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Research Article/Araştırma Makalesi

# Evaluation of Malatya province soils for apricot cultivation

## *Malatya ili topraklarının kayısı yetiştiriciliği bakımından değerlendirilmesi*

**İbrahim Halil YANARDAĞ[1*]**

[1]Malatya Turgut Özal Üniversitesi, Ziraat Fakültesi, Toprak Bilimi ve Bitki Besleme Bölümü, 44210 Battalgazi, Malatya, Türkiye.

[1] https://orcid.org/0000-0003-2558-9600

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****Address for Correspondence:***
*İbrahim Halil YANARDAĞ*
***e-mail:***
ibrahim.yanardag@ozal.edu.tr

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**ABSTRACT**

Malatya is the world's leading region in terms of dried apricot production. Understanding the optimal soil conditions for apricot growth is crucial for enhancing production. This study evaluated the soil fertility status of apricot orchards in Malatya province by analyzing key physicochemical soil properties and mapping their spatial variability using Geographic Information Systems (GIS). Malatya soils generally have high lime content (26.79%), neutral to slightly alkaline pH (7.25–8.13), high levels of Ca (5534.40 mg kg$^{-1}$) and K (633.25 mg kg$^{-1}$), moderate Fe (3.26 mg kg$^{-1}$), and low levels of organic matter, Zn (0.48 mg kg$^{-1}$), Mn (5.72 mg kg$^{-1}$), and B (0.33 mg kg$^{-1}$). While high levels of Ca and K improve fruit flavor, aroma, vitamin, and mineral content, limited availability of micronutrients restricts yield. Therefore, reducing soil pH with sulfur or acidic materials, improving soil properties by organic matter addition, and supplementing deficient micronutrients with foliar or soil applications are important for sustainable apricot production and yield improvement.

**Key Words:** Apricot, soil properties, nutrient elements, sustainable cultivation

**ÖZ**

Malatya, kuru kayısı yetiştiriciliğinde dünyanın önde gelen bölgesidir. Kayısı yetiştiriciliği için en uygun toprak koşullarının anlaşılması, üretimin artırılması için çok önemlidir. Bu çalışma, temel fizikokimyasal toprak özelliklerini analiz ederek ve Coğrafi Bilgi Sistemleri (CBS) kullanarak mekansal değişkenliklerini haritalayarak Malatya ilindeki kayısı bahçelerinin toprak verimlilik durumunu değerlendirmeyi amaçlamaktadır. Çalışma verilerine göre, Malatya toprakları genel olarak yüksek kireç içeriği (%26,79), nötr ile hafif alkali pH (7,25-8,13), yüksek Ca (5534,40 mg kg$^{-1}$) ve K (633,25 mg kg$^{-1}$), orta düzeyde Fe (3,26 mg kg$^{-1}$) ve düşük organik madde, Zn (0,48 mg kg$^{-1}$), Mn (5,72 mg kg$^{-1}$) ve B (0,33 mg kg$^{-1}$) seviyelerine sahiptir. Yüksek Ca ve K seviyeleri meyve tadını, aromasını, vitamin ve mineral içeriğini artırırken, mikro besin maddelerinin sınırlı bulunabilirliği kayısı verimini kısıtlamaktadır. Bu nedenle, kükürt veya asit karakterli materyaller uygulanarak toprak pH'sının düşürülmesi, organik madde ilavesiyle toprak özelliklerinin iyileştirilmesi ve yapraktan veya topraktan uygulamalar yoluyla eksik mikro besin maddelerinin takviye edilmesi, sürdürülebilir kayısı yetiştiriciliği ve verim artışı için çok önemlidir.

**Anahtar Kelimeler:** Kayısı, toprak özellikleri, besin elementleri, sürdürülebilir yetiştiricilik

## Introduction

The economic and technological advancement era has highlighted the need for sustainable and environmentally friendly soil management to optimize productivity per unit area because of the increasing consumption of agricultural inputs. Cultivating the most suitable crops is essential based on key parameters such as physical, chemical, and biological soil properties, topography, climate, and altitude. Identifying soil variability and preserving soil health is crucial for managing natural resources (Demir et al., 2019). Soil water cycles and soil organic matter (SOM) retention in terrestrial ecosystems have been subjects of significant research because of their beneficial impacts on climate change and ecosystems (Gwak & Kim, 2017).

Plants require different types of nutrients, which can be classified into macronutrients and micronutrients. These include nitrogen (N), phosphorus (P), potassium (K), calcium (Ca), zinc (Zn), iron (Fe), boron (B), sulfur (S), and magnesium (Mg), etc. Taha and Sherif (2015) found that Ca, Zn, B, and amino acids play a significant role in flowering, and fruit setting and development, leading to increased yield and quality. Clay-textured soils contribute to improved fruit set, yield, leaf chlorophyll content, increased Ca, Zn, and B contents, and higher total soluble solids (TSS) in fruits. Soil pH is a vital factor influencing nutrient availability, either enhancing or restricting nutrient uptake. Lower pH reduces the availability of secondary macronutrients, while higher pH limits the presence of micronutrients. Moreover, maintaining an optimum pH is essential for the successful application of herbicides, organic and inorganic fertilizers, consequently maximizing plant benefits (Toor et al., 2021).

Apricot (Prunus armeniaca L.) belongs to the Rosaceae family. Originating from Central and Western China, apricots have been consumed over 5,000 years and cultivated commercially for over 3,500 years (Manolopoulou & Mallidis, 1997; Karataş, 2021). Apricots have various uses as they can be consumed fresh as well as a significant portion is preserved by drying (Faust et al., 1998). Apricots play an important role in human nutrition due to their rich contents of sugar, organic acids, anthocyanins, phenolics, carotenoids, flavonoids, dietary fiber, minerals, and vitamins, making them a functional food beneficial for consumer health and disease prevention (Leccese et al., 2008; 2012; Milošević et al., 2013). Apricot flowering occurs before leaf development and relies on reserves accumulated from the previous season. Flowering phase often last one to two weeks, during which pollination and fruit development occur (Julian et al., 2010).

Turkey remains the world's leading apricot producer despite a decrease in production compared to previous years (Table 1). Turkey produced 750,000 tons of aprciots during 2023 which was highest in the world. However, the production was lesser than 833,000 tons apricots produced during 2020 in the country. The area under cultivation (144,941 hectares) increase from previous years, indicating continued investment in apricot orchards.

Table 1. Global apricot production, cultivation area, and yield by country in 2023.

| Rank | Country | Production (tons) | Rank | Country | Cultivation Area (ha) | Rank | Country | Yield (kg $ha^{-1}$) |
|---|---|---|---|---|---|---|---|---|
| 1 | Türkiye | 750000 | 1 | Türkiye | 144941 | 1 | Albania | 15751 |
| 2 | Uzbekistan | 500545 | 2 | Iran | 56137 | 2 | USA | 13519 |
| 3 | Iran | 318475 | 3 | Uzbekistan | 42936 | 3 | Egypt | 13485 |
| 4 | Italy | 207190 | 4 | Algeria | 28965 | 4 | Jordan | 13338 |
| 5 | Algeria | 200566 | 5 | Afghanistan | 22008 | 5 | Turkmenistan | 12426 |
| 6 | Afghanistan | 155429 | 6 | China | 21209 | 6 | Romania | 12093 |
| 7 | Pakistan | 135062 | 7 | China, mainland | 18046 | 7 | Italy | 11934 |
| 8 | France | 127780 | 8 | Spain | 18010 | 8 | Uzbekistan | 11658 |
| 9 | Armenia | 114494 | 9 | Italy | 17360 | 9 | Argentina | 11564 |
| 10 | Spain | 108450 | 10 | Pakistan | 13830 | 41 | Türkiye | 5174.5 |

Source: FAOSTAT, 2025

Turkey, with a yield of 5,174.5 kg $ha^{-1}$, ranks 41st globally, demonstrating that while it is the largest producer of apricots, its per hectare productivity is significantly lower to that of other countries, such Albania (15,751 kg $ha^{-1}$) and the USA (13,519 kg $ha^{-1}$). Although Turkey is the leading producer, its per hectare yield is significantly lower than several countries, highlighting the need for improvements in soil management practices, organic matter improvement, and micronutrient supplementation to improve yields on sustainable basis.

