chemistry and nutrients, providing important information for sustainable soil management in apricot cultivation.

MATERIALS AND METHODS

Soil sampling procedure

In this study, soil samples taken from **Battalgazi, Akçadağ, Hekimhan and Doğanşehir** regions were subjected to laboratory analysis. Battalgazi, Akçadağ, Hekimhan and Doğanşehir districts in Malatya province are under the influence of continental climate and each of them has suitable climate and soil conditions for apricot cultivation (Table 1). The soils in these districts are generally calcareous, high in pH, rich in organic matter content, and show deep, well-drained structures suitable for apricot cultivation (Soydan, 2019; Bassi et al., 2024). The climatic and soil characteristics in these regions have the potential to ensure efficient and sustainable apricot production (Zhebentyayeva et al., 2012).

Table 1. Location of the study area and some climatic characteristics

District	Altitude (m)	Precipitation (mm/year)	Temperature (°C)	Climate	Coordinate
Battalgazi	~950	350-400	13-14	Temperate, arid, microclimate effective	38.3600° N, 38.3300° E
Akçadağ	~1,050	400-450	11-12	Dry, windy, harsher winters	38.6000° N, 38.5000° E
Hekimhan	~1,250	450-500	10-11	Harsh continental, high pH and lime	38.4000° N, 38.6000° E
Doğanşehir	~1,250	600-700	11-12	Moist, fertile, microorganism rich	38.5500° N, 38.7500° E

The climatic and geographical characteristics of the studied districts reveal distinct environmental conditions that directly influence apricot cultivation potential. Battalgazi and Akçadağ, with their relatively lower altitudes and moderate temperatures, offer favorable conditions for apricot growth, though limited precipitation and arid tendencies may necessitate irrigation and organic matter enrichment. Hekimhan's high elevation and harsh continental climate, coupled with alkaline and lime-rich soils, can challenge nutrient availability, requiring targeted fertilization strategies. In contrast, Doğanşehir stands out with its higher precipitation and fertile, microorganism-rich soils, presenting an ideal environment for sustainable and high-quality apricot production. These regional differences underscore the need for location-specific soil and crop management practices in apricot orchards (Table 1).

Soil samples were collected from the 0–30 cm layer, which is considered the most biologically active zone and crucial for nutrient uptake in apricot orchards. Following collection, the samples were air-dried and sieved through a 2 mm mesh to remove debris and homogenize the texture. To preserve microbial integrity, the samples were sealed in polyethylene bags to minimize moisture loss and stored at +4 °C until analysis

Soil analyses were conducted to evaluate key parameters including macronutrients (N, P, K), micronutrients (Fe, Zn, Cu, Mn), as well as pH, Electrical Conductivity (EC), Lime Content ($CaCO_3$), Organic Matter (OM), Sodium (Na), Soil Carbon and Nitrogen Dynamics, Soluble N, Biomass N, Soluble C, Biomass C, Cation Exchange Capacity were performed. By comparing the average values in each region, regional differences were determined and the effects of these differences on agricultural management were analyzed.

Soil reaction (pH) 1:2.5 (w/v) and electrical conductivity (EC) 1:5 (w/v) were measured in a soil water mixture (Jackson 1958). Texture analysis was done by hydrometer and after determining % clay, % sand and % silt, the class was determined in the texture triangle (Bouyoucos 1951). Calcium carbonate ($CaCO_3$, %) content was determined by Scheibler calcimeter in a closed system (Allison and Moodie, 1965). Organic carbon content was determined by wet combustion method based on potassium dichromate oxidation (Walkley and Black 1934). Total nitrogen content was determined by the Kjeldalh method (Bremner and Mulvaney 1982). Available Phosphorus (P) was extracted using the Olsen method (0.5 M $NaHCO_3$, pH 8.5) for neutral to alkaline soils. The phosphorus concentration in the extract was determined colorimetrically using the molybdenum blue method (Olsen., 1954). Potassium (K) was measured by extracting soil with 1 M ammonium acetate (NH_4OAc) at pH 7.0. The potassium content in the extract was determined using flame photometry. Sodium (Na) similar to potassium, sodium was extracted using 1 M ammonium acetate, and quantified via flame photometry (Richards.,1954). Micronutrients such as Iron (Fe), Zinc (Zn), Copper (Cu), Manganese (Mn) were obtained using the DTPA (diethylenetriaminepentaacetic acid) extraction method (0.005 M DTPA + 0.01 M $CaCl_2$ + 0.1 M TEA, pH 7.3). Concentrations were determined via atomic absorption spectrophotometry (AAS) (Lindsay and Norvel., 1978). Soluble Carbon (SC) and Soluble Nitrogen (SN): Extracted using 0.5 M K_2SO_4 and analyzed via spectrophotometry (Vance et al., 1987). Microbial Biomass Carbon (MBC) and Microbial Biomass Nitrogen (MBN): Determined using the fumigation-extraction method (Vance et al., 1987; Joergensen et al., 1990)

Data Analyses

The SPSS 26.0 software (SPSS Inc.) and Origin pro 2024 were used to perform statistical analysis of the data. The fit of the data to a normal distribution for all properties measured was checked with the Kolmogorov-Smirnov test. Data were submitted to one-way repeated measures ANOVA as between-subject factors. Two-way ANOVA was performed to assess treatment effects and interactions, followed by Tukey's HSD test ($p < 0.05$). Principal Component Analysis (PCA) and Hierarchical Clustering Heat Map analysis were conducted to visualize soil biochemical relationships. All statistical analyses were performed using R (v4.2) and Python (v3.11) with ggplot2 and seaborn libraries for visualization.

