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**ARAŞTIRMA MAKALESİ** **RESEARCH ARTICLE**

# Assessing the Correlation among Soil Quality, Tree Species, and Productivity in forest ecosystems using SMAF Method

## SMAF Yöntemi Kullanılarak Orman Ekosistemlerinde Toprak Kalitesi, Ağaç Türleri ve Verimlilik Arasındaki Korelasyonun Değerlendirilmesi

**Ahmet REİS[1*], Nurullah ACİR[2], Turgay DİNDAROĞLU[3]**

## Abstract

Ensuring soil quality and sustainability is of vital importance in combating global climate change and desertification. Factors such as weakening of vegetation, soil erosion, compaction, and degradation reduce soil fertility, thus impacting soil quality. Evaluating soil quality accurately is essential, and the Soil Management Assessment Framework (SMAF) is a method that uses soil indicators to assess soil properties comprehensively. This study aimed to evaluate the relationship among tree species, bonitet classes, and soil quality in forest ecosystems at the watershed scale using the SMAF method. The research took place in the Karasu Watershed in Akifiye, Andırın district of Kahramanmaraş province. Soil indicators were selected from the physical and chemical properties of the soil. Soil indicators such as aggregate stability, water-filled pore volume, bulk density, carbon content, nutrient levels, pH, and electrical conductivity were used to determine soil quality indices in forest stands. Soil quality indices were determined and statistically interpreted by applying the SMAF method between tree species and bonitet classes in forest lands. Results showed that soil quality was lowest in black pine stands (69.42%) and the highest in oak stands (77.31%). Leafy stands had statistically higher soil quality. Soil quality indices ranged from 72.54 to 74.75 across bonitet classes, which are indicators of productivity (bonitet) in forest stands. No significant differences were found between bonitet classes and soil quality scores in karst forest ecosystems due to their karstic characteristics. Although soil quality may be high in karst areas, shallow soil depth limits plant growth. Therefore, a high soil quality index in karst areas can correspond to a low bonitet class. The negative effects of production activities and silvicultural interventions in forest ecosystems on soil quality can be eliminated by activities such as soil tillage. Implementing management strategies that prioritize soil protection and improvement in forest ecosystems with natural plant cover will enhance soil functionality and ensure long-term soil quality sustainability.

**Keywords:** Soil quality, SMAF, Bonitet classes, Karst forest ecosystem

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# Öz

Toprak kalitesinin ve sürdürülebilirliğinin sağlanması, küresel iklim değişikliği ve çölleşmeyle mücadelede hayati öneme sahiptir. Bitki örtüsünün zayıflaması, toprak erozyonu, sıkışma ve bozulma gibi faktörler toprak verimliliğini azaltır ve böylece toprak kalitesini etkiler. Toprak kalitesini doğru bir şekilde değerlendirmek esastır ve Toprak Yönetimi Değerlendirme Çerçevesi (SMAF), toprak özelliklerini kapsamlı bir şekilde değerlendirmek için toprak göstergelerini kullanan bir yöntemdir. Bu çalışma, SMAF yöntemini kullanarak havza ölçeğinde orman ekosistemlerindeki ağaç türleri, bonitet sınıfları ve toprak kalitesi arasındaki ilişkiyi değerlendirmeyi amaçlamaktadır. Araştırma, Kahramanmaraş ili Andırın ilçesi Akifiye'deki Karasu Havzası'nda yapılmıştır. Toprağın fiziksel ve kimyasal özelliklerinden toprak göstergeleri seçilmiştir. Agregat kararlılığı, suyla dolu gözenek hacmi, hacim ağırlığı, karbon içeriği, besin seviyeleri, pH ve elektriksel iletkenlik gibi toprak göstergeleri, ormanlık alanlardaki toprak kalitesi endekslerini belirlemek için kullanılmıştır. Orman arazilerinde ağaç türü ve bonitet sınıfları arasında SMAF yöntemi uygulanarak toprak kalitesi endeksleri belirlenmiş ve istatistiki olarak yorumlanmıştır. Sonuçlar, toprak kalitesinin karaçam ormanlarında en düşük (%69.42) ve meşe ormanlarında en yüksek (%77.31) olduğunu göstermiştir. Yapraklı ormanların toprak kalitesi istatistiksel olarak daha yüksektir. Toprak kalitesi endeksleri, orman alanlarındaki üretkenliğin (bonitet) göstergesi olan bonitet sınıfları arasında 72.54 ile 74.75 arasında değişmektedir. Karstik özellikleri nedeniyle karst orman ekosistemlerinde bonitet sınıfları ve toprak kalitesi skorları arasında önemli bir fark bulunamamıştır. Toprak kalitesi karst alanlarında yüksek olsa da, sığ toprak derinliği bitki büyümesini sınırlamaktadır. Bu nedenle, karst alanlarında yüksek bir toprak kalitesi endeksi düşük bir bonitet sınıfına karşılık gelebilir. Orman ekosistemlerinde üretim çalışmaları ve silvikültürel müdahalelerin toprak kalitesindeki negatif etkisi toprak işleme gibi faaliyetlerle ortadan kaldırılabilir. Doğal bitki örtüsüne sahip orman ekosistemlerinde toprak koruma ve iyileştirmeyi önceliklendiren yönetim stratejilerinin uygulanması, toprak işlevselliğini artıracak ve uzun vadeli toprak kalitesi sürdürülebilirliğini sağlayacaktır.