Spatial mapping and geographic information systems (GIS) in soil fertility assessments are essential tools increasingly being used to optimize agricultural production. These methods visualize the regional variability of soil properties in agricultural areas, enabling farmers and researchers to make more informed decisions (Kılıç et al., 2021). Determining spatial distribution of nutrients is essential for effectively planning fertilization programs and enhancing yield of soil quality-sensitive crops like apricot (Demir et al., 2019). The GIS-based analyses help to develop soil management strategies specific to apricot agriculture by determining the regional distribution of factors such as pH, organic matter, macro- and micronutrients. This study was aimed at enhance the efficiency and sustainability of apricot agriculture by spatial mapping of soil characteristics in Malatya province.

This study used a Geographic Coordinate System (GCS) based on WGS84 for the initial data collection to ensure compatibility with GPS-acquired soil sample locations. The data were converted into a Projected Coordinate System (PCS) using the Universal Transverse Mercator (UTM) projection to reduce distortions in distance and area computations for spatial mapping and interpolation. The use of a PCS ensures improved precision in geographical analysis, interpolation, and visualization, especially in large-scale agricultural evaluations (Snyder, 1987).

The physical and chemical characteristics of agricultural soils play a critical role in productivity and quality of crops. Apricot cultivation is directly affected by soil fertility, pH balance, organic matter content and nutrients (Karlıdağ et al., 2019). Malatya province is one of the most important apricot production centers in Turkey. It has high quality and yield potential due to its soil and climate conditions (Asma and Kan, 2007).

However, studies have revealed that apricot orchard soils in Malatya are deficient in some nutrients. Akın and Aygül (2022) analyzed 579 apricot orchard soils in Malatya and reported that 88.9% of the soils were slightly alkaline and 10.9% were neutral; thus, high pH limited the uptake of micronutrients. In the same study, it was emphasized that organic matter content was low in 93.8% of the soils, and iron (36.4%), zinc (46.1%) and manganese (91.7%) deficiencies were prevalent.

Existing literature shows that high lime content ($CaCO_3$) reduces the availability of micronutrients, and chlorosis is observed in apricot trees, especially due to Fe deficiency (Mengel & Kirkby, 1982; Udo et al., 1970). Akın and Aygül (2022) emphasized the importance of foliar Fe fertilization applications and organic matter addition to overcome this problem.

This study offers an extensive investigation of the chemical and physical characteristics of Malatya's soils concerning apricot cultivation, with the objective of assessing soil fertility in depth, identifying current macro- and micronutrient levels, and formulating effective soil management strategies. This study geographically maps nutrient availability across districts and provides region-specific suggestions to improve productivity and promote sustainable apricot cultivation, differing from previous studies.

## Materials and Methods

Soil sampling was conducted between 2021 and 2022 across multiple districts in Malatya province, covering diverse ecological and agronomic conditions. A total of 30 soil samples were collected from different apricot orchards, ensuring spatial representation across the study area.

At each sampling location, three replicate samples were taken at a depth of 0-30 cm, following standard soil sampling protocols (Jackson, 1958). These samples taken within a 2-meter radius were later homogenized to form a composite sample, minimizing small-scale variability and enhancing statistical robustness. The selection of sampling points was based on the spatial distribution criteria. Sampling locations were systematically distributed across Akçadağ (Bölüklü (38°15'42.09"N 37°55'12.76"E), Ören (38°14'45.23"N 37°56'0.33"E)), Yeşilyurt (Bindal (38°25'14.92"N 38°10'33.59"E)), Battalgazi (Karahan (38°24'56.66"N 38°22'42.27")), Kuluncak ( Karaçayır (38°52'17.85"N 37°44'52.30"E), Alvar (38°54'28.47"N 37°37'19.36"E), Çayköy (38°50'57.19"N 37°38'59.33"E), and Sofular (38°56'23.43"N 37°33'23.67"E)), Hekimhan (Kurşunlu (38°37'50.04"N 37°51'55.66"E)), and Yazıhan Dedekargın (38°28'50.49"N 38°19'48.41"E)) to ensure comprehensive coverage of the region.

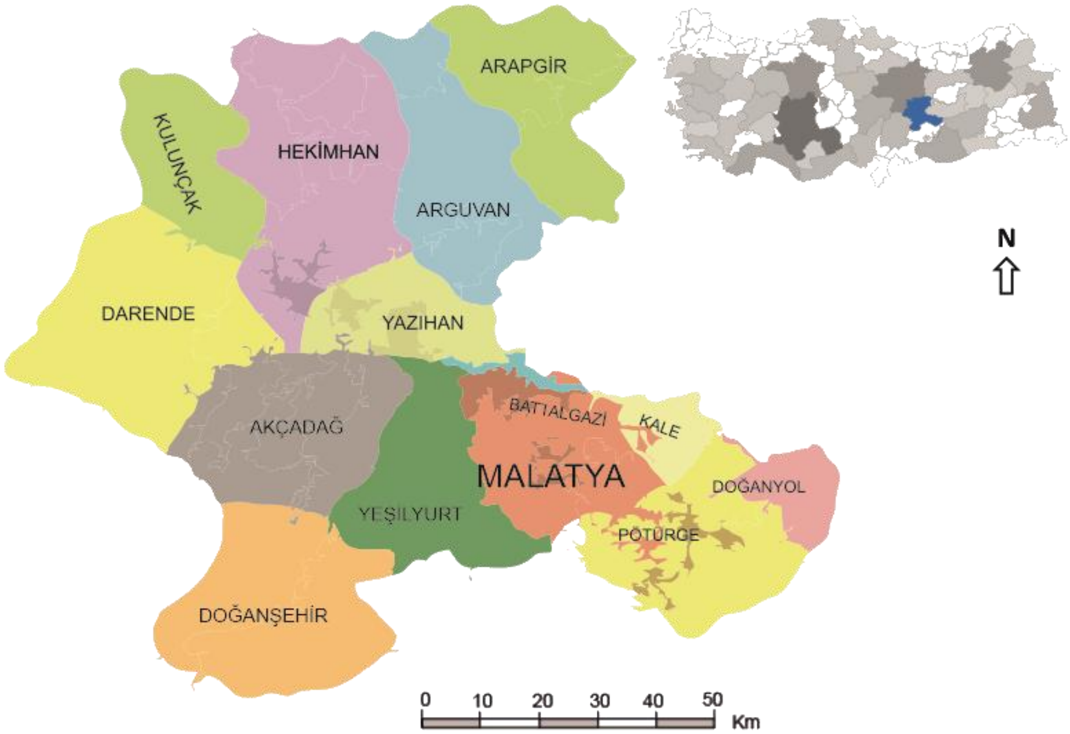


Figure 1. Map of Malatya province

Malatya province spans an area of 12,313 km$^2$, situated between 35° 54' and 39° 03' north latitude and 38° 45' and 39° 08' east longitude (Figure 1). Located in the Upper Euphrates region of Eastern Anatolia, Malatya does not fully exhibit the typical continental climate that prevails in many parts of the region. Instead, it experiences a transition between a subtropical and continental climate, making it a distinct microclimatic zone.