RESULTS AND DISCUSSION

Soil Chemistry and pH Changes

Soil pH is one of the main parameters affecting the uptake of nutrients by plants. The pH values of the soils analyzed within the scope of the study varied between 7.53 and 7.92 and were generally in the neutral to slightly alkaline range. Previous studies have shown that the optimum pH range for apricot cultivation is 6.5-7.5 (Ercisli and Güleryüz, 2001). pH values above 7.5 may cause developmental problems, especially (Figure 1) by limiting the uptake of micronutrients (Fe, Zn, Cu, Mn) by plants (Marschner, 2012).

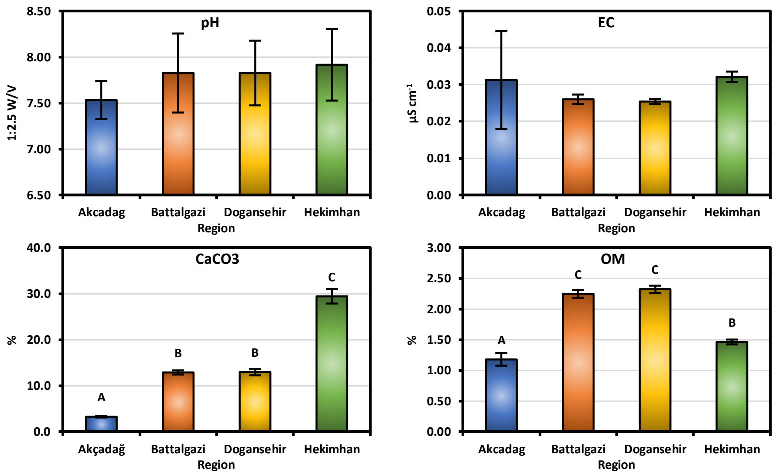

Figure 1. pH, EC, OM and $CaCO_3$ level of soils

The basic chemical properties of soils such as pH value, $CaCO_3$ content and OM content significantly affect the uptake of nutrients by plants. In this study, Hekimhan and Akçadağ regions were found to have high pH and lime content (Figure 1). Many studies have shown that calcareous soils reduce the uptake of micronutrients such as Fe, Zn, and Mn by plants (Marschner, 2012; Lindsay and Norvell, 1978). This inhibition typically occurs in soils with a pH above 7.5 and $CaCO_3$ content exceeding 15%, where micronutrients become increasingly unavailable due to precipitation and reduced solubility (Alloway, 2008; Kabata-Pendias, 2011).

Electrical conductivity analyses show that salinity levels are higher in Doğanşehir region (Figure 1). Soil salinity is one of the main factors limiting agricultural production, especially in arid and semi-arid regions (Rengasamy, 2010). High salinity disrupts soil structure due to the accumulation of Na and chlorine (Cl) ions and makes it difficult for plants to uptake water (Munns and Tester, 2008). Therefore, salinity management should be ensured by drainage practices and organic matter additions in areas with high EC values such as Doğanşehir.

The lime content in Malatya is highly variable, with the lowest measured in Akçadağ (3.23%) and the highest in Hekimhan (29.39%) (Figure 1). High lime content is often associated with micronutrient deficiencies, particularly Fe and Zn, and may result in visible symptoms such as chlorosis in apricot trees (Kacar and Katkat, 2010). However, explaining this phenomenon solely by lime content may be insufficient, as high total Zn levels in the soil do not necessarily ensure its bioavailability under alkaline conditions. In the Hekimhan district, for example, both lime and Zn contents were found to be high, yet zinc deficiency symptoms were observed, likely due to the reduced solubility and plant uptake of Zn in calcareous soils with elevated pH. To overcome these challenges, targeted strategies such as the application of chelated micronutrient fertilizers or foliar feeding are recommended for sustainable apricot production in calcareous regions (Mengel et al., 2001).

Significant differences were observed between regions in terms of OM content. The highest value was found in Doğanşehir (2.32%) and the lowest value was found in Akçadağ (1.18%) (Figure 1). Previous studies have shown that soils with organic matter content above 2% have higher microbial activity and nutrient retention capacity (Lal, 2015). Increasing organic matter content is of great importance for the long-term sustainability of apricot cultivation in Malatya.

Soil organic matter is one of the main indicators of soil fertility and is directly related to nitrogen mineralization (Brady and Weil, 2008). In this study, a strong relationship between organic matter content and soil nitrogen (N) was observed. Similarly, studies have shown that an increase in soil organic matter content increases microbial activity and leads to the production of more mineral nitrogen for plants (Jenkinson and Ladd, 1981; Jilling et al., 2018). In Akçadağ and Hekimhan regions, organic matter content was relatively high, which means better biological activity and nutrient cycling. In contrast, regions such as Battalgazi and Dogansehir have lower organic matter content, which may require the use of organic fertilizers to maintain productivity in these regions in the long term (Lal, 2004).

Carbon and Nitrogen Dynamics

Carbon and nitrogen parameters are presented in Figure 2. According to the data obtained, soluble carbon (Soluble C) content shows a significant difference between the regions. The highest value was found in Akçadağ (105.95 mg/kg) and the lowest in Doğanşehir (19.26 mg/kg). This indicates that Akçadağ soils are richer in organic carbon and microbial activity may be higher in this region. The higher soluble carbon content suggests that the organic matter decomposition process is active and the microbial biomass of the soil may be higher.