**Anahtar kelimeler:** Toprak kalitesi, SMAF, Bonitet sınıfları, Karst orman ekosistemi

## 1. Introduction

Soils contribute to overall ecosystem services, defined as "services ecosystems provide to society" that require cooperation between different disciplines (Dominati et al., 2014). Soil supports important ecosystem services such as water purification, carbon sequestration, nutrient cycling and providing habitat for biodiversity (Mikhailova et al., 2021; Andrea et al., 2017). In addition, soil has a very important place in the growth of all land plants. Therefore, studies investigating the physical and chemical structures of soils are of particular importance in order to know the most suitable soil conditions for the sustainability of forest existence and to select appropriate trees that can adapt to the soil structure of the areas to be afforested in the fight against erosion (Evren and Kaya, 2020). Soil quality, on the other hand, has the potential to contribute to the improvement of healthy soils and some key ecosystem services that can support sustainable development goals (Keesstra et al., 2016).

Soil quality is the function of a soil to maintain plant and animal production, maintain and improve the quality of water and air, support human health and the lives of other living things (SSSA, 1997). The interpretation of soil quality focuses on these soil functions and processes and provides a simple management of negative processes (erosion, compaction, pollution, etc.) in the soil. In addition, soil quality ensures that social benefits such as carbon sequestration, water quality and soil fertility are secured. Interpretation of soil quality also constitutes the basis for ecosystem restoration when needed, by prioritizing the determination of social benefits and by ensuring that their relations with each other are resolved.

It is important for planning, monitoring and treatment to determine the quality of the components that make up the ecosystem with methods that comply with the sustainability principle and efficiency principles. There are many approaches about monitoring and controlling the quality of soil, water and air, which are important elements of the ecosystem (Dindaroglu and Canbolat, 2013). Scientific methods continue to be developed to ensure the sustainability of soil functions (Karlen et al., 2008). Knowing the history of soil processes and environmental factors is one of the necessary conditions for good soil management (Sökmen et al., 2024). Environmental (climate, hydrology, etc.) factors affecting soil functions and land use types have an important place in the planning and management processes of soils. For this reason, it is necessary to determine the changes in the ability of soils to function. Ensuring the productivity of soil functions can only be possible with the sustainability of soil quality. Soil quality measurements are an effective method for observing the causes of variation in the productivity of soil functions. In recent years, concerns about forest management and efforts to ensure the sustainability of forest ecosystem features and to bring forest productivity to a very high level have revealed the importance of soil quality.

Karst ecosystems have unique habitats with their unique morphology, rich water and soil resources formed by the decomposition of mineral and evoporite rocks. Karst formations, which contain a significant amount of water potential and are the source of large rivers, often do not have water on the land surface (Peng et al., 2013; Bai et al. 2013). Therefore, it is very important to evaluate the distribution of spatial soil quality in order to ensure the sustainability of their habitats and to prevent desertification in karst ecosystems (Ozgul and Dindaroglu, 2021).

Soil Quality Scores in soil quality assessment studies (Harris et al., 1996; Romig et al., 1996; Shepherd, 2000; Shepherd et al., 2000; Acir, 2022), Soil Conditioning Index (Laws, 1961; Hubbs et al., 2002; Zobeck et al., 2007), Agricultural Ecosystem Assessment Tool (AEPAT) (Liebig et al., 2004), Cornell Soil Health Test (Doran and Parkin, 1994), Soil Management Assessment Framework (SMAF) (Andrews et al., 2004; Karlen et al., 2006; Acir, 2019) are the main methods used. Soil Quality Scores and Soil Conditioning Index methods were the first methods developed by the US Natural Resources Conservation Service. Although the results obtained with soil quality indices determined by different methods are different, there are strong correlations between them (Dindaroglu and Canbolat, 2013). These methods are studies to establish a basic sensitivity about soil quality or to evaluate the trend of one or more soil properties (Doran et al., 1996; Liebig et al., 1996). Ozgul and Dindaroglu (2021) argued that creating specific indices for determining soil quality index in karstic forest ecosystems gives more sensitive and highly validated results. AEPAT, Cornell Soil Health Test and SMAF soil quality assessment methods are more comprehensive.