Table 2. Malatya climate data (Meteorology General Directorate, 2025

| Month | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec | Annual |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Temperature (°C) | -0.2 | 1.6 | 6.8 | 13 | 18 | 23.1 | 27.1 | 27.1 | 22.5 | 15.6 | 8 | 2.2 | 13.7 |
| Highest Temperature (°C) | 3.2 | 5.6 | 11.7 | 18.5 | 24 | 29.7 | 34 | 34 | 29.2 | 21.4 | 12.6 | 5.6 | 19.1 |
| Lowest Temperature (°C) | -3.2 | -2 | 2.3 | 7.6 | 11.9 | 16.3 | 19.9 | 20 | 15.6 | 10 | 4 | -0.7 | 8.5 |
| Precipitation (mm) | 42.4 | 41.1 | 48.8 | 55 | 45.6 | 17.4 | 3.9 | 3.5 | 8.1 | 35.7 | 41.7 | 40.4 | 383.6 |

The annual average number of cloudy days is 77 days in the province. Additionally, the province experiences 152 days of partly cloudy weather and 136 days of clear skies per year. The average number of foggy days is 13 per year, mostly occurring in December and January. Cloudy days are primarily observed during the winter and spring months.

Long-term climate data for the province, recorded between 1929 and 2024, is presented in Table 2. According to MGM (2025) data, the highest average temperature is recorded in July at 34.0°C, while the lowest average temperature occurs in January at -3.2°C.

*Soil Analyses*

Soil samples were collected from 0–30 cm depth, with three replications per location. Soil samples were collected to ensure a homogeneous representation of the study area. In the laboratory, the samples were air-dried, sieved through a 2 mm mesh, and prepared for analysis. Soil pH was measured using the Peech method (1965) (1:25 w/v), while electrical conductivity (EC) was determined in deionized water following the Bower and Wilcox method (1965) (1:5 w/v). Exchangeable cations were analyzed using $CH_3COONH_4$ (Ammonium Acetate, pH 7.0) according to Knudsen et al. (1982). Organic carbon content was determined using the wet oxidation method with potassium dichromate (Nelson & Sommers, 1982). Total nitrogen (N) was measured using the Kjeldahl method (Mulvaney & Page, 1982), while plant-available metals (Fe, Cu, Mn, Zn) were extracted using DTPA and analyzed via Atomic Absorption Spectroscopy (AAS) (Pueyo et al., 2004). Available phosphorus (P) was determined through $NaHCO_3$ extraction and spectrophotometric analysis (Olsen & Dean, 1965). Plant-available boron (B) was extracted with 0.01 M mannitol + $CaCl_2$, and its concentration was determined based on the color intensity of the complex formed with carmine (anthraquinone dye) (Hatcher & Wilcox, 1950).

*Soil Property Mapping*

The analyzed soil properties were mapped using ArcGIS 10.8 (Figure 2). During the mapping process, the analyzed parameters were first matched with district-specific coordinate data and integrated into a spatial database. In this study, we used a PCS for spatial mapping and interpolation. Specifically, we employed UTM coordinate system, Zone 37N, based on the WGS84 datum. Ordinary Kriging was used for the soil parameters because it accounts for spatial autocorrelation, making it suitable for soil properties that exhibit a strong regional trend (Goovaerts, 1997). This method was chosen based on their effectiveness in modeling different soil properties and their proven application in agricultural soil mapping studies.

Ordinary Kriging is a geostatistical interpolation method that works with spatial data and is defined as BLUE (Best Linear Unbiased Estimator). This method provides a "best" (minimum error variance), "linear" (uses weighted linear combinations of available data) and "unbiased" (mean error equal to zero) estimate. The basic principle of Ordinary Kriging is to estimate the value of a regionalized variable (*Zs* 0) at a location to be estimated (1) (Mesic Kis, 2016):

$$Z(s_0) = \sum_{\{i=1\}}^{n} \lambda_i Z(s_i) \tag{1}$$

(Webster & Oliver, 2007)

λi : Weight coefficients,

$Z(s_i)$: Observations at available data points,

$n$: The number of data points used.

These weights, the no bias condition (2) and the Minimum Variance Condition (3) are determined to satisfy the following conditions (Journel & Huijbregts, 1978) :

$$\sum_{\{i=1\}}^{n} \lambda_i = 1 \tag{2}$$

$$min\, VAR\left[\, Z(s_0) - \sum_{\{i=1\}}^{n} \lambda_i Z(s_i)\right] \tag{3}$$

To find the weights, the equation in matrix form in equation 3 is used (Malvić & Balić, 2009) :

$$\begin{bmatrix} \gamma(s_1,s_1) & \gamma(s_1,s_2) & \cdots & \gamma(s_1,s_n) & 1 \\ \gamma(s_2,s_1) & \gamma(s_2,s_2) & \cdots & \gamma(s_2,s_n) & 1 \\ \vdots & \vdots & \ddots & \vdots & \vdots \\ \gamma(s_n,s_1) & \gamma(s_n,s_2) & \cdots & \gamma(s_n,s_n) & 1 \\ 1 & 1 & \cdots & 1 & 0 \end{bmatrix} \cdot \begin{bmatrix} \lambda_1 \\ \lambda_2 \\ \vdots \\ \lambda_n \mu \end{bmatrix} = \begin{bmatrix} \gamma(s_1,s_0) \\ \gamma(s_2,s_0) \\ \vdots \\ \gamma(s_n,s_0) 1 \end{bmatrix} \tag{3}$$

here:

- $\gamma(s_i,s_j)$: refers to the semivariogram value between points $s_i$ and $s_j$,
- μ: Lagrange multiplier.
- *Statistical Analysis*

- To assess the differences in soil properties, data were analyzed using one-way analysis of variance (ANOVA). A p-value of <0.05 was considered statistically significant, and Tukey's test was applied for multiple comparisons. Relationships among the investigated properties were examined using Pearson correlation and linear regression analyses. All statistical analyses were conducted using SPSS software (version 26.0, IBM Corp., Armonk, NY, USA).
- Hierarchical clustering analysis (HCA) was performed to determine the similarities among the soil properties of Malatya's districts. All analyses were carried out using Python's Pandas, NumPy, Seaborn, and SciPy libraries. Additionally, data normalization and statistical tests were conducted using SPSS and Python-supported analyses. The relationships between soil properties were assessed through Pearson correlation analysis, and the silhouette score was calculated to evaluate clustering accuracy.

## Results and Discussion

### *Soil pH and Soil Salinity*

Soil pH plays a crucial role in nutrient uptake and directly affects the availability of essential elements. The analysis of Malatya's soils revealed that pH levels were generally neutral to slightly alkaline, though some areas exhibited pH values >8. Elevated pH levels significantly reduce the solubility of micronutrients such as Zn and Fe, making them less available for plant uptake. This deficiency is a common issue in apricot orchards and can lead to reduced fruit quality and yield.