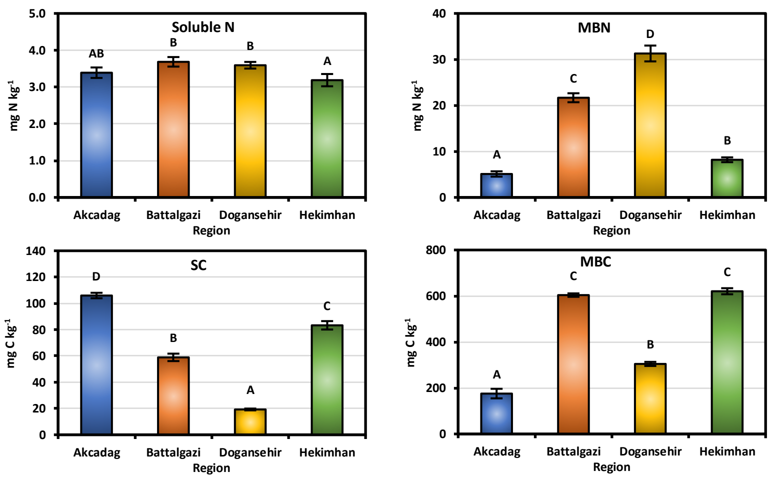

Figure 2. Soil C and N Dynamics

In terms of Total N content, the highest value was found in Doğanşehir with 0.12% and the lowest value was found in Akçadağ with 0.06%. Nitrogen is a critical macronutrient for plant growth and is directly related to shoot development, especially in apricot cultivation. The high total nitrogen content of Doğanşehir indicates that soil organic matter transformation and nitrogen mineralization processes may be more active in this region. When Biomass C and Biomass N are analyzed, Battalgazi and Akçadağ regions stand out as regions with higher microbial activity. Since biomass carbon and nitrogen contents reflect the activity of microorganisms in the soil and organic matter transformation processes, it can be said that microbial activities are more intense in these regions. When the relationship between organic matter content and nitrogen dynamics was analyzed, it was observed that there was a positive correlation between organic matter content and total nitrogen ($r = 0.67$). This finding indicates that soils rich in organic matter contain more nitrogen and this nitrogen becomes available for plants through mineralization.

Soil carbon and nitrogen cycling is a critical process for microbial activity, organic matter mineralization and plant uptake of nutrients. In this study, significant differences were found between soluble carbon and total nitrogen levels. The low levels of total nitrogen, especially in the Akçadağ region where soluble carbon is high, reveal the importance of biochemical interactions between carbon and nitrogen for regional soil management. Adequate soil carbon availability is critical for sustaining microbial activity and soil fertility (Schmidt et al., 2017).

Sufficient organic matter in the soil promotes nitrogen mineralization by enhancing microbial activities, thus allowing plants to take up more nitrogen. However, high lime content and pH level can reduce the bioavailability of some micronutrients, limiting the effective utilization of nitrogen by plants. This was particularly observed in the Hekimhan region, where high $CaCO_3$ content was associated with relatively lower amounts of organic matter and nitrogen (Wright and Bailey, 2001).

The high total nitrogen levels in Dogansehir region indicate that the nitrogen cycle works more efficiently here. Nitrogen is a vital element for shoot development and fruit set in apricot cultivation, and yield and quality may decrease in nitrogen deficient soils (Fageria et al., 2010). In areas where nitrogen levels are inadequate, it is recommended to optimize nitrogen fertilization programs. However, high Na levels were detected in this region. Excess sodium can disrupt soil structure and hinder the uptake of water and nutrients by plants (Wakeel, 2013). Therefore, salinity management should be ensured through drainage practices and organic matter supplements in soils with high sodium content such as Doğanşehir.

The relationship between soil carbon and nitrogen is of great importance for sustainable soil management (Yuan et al., 2023). Increasing organic matter content and implementing balanced fertilization programs, especially in apricot farming regions, will help to maintain a healthy carbon and nitrogen cycle (Akın and Aygül, 2022).

Climate change and related environmental factors such as temperature fluctuations, irregular precipitation patterns, and increased evapotranspiration have significant implications for soil carbon (C) and nitrogen (N) dynamics. In semi-arid regions like Malatya, rising temperatures and decreasing soil moisture can accelerate organic matter decomposition, leading to rapid carbon loss and altered nitrogen mineralization processes (Davidson & Janssens, 2006; Smith et al., 2008). These changes may disrupt the balance between microbial activity and nutrient availability, thereby affecting plant nutrient uptake and soil fertility (Lal, 2004).

Moreover, increased frequency of droughts may limit nitrogen fixation and reduce microbial biomass carbon, while sporadic heavy rains may intensify nutrient leaching—particularly in soils with low water-holding capacity (Schimel et al., 2007). The interaction between high pH, lime content, and climatic stress further complicates micronutrient availability in certain regions like Hekimhan (Marschner, 2012).

Considering these vulnerabilities, adaptive soil management strategies that enhance organic matter retention, improve soil moisture conservation, and stabilize microbial ecosystems become increasingly important. Integrating climate-smart practices—such as cover cropping, reduced tillage, mulching, and organic amendments—can help buffer the negative impacts of climate change on soil C and N dynamics, ensuring long-term sustainability in apricot production (FAO, 2017).

Macro-Micro Nutrients and Apricot Yield

Macronutrients play an important role in apricot tree growth and fruit quality (Figure 3). Phosphorus content was highest in Hekimhan (11.45 mg/kg) and lowest in Akçadağ (2.36 mg/kg). Since P plays a critical role in root development and flowering processes, low phosphorus levels may limit fruit yield (Shen et al., 2011).

In terms of K content, the lowest value was found in Doğanşehir (167.17 mg/kg) and the highest in Hekimhan (207.66 mg/kg). Potassium is known to improve fruit quality and sugar accumulation (Wang et al., 2013). Especially the fact that Malatya apricot stands out in the world market with its high brix (sugar) content reveals the importance of potassium management (Duymuş, 2023).

In terms of Ca and Mg content, Akçadağ and Hekimhan stand out. Calcium is an element that increases fruit firmness and storage time, and Ca deficiency may cause softening and shorter shelf life of apricots (Fallahi et al., 2013). Sodium content was high in Akçadağ and Hekimhan (4.43-5.51 mg/kg). Excess sodium can degrade soil structure and reduce water holding capacity and nutrient uptake (Rengasamy, 2010). These results support the need for careful irrigation water management in Malatya.