SMAF is one of the newest and most advanced techniques widely used worldwide to assess soil quality response to soil and crop management strategies (Erkossa et al., 2007; Gelaw et al., 2015; Kalu et al., 2015; Cherubin et al., 2016; 2021; Karlen et al., 2019). One of the soil quality assessment methods, SMAF was developed to express quantitative interpretations of the soil quality dimension to ensure continuity of management (Andrews et al. 2002, 2004). SMAF consists of three basic stages: choosing indicators for soil quality indexing, interpreting indicator scores, and collecting indicator scores in an index, after the management objectives of the system are established. Soil properties that affect the soil's ability to produce products are called soil quality indicators (Arshad and Martin, 2002). Karlen et al. (2008) found that the application of the SMAF method in the basin soils was effective in 87% of the soil potentials. They stated that SMAF, one of the soil quality assessment methods, gives more information about the effects of management practices in the watersheds. In a study on the watershed, many soil quality indicators were measured by SMAF method and three were evaluated in well-developed vegetation layer and one in underdeveloped vegetation layer. Soil indicator scores were significantly lower in soils with underdeveloped vegetation compared to other region soils (Stott et al., 2011).

When soil quality is evaluated by SMAF method in karst forest ecosystems, plants in poor bonitet classes and low soil quality are less productive.

In this study, which was carried out in the Karasu watershed, the background of rehabilitation works to be applied in unproductive areas was investigated by evaluating the relationships between different tree species, actual productivity (bonitet class) and soil quality by using the Soil Management Assessment Framework (SMAF) with the evaluation of soil quality in karst forest ecosystems. In the assessment of soil quality in the karst forest ecosystems on the basin, the detection of infertile areas under different tree species by scoring with the SMAF method will contribute to science in taking soil protective measures and ensuring the sustainability of soil quality.

## 2. Material and Method

### *2.1. Study Site*

The research area is located in the Karasu watershed within the borders of Akiye Forestry Operations Directorate of Andırın district of Kahramanmaraş, which is located in the Eastern Mediterranean region of Turkey. The basin area is located at 37° 44' 25" north latitude and 36° 21' 45" east longitude. There is Çokak sub-district in the north of the area, Akçadağ (2285 m) in the west, Ziyaret Hill (1844 m) in the east, and Tırıl Mountain (1894 m) in the south (*Figure 1*).