Globally, low soil pH is recognized as a major factor contributing to crop yield losses. Milosevic et al. (2010) identified excessively dry, shallow, sandy-loam, and acidic soils as the most limiting edaphic factors for apricot cultivation. In this study, the average soil pH was 7.78, indicating a slightly alkaline nature. The lowest pH (7.25) was recorded in Arguvan, while the highest (8.13) was observed in Kuluncak (Figure 2). While slightly alkaline soils can be beneficial for apricot growth, excessively high pH levels restrict the availability of essential nutrients, particularly micronutrients.

Soil pH directly affects the solubility of nutrients in the soil solution, which determines how easily plants can absorb them. The optimum pH range for most crops is 6.0-7.5. Outside this range, particularly above pH 7.5, the availability of Fe, Zn, and Mn decreases, making nutrient uptake more difficult.

Apricot is one of the fruit crops that is highly sensitive to salinity. According to Maas and Grattan (1999), the threshold soil salinity level for apricot yield reduction is 1.6 dS $m^{-1}$. Beyond this threshold, increased salinity levels lead to progressive yield losses.

However, the results of this study indicate that the average soil salinity in Malatya is 0.16%, which is classified as non-saline. The lowest salinity level (0.01%) was recorded in Doğanyol district, while the highest salinity level (0.44%) was observed in Darende district. These results suggest that soil salinity is not a significant limiting factor for apricot cultivation in Malatya.

The analysis showed that the average total lime content was 22.91%, with the lowest values recorded in Arguvan (1.26%), Kale (2.91%), Doğanşehir (3.24%), and Doğanyol (3.76%) (Figure 2). The highest lime content was found in Darende (51.19%), indicating that lime management is crucial for improving nutrient uptake in apricot orchards.

### *Lime and Organic Matter content*

High calcium carbonate ($CaCO_3$) content contributes to increased soil pH, leading to alkaline soil conditions. One of the most common consequences of high lime levels is iron deficiency-induced chlorosis, which manifests itself as leaf yellowing of leaves and stunted plant growth. In calcareous soils, reducing pH or applying chelated iron fertilizers is recommended to increase Fe availability.

Soil organic matter is essential for improving soil structure, water retention, and nutrient availability. The soils of Malatya had a low content of organic matter, which has a negative impact on soil health, nutrient retention, and water infiltration. A lack of organic matter leads to weaker soil structure, faster water drainage, and increased nutrient loss, all of which can negatively impact apricot growth and yield.

The analysis revealed that the average organic matter content was 1.59%, with the lowest level recorded in Doğanyol (0.61%) and the highest in Hekimhan (2.61%) (Figure 2). To improve soil fertility, it is essential to incorporate organic amendments such as green manure, compost, and organic fertilizers into the soil.

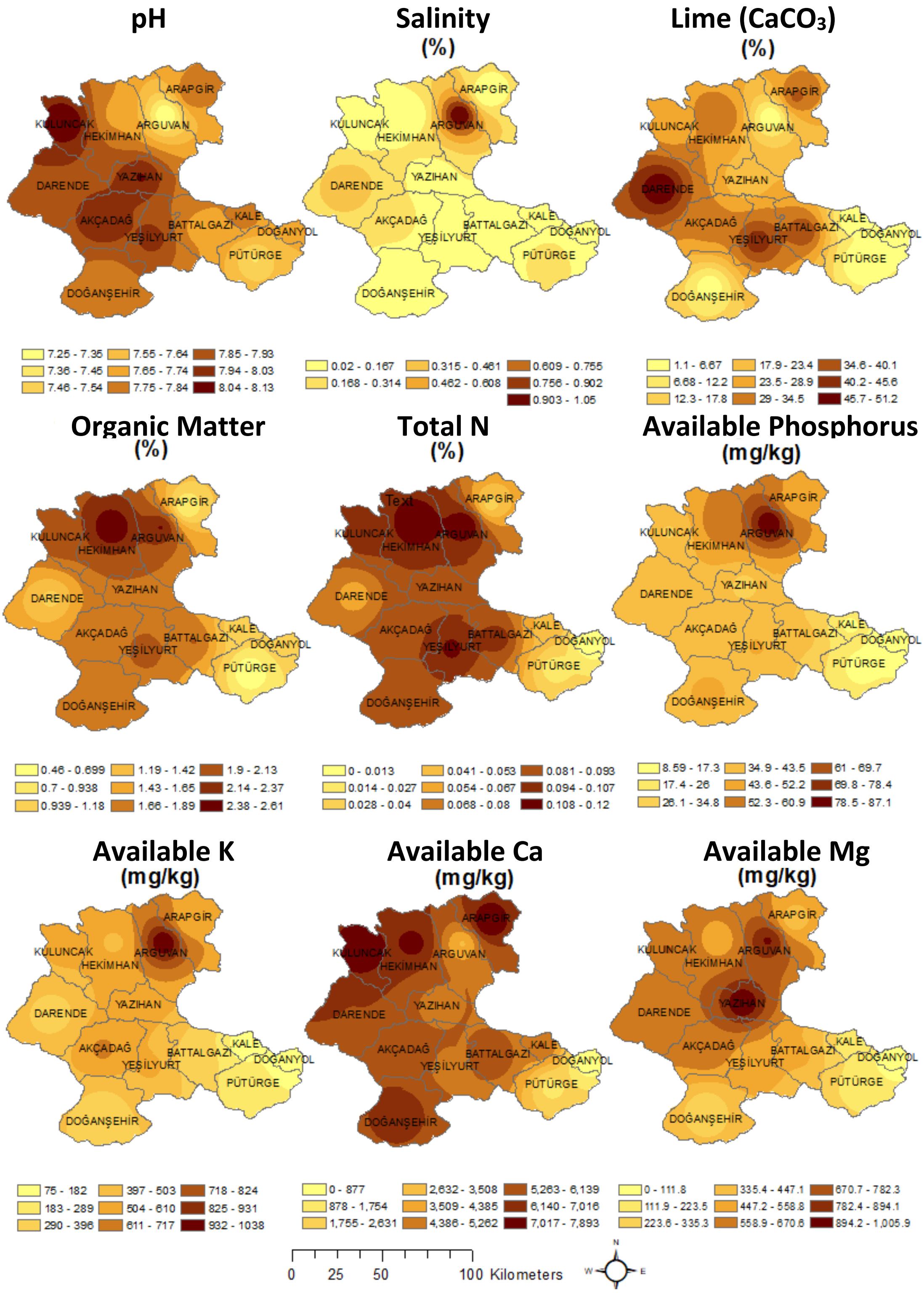

Figure 2. Some soil chemical properties and macronutrients of Malatya province soils

*Soil pH Management and Fertilization Strategies*

Effective soil pH management is key to optimizing nutrient availability and improving plant health and productivity. In high pH soils, nutrient uptake is limited and requires targeted interventions to maintain balanced soil conditions.

Lowering high soil pH: The application of elemental sulfur or organic matter amendments can help reduce soil alkalinity and improve nutrient availability. Regular soil testing: Conducting routine soil analysis allows for the development of site-specific fertilization programs that address nutrient deficiencies. Chelated micronutrient applications: In alkaline soils, the use of chelated Fe, Zn, and Mn fertilizers can significantly improve plant nutrient uptake. High soil pH and excessive lime content can negatively affect plant nutrient uptake, ultimately leading to yield and quality losses. Therefore, implementation of soil amendments, targeted fertilization strategies, and regular soil monitoring are essential to ensure sustainable apricot production in Malatya.