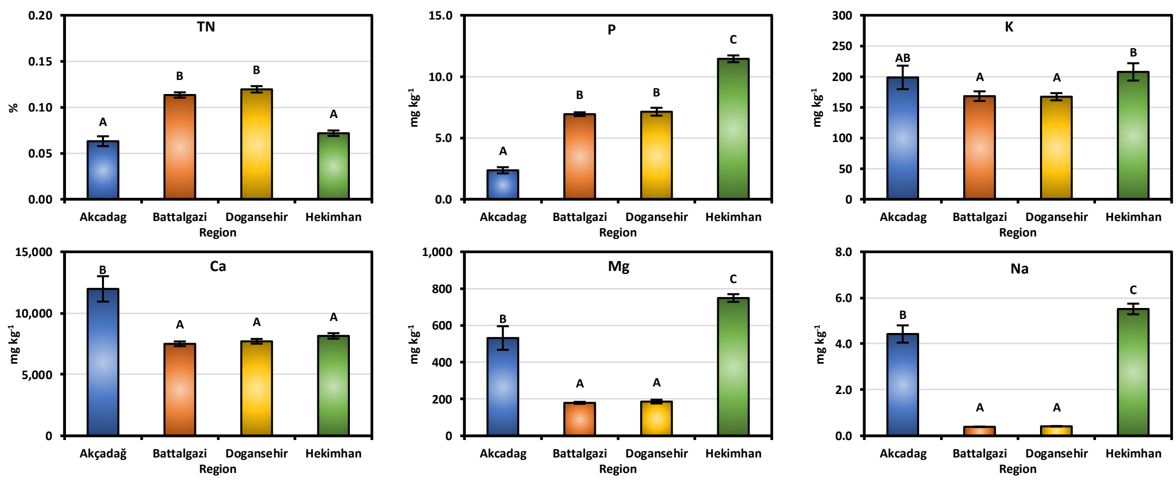

Figure 3. Macronutrient Levels in Soil (N, P, K, Ca, Mg, Na)

Iron, Zn, Cu and Mn are important micronutrients that affect quality and yield in apricot cultivation (Figure 4). When Fe value was analyzed; Akçadağ had the highest Fe content (5.55 mg/kg), while Hekimhan had the lowest (2.66 mg/kg). Iron deficiency causes leaf yellowing such as chlorosis and decreases photosynthetic capacity (Marschner, 2012). When Zn value was analyzed; the lowest zinc content was found in Akçadağ (0.26 mg/kg). Zinc deficiency may reduce apricot fruit setting by delaying flowering (Alloway, 2008).

When the Cu value is analyzed; Hekimhan (12.86 mg/kg) has the highest Cu content (Figure 4) and it is known that copper is important for lignin synthesis and plant resistance (Broadley et al., 2012). When the Mn value is analyzed; Mn deficiency is mostly observed in Hekimhan region (7.12 mg/kg). Manganese is a critical element for photosynthesis and carbohydrate metabolism (Millaleo et al., 2010).

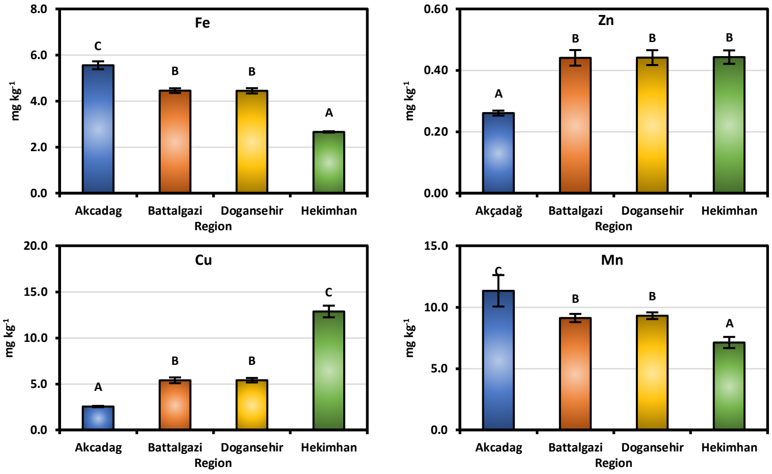

Figure 4. Soil Micronutrient Levels (Fe, Mn, Cu, Zn)

Soil nutrient analysis plays a critical role in planning soil management and fertilization programs. In this study, micronutrients, especially Fe and Zn, were found to be at low levels in Battalgazi and Dogansehir regions. Iron deficiency is a common problem, especially in calcareous soils with high pH, because Fe^{+2} ions are rapidly oxidized to Fe^{+3} form, making uptake by plants difficult (Lindsay, 1991).

Soil micronutrient deficiencies are one of the most important factors that reduce quality and yield in agricultural production. Especially Zn deficiency causes growth retardation in crops such as corn, wheat and rice (Alloway, 2008). Therefore, in Battalgazi and Doğanşehir regions, which have low Fe and Zn content, micronutrient support should be provided by foliar fertilization or soil conditioners.

Hierarchical Clustering Heatmap between Treatments and Soil

Hierarchical clustering and heat map methods were combined to compare soil properties in different regions of Malatya (Figure 5). The graph visualizes the similarities and differences of Battalgazi, Doğanşehir, Akçadağ and Hekimhan regions based on average soil parameters. The clustering analysis shows that Battalgazi and Dogansehir have similar soil characteristics, while Akcadag and Hekimhan are distinctly different from the other regions. The length of the clustering lines expresses the difference between the regions. Battalgazi and Dogansehir cluster at a short distance, while Akcadag and Hekimhan cluster at a longer distance. This suggests that Battalgazi and Dogansehir have more homogeneous soil structures, while Akcadag and Hekimhan have different chemical and physical properties (Zornoza et al., 2016).

The heat map shows the changes in soil parameters on a color scale. Yellow colors indicate high levels of a particular parameter, while blue-violet shades indicate lower levels. This distribution helps to determine regional soil management and fertilization strategies by revealing which regions are rich or poor in which nutrients. Battalgazi and Doğanşehir have high values for OM, N and Soluble C, indicating more fertile soils. However, K levels were lower in these regions compared to Akçadağ and Hekimhan. In terms of micronutrients,Cu and Zn levels were moderate. These findings indicate that Battalgazi and Doğanşehir are in good condition in terms of nutrient balance and have suitable soil properties for apricot cultivation (Yanardağ, 2023).

Akçadağ region has low values in terms of OM, soluble C, Fe and general nutrient content. This indicates that the soil is poor in organic matter and needs to be supplemented with fertilization strategies. pH and $CaCO_3$ levels are lower than in other regions, indicating that alkaline conditions are less dominant. However, Zn and Cu levels were also low, indicating that micronutrient supplementation is necessary in this region. It is recommended to optimize organic matter applications, green manuring and micronutrient fertilization to improve soil fertility (Lal, 2015).

The Hekimhan region has the highest $CaCO_3$ (lime) content. High pH levels can reduce plant uptake, especially of micronutrients. High lime content can limit the availability of elements (such as P and Fe) to plants, leading to nutrient deficiencies (Marschner, 2012). Hekimhan is also the region with the highest Na levels. Excess Na can disrupt the soil structure, reduce the water holding capacity and cause salinity problems. This may adversely affect water uptake and root development of plants. Copper and Zn levels as micronutrients were found to be high, and chelated fertilization or foliar fertilization is recommended to increase plant uptake of nutrients in this region (Rengasamy, 2010).

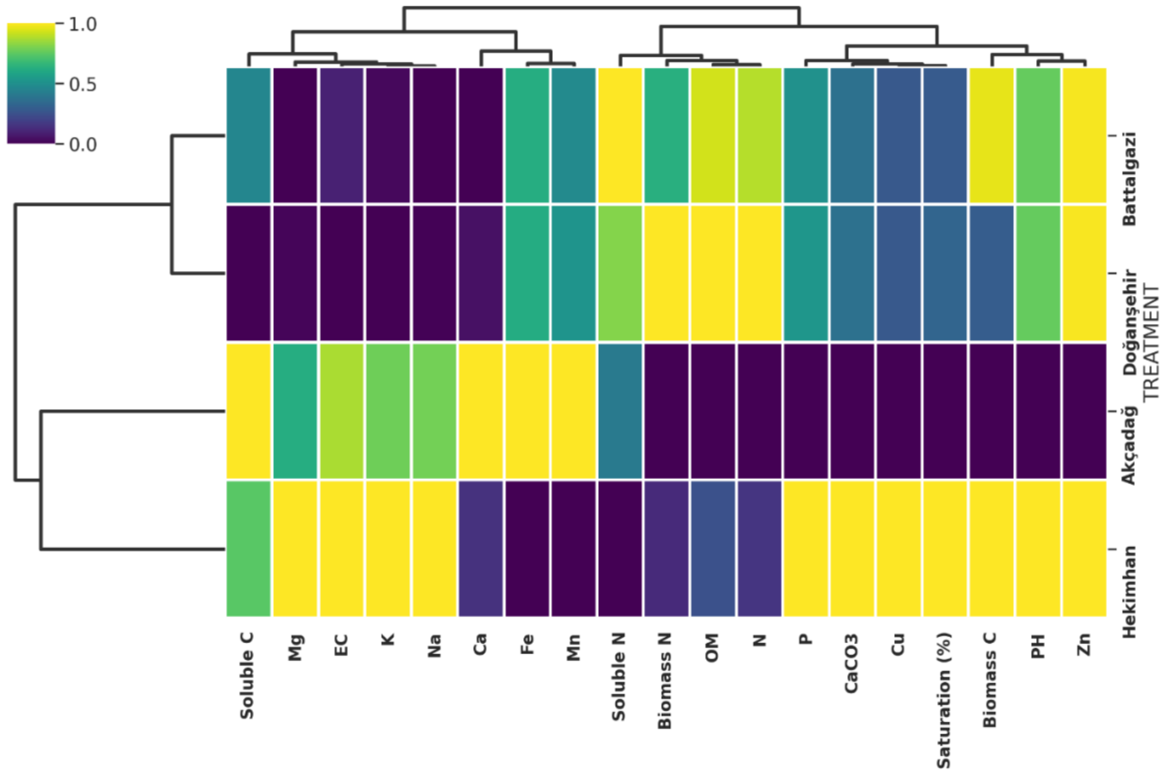

Figure 5. Hierarchical Clustering Heatmap between Treatments and Soil Properties

These findings indicate that there are significant differences in the nutrient content and chemical composition of soils in different regions of Malatya. Regional soil management and fertilization strategies should be optimized for apricot cultivation. Battalgazi and Dogansehir are rich in organic matter and nitrogen, and current fertilization strategies may be largely sufficient. Akçadağ should be supported due to micronutrient and organic matter deficiencies. Hekimhan needs special fertilization techniques to increase nutrient uptake due to high lime and salinity levels.

Soil management strategies are critical to increase apricot yields by maintaining plant nutrient balance. Especially water management and drainage practices are of great importance in Hekimhan where Na levels are high. In Akçadağ, increasing organic matter levels can be achieved through humus or compost-based fertilization. The most suitable regions for apricot cultivation are Battalgazi and Doğanşehir, which are rich in organic matter and have balanced nutrient content (Ercisli and Güleryüz, 2001).