*Macronutrients*

Nitrogen is essential for plant growth, development, and flower formation. Its deficiency reduces flower production and negatively affects fruit yield (Karlıdağ et al., 2017). Additionally, nitrogen significantly influences dehydrogenase and urease activities, which are key indicators of total microbial activity in soil (Dick, 1994).

In this study, the average total nitrogen content was 0.08%, with the lowest values (0.02%) recorded in Doğanyol and Pütürge, while the highest (0.12%) was found in Hekimhan and Arguvan (Figure 2). According to Bussi et al. (2003), high nitrogen fertilization enhances vegetative growth, yield, and average fruit weight, while increasing K fertilization improves soluble solids and fruit color. However, Maas and Grattan (1999) reported that excessive nitrogen applications can promote excessive vegetative growth, leading to shading, poor fruit color, and reduced sugar accumulation. Similarly, Radi et al. (2003) found that optimum nitrogen levels were the most influential factor in improving fruit quality. Additionally, Bussi and Smith (1998) noted that increasing nitrogen fertilization increases the nitrogen content of the fruit while decreasing the Ca concentration, which may affect fruit firmness and shelf-life.

Phosphorus plays a vital role in plant metabolism and energy transfer processes, as it is a key element in the nitrogen cycle, nitrate uptake, amino acid conversion, and protein synthesis during photosynthesis (Marschner, 1995). It also facilitates protein transfer to seeds during flowering and seed maturation through ATP-driven mechanisms. The average available phosphorus content was 37.68 mg $kg^{-1}$, with the lowest value (7.26 mg $kg^{-1}$) recorded in Pütürge and the highest (87.15 mg $kg^{-1}$) in Arguvan. The differences between the regions are probably due to differences in fertilization practices and the phosphorus content of the parent soil materials.

Potassium is considered a quality factor in plants, as it contributes to growth and high agricultural yields (Usherwood, 1985). It is essential to produce ATP, which supports transpiration, photosynthesis, and general metabolic processes. Potassium plays a vital role in stimulating photosynthesis, improving oil, starch, protein, and vitamin synthesis, and enhancing fruit quality (Nitin et al., 2017). In this study, potassium availability in Malatya soils was generally high, with an average of 439.25 mg $kg^{-1}$. The lowest value (117 mg $kg^{-1}$) was found in Kale, while the highest (1,038 mg $kg^{-1}$) was found in Arguvan. The high potassium content of Malatya's soils explains why apricots grown in the region are superior in flavor, aroma, mineral content, and vitamins compared to apricots from other regions.

Calcium is the most abundant alkali earth metal in the Earth's crust, comprising 2.94% of the upper continental crust. Calcareous or $Ca^{2+}$-rich soils cover over 30% of the Earth's surface, while basic soils account for at least 12% of global soil resources (Bertrand et al., 2007; Rowley et al., 2018). One of the best-known function of Ca in plants is stabilize cell membranes and maintain cellular integrity (Kirkby & Pilbeam, 1984). In addition, calcium has been shown to inhibit pathogen activity in jujube fruits (Guo et al., 2016). Due to the cross-linking between $Ca^{2+}$ and carboxyl groups in pectin, calcium is widely used to extend the shelf life of apricots by preventing cell wall degradation (Liu et al., 2017). In this study, the average available Ca content was 5,127.04 mg $kg^{-1}$. The lowest value (75 mg $kg^{-1}$) was recorded in Doğanyol, while the highest (7,893 mg $kg^{-1}$) was found in Arapgir.

Magnesium is involved in many physiological and biochemical processes that are essential for plant growth and development. It plays a key role in plant defense mechanisms against abiotic stress and is most widely known as the central atom in the chlorophyll molecule, which is essential for photosynthetic carbon fixation (Şenbayram et al., 2015). The average available magnesium content was 490.20 mg $kg^{-1}$, with the lowest value (122 mg $kg^{-1}$) in Doğanyol and the highest value (1,006 mg $kg^{-1}$) in Yazıhan. This variation suggests that soil amendments may be necessary in certain regions to ensure optimal magnesium availability for plant growth.

*Micronutrients*

Micronutrients are essential for plant growth and metabolic processes. Soil analyses in Malatya have shown variations in micronutrient levels, particularly in elements such as Zn, Mn, B, Cu, and Fe, which play a critical role in apricot cultivation (Figure 3). Deficiencies in these micronutrients can result in poor tree growth, reduced fruit set, and poor fruit quality in apricots. This section examines micronutrient deficiencies, their relationship to soil pH, and their effect on apricot fruit production.

Zinc is required for enzymatic reactions, metabolic processes, and redox reactions in plants, animals, and humans. It is essential for nitrogen metabolism, energy transfer, and protein synthesis by activating various enzymes (Hafeez et al., 2013). Increased soil pH promotes Zn adsorption onto soil components (e.g., clay minerals and metal oxides), significantly reducing its availability. The soluble Zn content in soil solution decreases by 30 to 45 times for each unit increase in soil pH (Gupta et al., 2016; Gondal et al., 2021). In Malatya, critical Zn deficiencies were detected in Kale (0.17 mg $kg^{-1}$) and Battalgazi (0.82 mg $kg^{-1}$) (Figure 3). Due to high soil pH and lime content, the solubility of Zn decreases, making it difficult for plants to absorb. Zinc deficiency in apricot trees causes stunted growth, bronzing of leaves, and small leaf formation (Alloway, 2008). Moreover, Zn deficiency reduces fruit size, delays fruit ripening, and lowers fruit sugar content, affecting overall fruit quality and marketability (Erdal et al., 2004). To correct zinc deficiency, zinc sulfate or chelated zinc fertilizers should be applied through both foliar sprays and soil amendments.

Manganese plays a vital role in photosynthesis and oxidative stress regulation and is essential for carbohydrate and lipid metabolism in plants (Alloway, 2008). As soil pH increases, manganese oxidizes into forms that are less available to plants, making it one of the primary limiting factors for Mn uptake (Fageria, 2001). The analysis showed that Mn levels were high in Pütürge (37.33 mg $kg^{-1}$) and Arguvan (11.78 mg $kg^{-1}$) but low in Kale (1.37 mg $kg^{-1}$) and Battalgazi (1.46 mg $kg^{-1}$). Manganese deficiency is commonly observed in high-pH soils, leading to chlorosis (leaf yellowing) and leaf spotting (Figure 3). In apricot trees, Mn deficiency reduces fruit firmness and affects skin color, leading to paler, less vibrant fruit with reduced shelf life (Tisdale et al., 1993). In low-Mn areas, manganese sulfate foliar sprays should be applied, and pH-lowering soil amendments should be considered.