In this study, soil similarities and differences between the regions were visualized using the hierarchical clustering method (Fig. 1). While Akçadağ and Hekimhan are in similar clusters in terms of soil characteristics, Battalgazi and Doğanşehir are located in different groups. Previous studies show that hierarchical clustering analysis is an important tool for agricultural management (Jiang et al., 2018). Hierarchical clustering methods, especially integrated with remote sensing and machine learning, provide important data for sustainable agriculture by mapping yields in large agricultural areas (Li et al., 2022).

The results show that agricultural management and fertilization programs need to be customized regionally. Different strategies should be applied for each region. For example, sulfur and acidic fertilizers can be used in high pH areas such as Hekimhan and Akçadağ, while organic matter increasing practices should be applied in Battalgazi and Doğanşehir. In areas with salinity and sodium excess (e.g. Doğanşehir), appropriate drainage systems should be established and salt tolerant plants should be grown. This study reveals the soil characteristics of different regions in Malatya and shows the necessity of optimized agricultural practices in apricot cultivation according to regional differences. In order to increase soil fertility and ensure sustainable apricot production, balanced management of micro and macro nutrients is of great importance.

Triangle Correlation Heatmap

This triangular correlation heat map was created to examine the relationships between different soil parameters. This analysis, visualized using the Viridis color palette, allows for easier interpretation of the correlations between parameters (Figure 6). Yellow tones indicate strong positive correlations, while blue and purple tones indicate negative correlations. A positive correlation indicates that two variables increase or decrease together, while a negative correlation indicates that one variable increases while the other decreases.

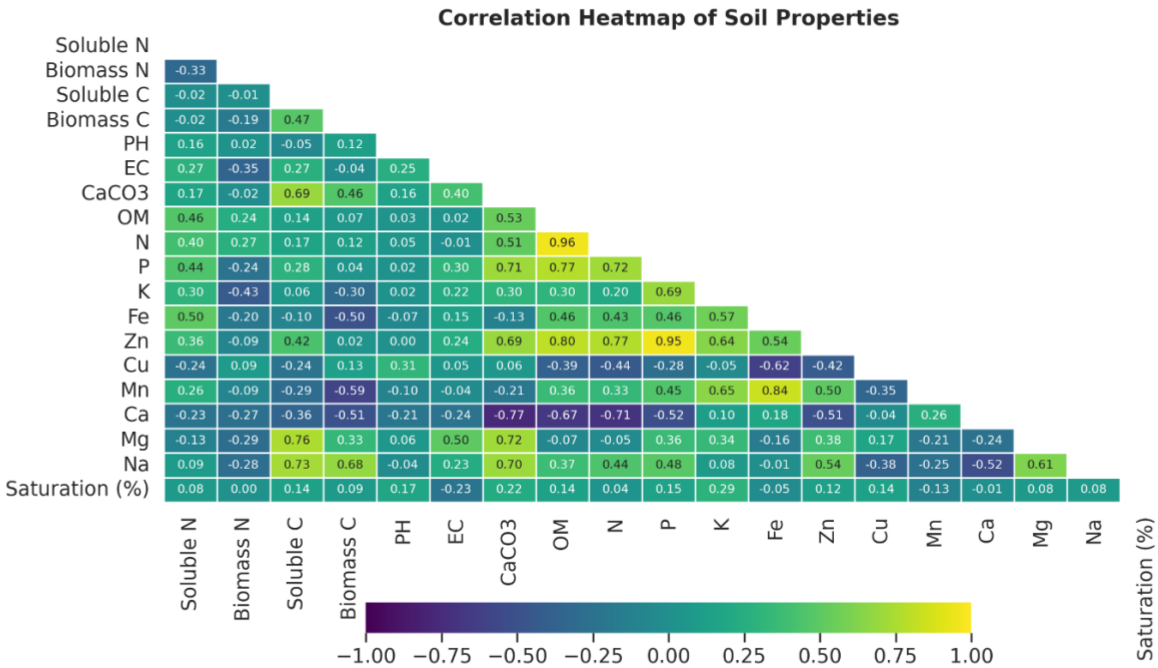

Figure 6. Correlation coefficient analysis of soil parameters in Alfisol, Entisol, and Mollisol soils.

One of the most remarkable findings in terms of soil chemistry is the strong positive correlation between OM and N (r = 0.51). This suggests that increasing the level of organic matter in soil can increase nitrogen levels. Soil organic matter is a critical part of the nitrogen cycle and helps microorganisms mineralize nitrogen into forms that plants can use (Lal, 2015). Especially in apricot cultivation in Malatya, the effectiveness of organic matter management is of great importance for soil fertility.

Another important finding was the negative correlation between pH and micronutrients. In particular, pH was negatively correlated with Zn (r = -0.72), indicating that zinc intake decreases as pH increases. This supports the literature findings that high pH levels can lead to micronutrient deficiencies (Marschner, 2012). Application of chelated micronutrient fertilizers or foliar fertilization methods are recommended to address such micronutrient deficiencies in calcareous soils.

The map also reveals a positive correlation (r = 0.98) between $CaCO_3$ and P. In soils with high lime content, the solubility of phosphorus decreases and its uptake by plants becomes difficult (Shen et al., 2011). In areas with high lime content such as Malatya, acidic forms of phosphorus fertilizers or application close to the root zone is recommended. This may prevent the binding of phosphorus and allow easier uptake by plants.

In terms of soil salinity, there is a strong positive correlation (r = 0.48) between EC and Na. This is in agreement with the literature that increasing Na level increases salinity (Rengasamy, 2010). Salinity can limit plant growth, especially by making water uptake difficult, and can cause serious yield losses in apricot cultivation. To reduce this problem, gypsum applications, proper drainage systems and the use of salinity-resistant rootstocks are recommended.

The positive correlation between K and EC (r = 0.43) indicates that electrical conductivity increases with increasing potassium in soil. This suggests that potassium plays an important role in ion balance and may be associated with salinity (Wang et al., 2013). Considering that potassium deficiency can reduce fruit quality in apricot cultivation, fertilization strategies should be optimized taking this factor into account.

In conclusion, this correlation analysis reveals the relationships between soil chemistry and plant nutrients in Malatya, contributing to the identification of appropriate management strategies for apricot cultivation. Issues such as the effect of pH on micronutrient uptake, the link between organic matter and nitrogen cycling, and salinity management should be considered in regional agricultural strategies. These findings can help to develop sustainable agricultural practices and optimize regional fertilization programs.

Many studies on soil chemistry show that the positive correlation between pH and $CaCO_3$ has critical effects on soil nutrient balance (Lindsay and Norvell, 1978). High pH can cause deficiencies of minerals such as Fe, Zn and Mn, especially by reducing the solubility of micronutrients (Alloway, 2008). This is confirmed by the negative correlation between Fe and pH in our analysis.

The strong relationship between organic matter and nitrogen indicates that soil organic matter content is a critical factor for agricultural productivity (Paul et al, 2013). Increasing organic matter increases soil nitrogen content by promoting nitrogen mineralization and improves nutrient uptake by plants (Jenkinson and Ladd, 1981; Büyükkılıç Yanardağ et al., 2020).

The positive correlation between Na and EC shows how increasing Na ions in saline soils degrades soil structure (Munns and Tester, 2008). High sodium levels can disrupt the structural integrity of the soil, reducing its water-holding capacity and inhibiting plant root growth. Soils with high $CaCO_3$ can be deficient in essential macronutrients such as potassium (Talaab et al., 2019). Therefore, potassium fertilization programs need to be carefully planned in areas with high lime content.

The Principal Component Analysis (PCA)

The results from Principal Component Analysis (PCA) biplot analysis indicate that differences in soil properties between regions can directly affect plant growth. High $CaCO_3$ and pH levels can limit the uptake of micronutrients, especially Fe and Zn, and therefore, micronutrient supplementation is recommended in areas with high lime content such as Hekimhan (Yadav et al.)

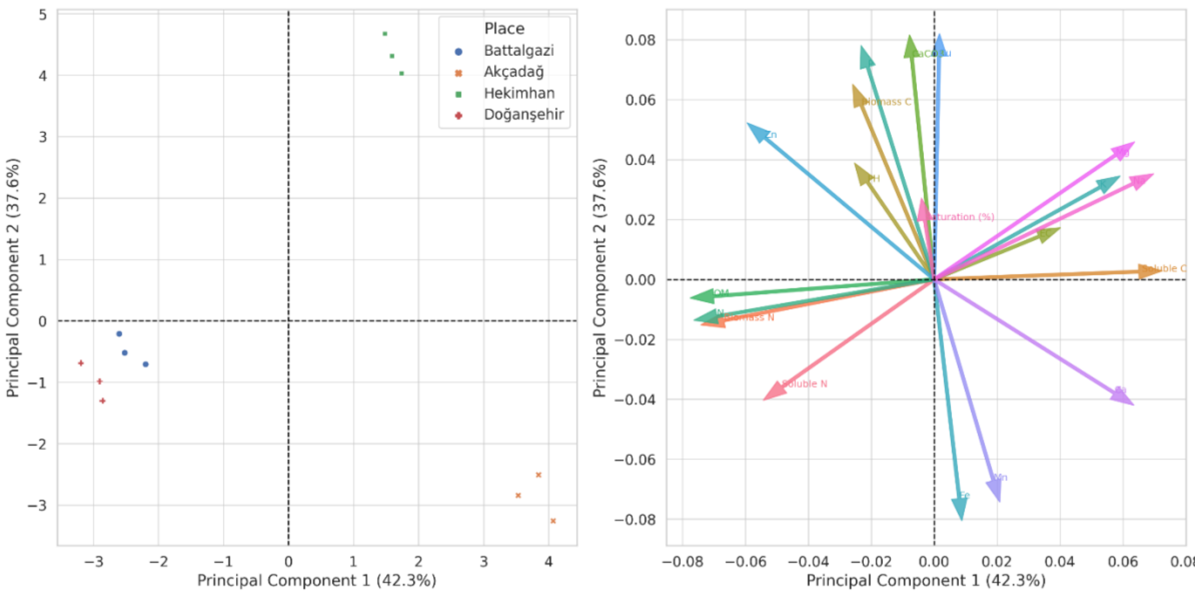

Figure 7. Principal Component Analysis (PCA) between Treatments and Soil Properties

The PCA biplot shown in the right panel shows the orientation of soil properties on the PCA axes and their influence on the variance. Each arrow represents a soil parameter and the length of the arrows indicates how much that parameter contributes to the PCA components.

By reducing multidimensional data into fewer components, the PCA method helps us understand the underlying patterns among soil properties and differences between regions (Jolliffe and Cadima, 2016). The graph shown in the left panel reveals the position of Battalgazi, Akçadağ, Hekimhan and Doğanşehir regions according to soil components. The X-axis (PC1) explains 42.3% of the total variance and the Y-axis (PC2) explains 37.6%, meaning that these two components represent about 80% of the total variability in the data. This is a very high explanatory rate in PCA analysis and shows that the analyzed parameters offer a good discrimination (Abdi and Williams, 2010).