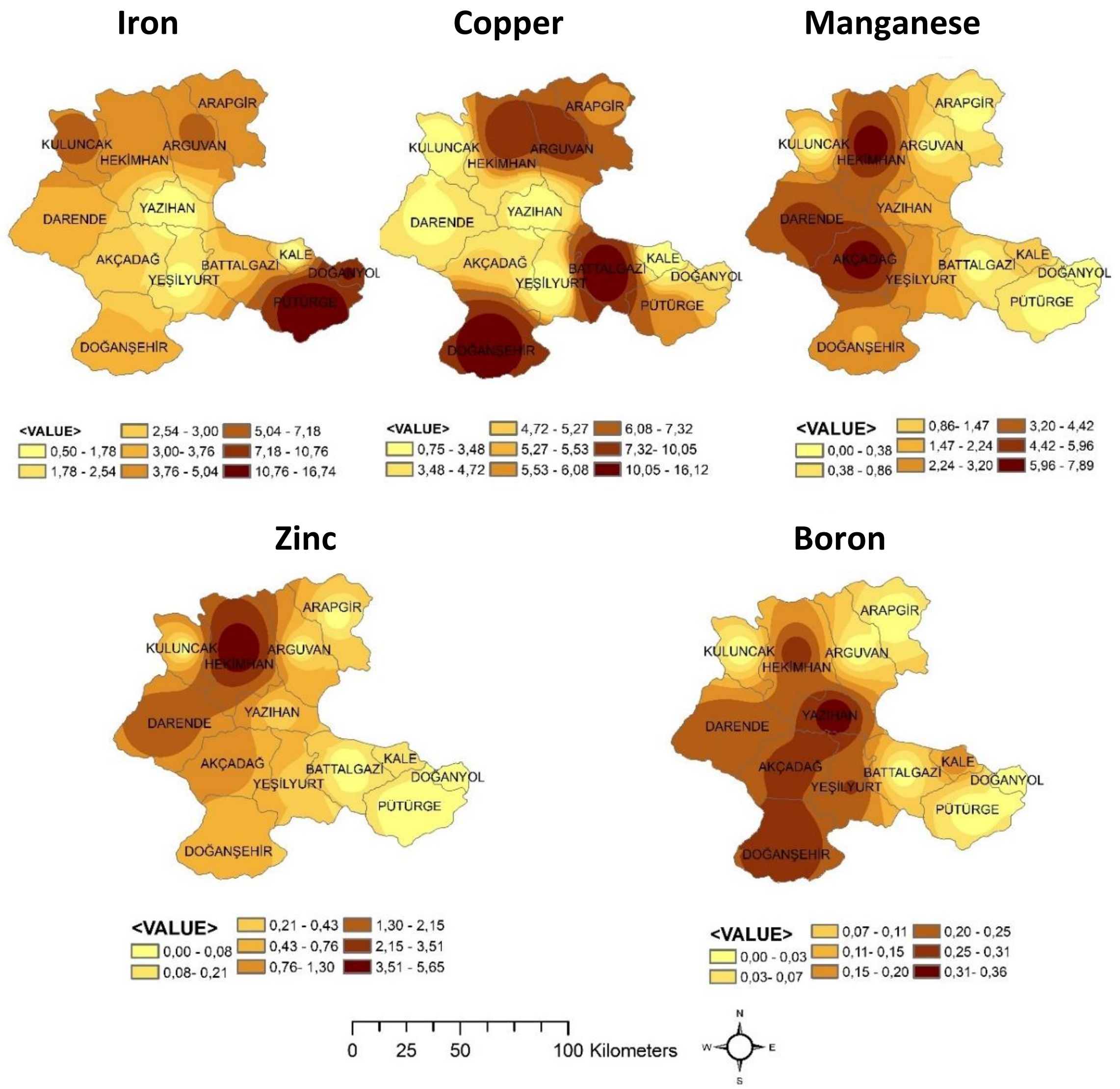


Figure 3. The micronutrient content of soils in Malatya province.

Boron is critical for cell wall development and flowering (Shorrocks, 1997). Boron deficiency adversely affects pollen germination and fruit set, resulting in reduced apricot yields (Brown et al., 2002). In soils with low B content, cell division and growth processes are disrupted (Sotiropoulos et al., 2019). Soil analysis showed that B levels ranged from 0.17 mg kg$^{-1}$ in Kale to 0.47 mg kg$^{-1}$ in Kuluncak (Figure 3). Boron deficiency during flowering significantly reduces fruit set, resulting in small, misshapen, or cracked fruits (Wójcik & Treder, 2006). Apricot trees suffering from boron deficiency often show hollow or spongy fruit centers and premature fruit drop (Nyomora et al., 1997). In low-B regions, B-fertilizers (e.g., borax) should be applied carefully to avoid toxicity due to over-application.

Copper is essential for lignin synthesis and plays a role in disease resistance, chlorophyll synthesis, and respiratory enzymes (Marschner, 2012). However, excessive copper accumulation can lead to phytotoxicity (Kabata-Pendias, 2010). Soil analysis in Malatya indicated that copper levels were generally adequate (Figure 3). However, in high lime soils, Cu can be tightly bound, limiting plant uptake (Yadav et al., 2019). In apricots, Cu deficiency reduces fruit firmness and color intensity while increasing fruit susceptibility to cracking and fungal infection (Reuter & Robinson, 1997). In areas of low Cu availability, copper sulfate or copper-based fungicides should be applied carefully to avoid toxicity.

Iron is essential for chlorophyll synthesis and photosynthesis. High soil pH significantly reduces Fe bioavailability, as Fe precipitates in forms that plants cannot absorb when pH exceeds 7 (Lindsay & Schwab, 1982). Additionally, high lime content promotes the formation of iron phosphates, further restricting Fe availability (Mengel & Kirkby, 2001). The study found that Fe-deficiency is widespread in the high pH soils of Malatya, with Kuluncak (5.82 mg $kg^{-1}$) and Arguvan (5.87 mg $kg^{-1}$) showing particularly low levels. Reduced Fe solubility in high pH soils limits plant uptake, leading to chlorosis (leaf yellowing) in apricot trees (Figure 3). Iron deficiency is known to reduce fruit size, lower sugar content, and delay fruit ripening, significantly affecting fruit quality and economic value (Álvarez-Fernández et al., 2006). To address Fe deficiency, foliar or soil applications of chelated iron (EDDHA-Fe) should be used.

Table 4. Pearson correlation analysis of soil properties in Malatya province

| Parametre | EC | pH | $CaCO_3$ | OM | Total N | P | K | Ca | Mg | Na | Fe | Cu | Mn | Zn | B |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Saturation** | 0.34 | 0.326 | **0.616*** | 0.22 | 0.282 | 0.445 | 0.324 | **0.598*** | 0.408 | 0.015 | -0.3 | -0.02 | -0.318 | 0.137 | 0.023 |
| **EC** | | -0.5 | -0.158 | 0.29 | 0.309 | **0.678*** | **0.713**** | -0.131 | 0.541 | -0.027 | 0.072 | 0.078 | 0.085 | 0.259 | 0.151 |
| **pH** | | | 0.532 | 0.07 | 0.142 | -0.236 | -0.126 | 0.547 | 0.222 | **0.579*** | -0.58 | -0.49 | -0.561 | -0.18 | 0.243 |
| **$CaCO_3$** | | | | 0.18 | 0.275 | 0.158 | 0.095 | 0.548 | 0.255 | 0.025 | -0.306 | -0.12 | -0.318 | 0.002 | 0.01 |
| **OM** | | | | | **0.974**** | **0.705**** | 0.658* | 0.421 | **0.627*** | 0.515 | -0.342 | 0.3 | -0.362 | 0.501 | **0.617*** |
| **Total N** | | | | | | **0.757**** | 0.673* | 0.522 | **0.634*** | 0.497 | -0.514 | 0.275 | -0.543 | 0.361 | 0.567 |
| **P** | | | | | | | **0.856**** | 0.435 | **0.587*** | 0.111 | -0.254 | 0.342 | -0.281 | 0.429 | 0.384 |
| **K** | | | | | | | | 0.237 | **0.786**** | 0.373 | -0.119 | 0.035 | -0.081 | 0.404 | 0.543 |
| **Ca** | | | | | | | | | 0.305 | 0.276 | **-0.685*** | 0.104 | **-0.760**** | 0.196 | 0.348 |
| **Mg** | | | | | | | | | | **0.716**** | -0.313 | -0.21 | -0.262 | 0.254 | **0.661*** |
| **Na** | | | | | | | | | | | -0.333 | -0.37 | -0.32 | 0.279 | **0.841**** |
| **Fe** | | | | | | | | | | | | 0.119 | **0.981**** | 0.358 | -0.055 |
| **Cu** | | | | | | | | | | | | | -0.006 | 0.069 | 0.038 |
| **Mn** | | | | | | | | | | | | | | 0.301 | -0.117 |
| **Zn** | | | | | | | | | | | | | | | 0.597 |

Significant at *$P < 0.05$, **$P < 0.01$ and ***$P < 0.001$; ns= not significant ($P > 0.05$).

Understanding the relationships between soil properties and nutrient availability is critical for optimizing soil fertility and improving apricot production. The correlation analysis in this study provides valuable insights into the interactions between macronutrients, micronutrients, and soil properties, which are essential for developing effective soil management and fertilization strategies. These findings are compared with previous studies to highlight the significance of nutrient interactions in different agricultural systems.

*Soil pH and Micronutrient Deficiencies*

Soil pH plays a fundamental role in nutrient availability. The positive correlation between pH and Ca (r = 0.547) and Mg (r = 0.579) suggests that higher pH conditions favor the solubility of these macronutrients, which is consistent with Lindsay & Schwab (1982), who reported that alkaline soils increase Ca and Mg availability but significantly decrease Fe, Mn, and Zn solubility.

This study confirms these findings, as Fe (r = -0.58), Mn (r = -0.561), and Zn (r = -0.183) showed negative correlations with pH. A similar pattern was observed by Mengel & Kirkby (2001) in Mediterranean soils, where high pH levels in calcareous soils caused severe Fe and Mn deficiencies in fruit crops, resulting in leaf chlorosis and reduced yield.

Furthermore, Fageria et al. (2018) demonstrated that Fe solubility decreased by nearly 1000-fold when pH increased from 5.5 to 7.5, further supporting the need for acidifying amendments such as elemental sulfur or organic matter applications to improve Fe bioavailability in apricot orchards.

*Lime ($CaCO_3$) Content and Nutrient Solubility*

Lime content significantly affects nutrient interactions in soils. The positive correlation between $CaCO_3$ and Ca (r = 0.548) is expected, because calcareous soils naturally contain high levels of Ca. However, the negative correlations with Fe (r = -0.306) and Mn (r = -0.318) confirm that excess lime limits the solubility of these micronutrients, in agreement with Marschner (2012).

Studies by Rombolà & Tagliavini (2020) indicate that Fe and Mn deficiencies are widespread in high lime soils due to the precipitation of these elements as insoluble oxides, reducing their uptake by plants. This suggests that chelated Fe and Mn fertilizers (EDDHA-Fe) are necessary in apricot orchards to counteract lime-induced deficiencies.

*Organic Matter and Nutrient Retention*

Organic matter plays a crucial role in nutrient retention and microbial activity. The strong positive correlation between organic matter and total N ($r = 0.974$, $p < 0.01$), P ($r = 0.705$, $p < 0.01$), and K ($r = 0.658$, $p < 0.05$) suggests that higher organic matter enhances soil fertility and nutrient availability.

This is consistent with the findings of Kabata-Pendias (2010), who reported that organic matter increases Zn availability by forming stable organic complexes that prevent Zn from being adsorbed to soil particles. The positive correlation between organic matter and Zn ($r = 0.617$, $p < 0.05$) further supports this mechanism.

Additionally, Havlin et al. (2005) found that organic matter application in orchards significantly improved micronutrient uptake, enhanced root growth, and increased fruit yield, reinforcing the importance of compost and green manure application in Malatya's apricot orchards.

*Soil Saturation and Nutrient Availability*

Soil saturation reflects the water holding capacity of soil particles, which is critical for nutrient solubility and root uptake. The positive correlation of saturation with $CaCO_3$ ($r = 0.616$, $p < 0.05$) and Ca ($r = 0.598$, $p < 0.05$) suggests that calcareous soils retain more water, increasing the availability of Ca. However, negative correlations with Fe ($r = -0.3$) and Mn ($r = -0.318$) indicate that excess soil moisture reduces the solubility of these micronutrients, potentially leading to iron and manganese deficiency.

Similar findings were reported by Singh et al. (2017), who found that high soil saturation in calcareous soils reduced Fe and Mn availability, leading to chlorosis in fruit trees. In contrast, non-calcareous soils with lower water retention showed improved Fe and Mn uptake, supporting the idea that drainage and aeration management are crucial for micronutrient solubility in apricot orchards.

*Soil Salinity and Nutrient Uptake*

Soil salinity has a significant effect on nutrient mobility and plant uptake. In this study, salinity showed a strong positive correlation with P ($r = 0.678$, $p < 0.05$) and K ($r = 0.713$, $p < 0.01$), suggesting that higher salinity may increase the availability of these macronutrients. However, the negative correlation with pH ($r = -0.502$) indicates that saline soils tend to be more acidic, a finding consistent with Hussain et al. (2020), who observed that salinity-induced soil acidification increases phosphorus solubility but limits the availability of micronutrients like Fe and Zn.

Römheld and Marschner (1991) further support these results, showing that high salt concentrations in soil solution enhance P and K solubility while simultaneously reducing Fe and Zn availability, leading to nutrient imbalances in fruit orchards. This highlights the need for site-specific fertilization strategies to compensate for salinity-induced nutrient deficiencies.

*Interactions Between Macro and Micronutrients*

Phosphorus and potassium (P-K relationship): A strong positive correlation ($r = 0.856$, $p < 0.01$) was observed between P and K, indicating that both nutrients complement each other in plant development. Similar results were reported by Alloway (2008), who found that P-K interactions are critical for improving fruit quality and resistance to abiotic stresses.

Calcium and magnesium (Ca-Mg relationship): A moderate positive correlation ($r = 0.305$) was observed between Ca and Mg. However, excess Ca can interfere with Mg uptake, a phenomenon well documented by Rombolà & Tagliavini (2020).

Iron and Manganese (Fe-Mn relationship): A strong positive correlation ($r = 0.981$, $p < 0.01$) suggests that both elements are influenced by oxidation-reduction processes in the soil, similar to the findings of Fageria (2001) in calcareous orchard soils.

This logarithmic scale clustered heatmap visualizes the similarities and differences in soil parameters among Malatya's districts (Figure 4). In the graph, the districts are listed on the vertical axis, while the soil parameters are displayed on the horizontal axis. The clustering algorithm groups districts with similar soil properties, enabling a more systematic analysis of regional soil characteristics. Color intensity, ranging from light green to dark green, represents different levels of soil parameters, with light green indicating low values and dark green representing high values.

The heat map analysis reveals that Arguvan, Hekimhan, and Kuluncak have similar soil properties, characterized by high lime ($CaCO_3$), Ca, and organic matter content. In contrast, Pütürge and Yazıhan form a distinct cluster, significantly differing from other districts in their soil characteristics. Darende and Akçadağ show moderate similarity, sharing some common soil characteristics but remaining distinct from the other major clusters.