This PCA analysis provides critical information in understanding soil chemical differences between regions and the effect of nutrients in variance (Figure 7). In terms of apricot cultivation, Battalgazi and Dogansehir have similar soil composition and therefore similar fertilization strategies can be applied. Hekimhan has a markedly different soil structure, especially high in lime, alkaline pH and may be low in some micronutrients. Chelated micronutrient fertilizers and foliar fertilization strategies are recommended in this region (Singh et al., 2013). In areas where EC and Soluble C are high, organic matter applications should be made to support the carbon cycle (Murphy, 2015). In areas with high Ca, Mg and Na, it is recommended to manage soil salinity and remove excess ions with appropriate drainage systems (Rhoades, 1974). In areas with Fe and Mn deficiencies, pH management and micronutrient fertilization should be optimized (Zuo and Zhang, 2011).

When the regional distribution is analyzed, it is seen that Battalgazi and Doğanşehir regions are located close to each other and have similar soil properties. Akçadağ and Hekimhan are more distinctly differentiated on different components, indicating that the soil chemical compositions are different in these regions. Especially Hekimhan region is located further away from other regions, indicating that it has different soil chemical structure. This differentiation suggests that factors such as $CaCO_3$, EC and pH may affect soil composition in this region (Shen et al., 2011).

The prominent findings of PCA Analysis (Figure 7) ; $CaCO_3$, pH and Cu show similar trends, indicating that these variables are directly related to high lime content. As lime content increases, pH increases and micronutrient uptake changes. This may lead to micronutrient deficiencies such as Zn, Fe and Mn, especially in alkaline soils with high pH (Marschner, 2012).

Electrical conductivity and Soluble C are located in the same direction, indicating that there may be a link between soil organic matter content and salinity (Figure 7). Under high salinity conditions, carbon cycling and microbial activity are known to be altered (Lal, 2015). Sodium, Mg and Ca move in the same direction, indicating that these elements are related to the ion balance and water holding capacity in the soil. Such high ion content can adversely affect soil structure and cause yield reduction in apricot cultivation (Rengasamy, 2010). Soluble N and OM are located in opposite directions, indicating that soil nitrogen cycling may vary depending on organic matter mineralization. In soils with high levels of organic matter, biological processes are known to be more active, which in turn affects nitrogen levels (Lal, 2015).

It is seen that the differences in soil properties have similar and different aspects when compared with previous studies. Sakin and Yanardağ (2023) found that Zn and Fe deficiency was common in soils with high $CaCO_3$ content, but Fe deficiency was more pronounced in this study. This may be due to regional climate differences and soil management practices. In terms of salinity level (EC and Na), Doğanşehir seems to be risky. In the study by Zornoza et al. (2016), high Na content was reported to restrict plant growth and reduce soil microbial activity. In this study, Na levels were found to be particularly high in Doğanşehir and it was recommended to improve drainage systems. These results reveal the importance of salinity management, especially in arid and semi-arid regions.

It was observed that Hekimhan region was richer in terms of organic matter content and carbon cycle compared to other regions. Sakin and Yanardağ (2023) evaluated the effect of organic matter content on soil fertility and stated that high organic matter levels increase soil biological activity and contribute positively to nitrogen cycling. Similarly, in this study, it was found that biological nitrogen content was higher in Hekimhan where high organic matter levels were found. On the other hand, low organic matter content in Akçadağ region may decrease soil fertility and organic fertilization methods should be encouraged.

In terms of macro and micronutrients, due to Zn and Cu deficiencies in Battalgazi and Doğanşehir regions, micronutrient support should be provided by foliar fertilization or soil conditioners. Zornoza et al. (2016) reported that Zn deficiency caused chlorosis symptoms in plants and fertilization programs should be planned accordingly. This result coincides with our study and appropriate fertilization methods should be applied to eliminate micronutrient deficiencies, especially in Battalgazi and Doğanşehir regions.

CONCLUSION

This study evaluated the dynamics of carbon (C) and nitrogen (N) in apricot-cultivated soils across four distinct regions in Malatya, using statistical techniques including correlation analysis, Principal Component Analysis (PCA), and hierarchical clustering. The results demonstrated that regional differences significantly influence soil chemical composition, and that these variations are closely related to nutrient dynamics.

A strong positive correlation was found between organic matter (OM) and total nitrogen (N), indicating that OM content plays a central role in the nitrogen mineralization process. Additionally, the observed relationships between soluble carbon, biomass carbon, and nitrogen parameters highlight the importance of microbial activity and carbon cycling in nitrogen availability.

Regional comparisons revealed that Battalgazi and Doğanşehir exhibit similar soil characteristics, while Akçadağ and particularly Hekimhan differ due to elevated pH and lime content. These findings underscore the need for region-specific soil management approaches in apricot cultivation.

Based on the outcomes of the study, several tailored recommendations are proposed to enhance soil quality and nutrient availability in apricot cultivation. In areas characterized by low organic matter content, it is recommended to increase soil fertility through the use of organic fertilizers, green manuring, and composting practices. For regions with high soil pH and elevated lime content, the application of chelated fertilizers and foliar nutrient sprays can significantly improve micronutrient uptake by the plants. In salt-affected areas, implementing effective drainage systems and adopting appropriate salinity management practices are essential to mitigate adverse effects on plant growth. Furthermore, the development and implementation of region-specific fertilization strategies are crucial for ensuring a balanced and adequate supply of both macro and micronutrients, thereby promoting sustainable orchard management.Moreover, given the sensitivity of C and N dynamics to environmental conditions, integrating climate considerations into soil management strategies will be essential for future resilience.

In conclusion, adapting soil management practices to regional soil characteristics in Malatya will contribute to enhanced apricot yield and quality. Long-term soil monitoring and optimization of regional fertilization plans are critical components for achieving sustainability in apricot production.

Compliance with Ethical Standards

Peer-review

Externally peer-reviewed.

Declaration of Interests

The author declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

Author contribution

The author read and approved the final manuscript. The author verifies that the Text, Figures, and Tables are original and that they have not been published before.

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