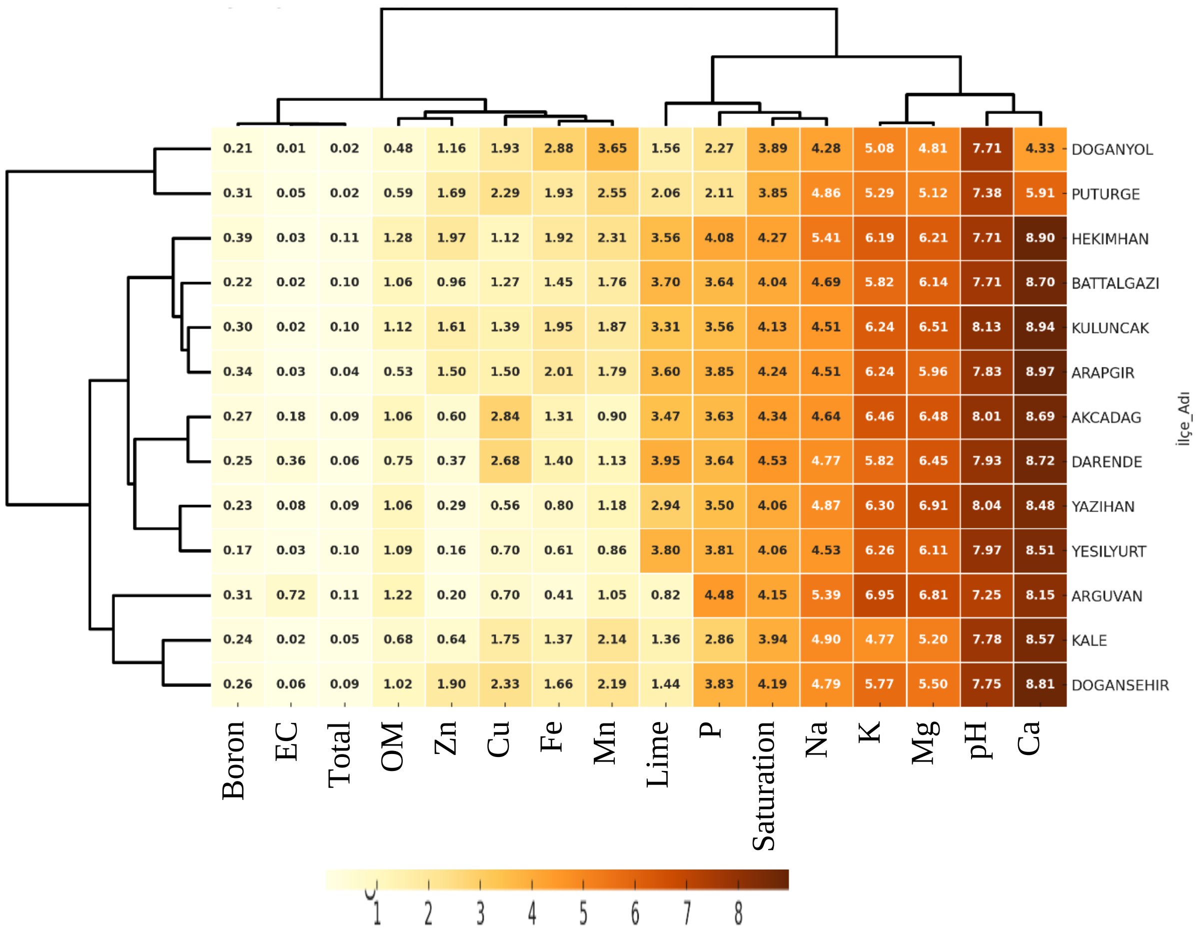


Figure 4. Clustered heatmap of soil parameters in Malatya districts

Examining the relationships between soil parameters, it is evident that pH, lime ($CaCO_3$), and Ca are closely clustered together, reinforcing the well-documented relationship that high pH soils tend to have elevated lime and calcium contents. Similarly, P, K, and Mg appear in the same cluster, suggesting that these elements play complementary roles in plant nutrition and tend to coexist in similar soil conditions. Additionally, organic matter and N are grouped together, highlighting that organic matter content directly influences nitrogen availability, which aligns with previous studies on soil fertility dynamics.

Based on these findings, district-specific soil management strategies should be developed to enhance apricot cultivation in Malatya. Districts within the same cluster can benefit from common fertilization and soil management programs, while distinct clusters require customized strategies. For example, in Hekimhan, Kuluncak, and Arguvan, where similar micronutrient deficiencies are likely, joint fertilization programs focusing on micronutrient supplementation can be implemented. Conversely, in Pütürge and Yazıhan, which have different soil characteristics, targeted soil amendments and pH management strategies should be applied to optimize soil fertility.

In areas with high pH levels, deficiencies of Fe, Zn, and Mn are more prevalent, requiring foliar applications or soil amendments rich in these micronutrients. Similarly, regions with low potassium levels should be supplemented with potassium sulfate or potassium nitrate fertilizers to maintain optimal soil conditions.

Apricot is one of the most important fruit crops due to its high nutritional value and long history of cultivation (Karlıdağ et al., 2019). Apricot trees require significant amounts of mineral nutrients for proper growth and fruit production. To maintain optimal nutrient levels and sustain high yields, it is essential to supplement deficient nutrients either through soil fertilization or foliar applications (Medan, 2020).

Overall, this analysis underscores the importance of scientific data-driven agricultural management strategies for improving apricot production in Malatya. Clustering districts based on soil characteristics allow for more efficient agricultural policies, contributing to the sustainable enhancement of apricot yields in the region.

## Conclusion

The soils of Malatya province are predominantly calcareous and alkaline, with neutral to high pH values throughout the soil profile. The high levels of Ca and K in these soils contribute positively to the flavor, aroma, vitamin, and mineral composition of apricots grown in the region. However, the alkaline nature of the soil poses a significant challenge to the availability of essential micronutrients such as Fe, Zn, B, and Mn. Additionally, a considerable portion of applied P binds with Ca, forming insoluble compounds, which limits its availability to plants.

To enhance soil fertility and apricot productivity, targeted soil management strategies should be implemented. The following recommendations are essential for improving soil conditions and sustaining high apricot yields in Malatya:

Regular soil testing to monitor pH, salinity, and organic matter levels, ensuring informed decision-making for soil amendments and fertilization. Acidifying soil amendments, such as elemental sulfur or organic matter applications, to lower soil pH and enhance the availability of Fe, Mn, and Zn. Organic material incorporation, including compost and agricultural residues, to improve soil productivity by enhancing water retention capacity, cation exchange capacity, organic matter content, and nitrogen fractions while increasing the availability of P, K, Fe, Zn, and Mn. Balanced fertilization programs, considering the interaction between P and K, as well as the competition between Ca and Mg, to optimize nutrient uptake and minimize antagonistic effects. Chelated micronutrient fertilizers (EDDHA-Fe, Mn, Zn) to counteract lime-induced deficiencies and ensure optimal nutrient absorption by apricot trees.

By adopting these science-based soil management practices, apricot farmers in Malatya can enhance soil fertility, improve nutrient availability, and sustain high-quality fruit production despite the challenges posed by calcareous soil conditions.

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