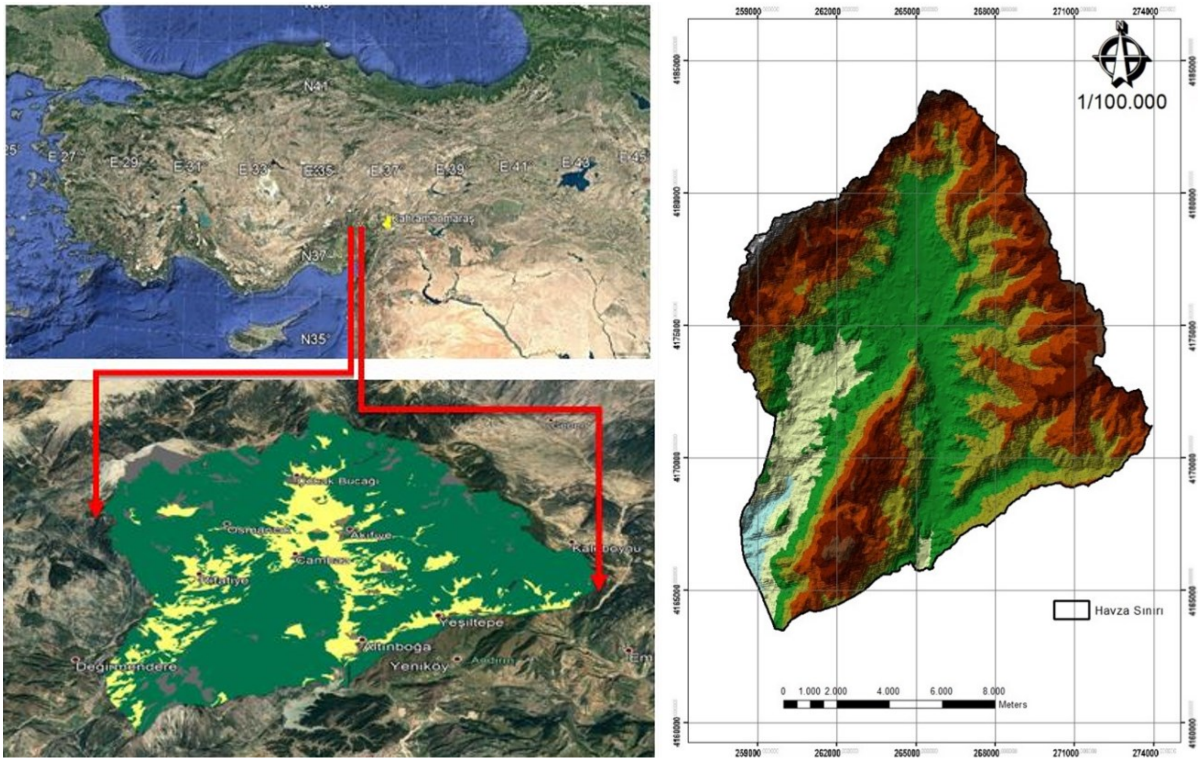

*Figure 1. Study area (Karasu watershed)*

### 2.1.1. Geology and geomorphology of the study area

Çokak Polje is dominant in the research area. The length of the polje extending from north to south is approximately 10 km and its width is 1-4 km. Çokak Polje has an altitude of approximately 1240-1250 m. In the Miocene, the northern areas of the area were uplifted by the eprogenetic movements of the Çokak Polje, forming the Akçadağ and Ziyaret Tepe anticline ridges. Faulting and collapses due to tectonism caused the formation and progression of karst morphology and a tecteno-karstic structure was formed. During the development of the Çokak Polje, the Karasu Stream alluvialized the base of the polje. Thus, Çokak Polje has acquired today's morphological appearance as a result of the interaction of tecteno-fluvial-karstic processes (Karaosmanoğlu, 2011). The geomorphological structure of the watershed is composed of Andırın limestone, alluvium, Koçali complex, Karataş, Ahmetçik, Ahırdağı and Ballıkısık formations (MTA, 2000) (*Figure 2*).

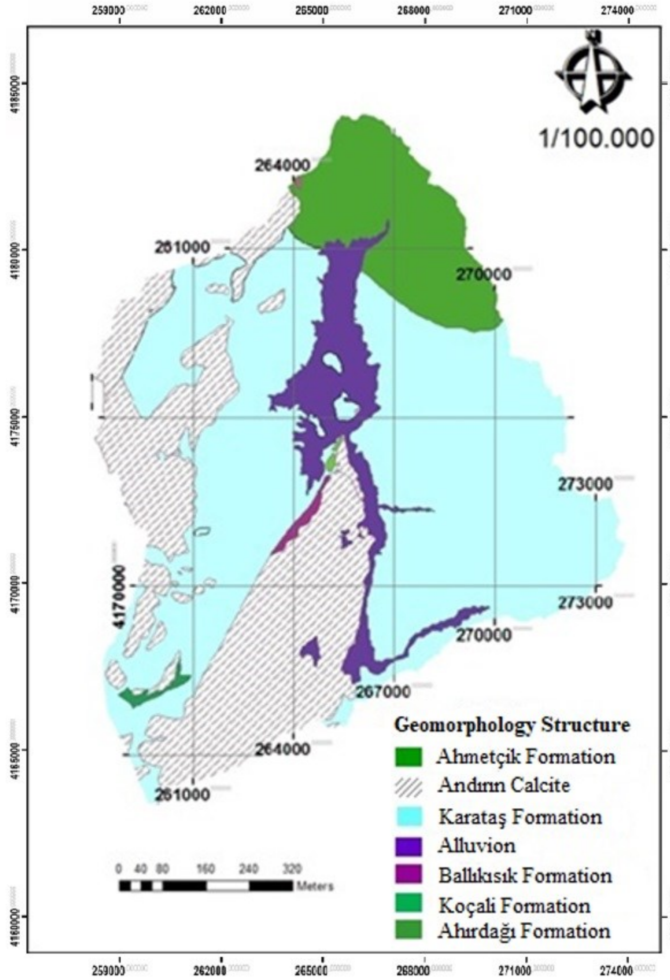

***Figure 2. Geological structure of the study area***

### 2.1.2. Climate, vegetation and soil of the study area

The humid air reaching the region from the Mediterranean rises in this region with high mountains and forests, causing precipitation. Precipitation generally falls as rain in winter and autumn seasons. The average annual precipitation in the region is 1427 mm. As the altitude increases from south to north in the research area, the temperature decreases. In the north of the watershed (around Çokak sub-district), precipitation in the form of snow occurs in winter due to the decrease in temperatures due to the altitude. Most snowfall falls in January. While the Mediterranean climate is dominant in the southern parts of the study area and in the valleys and residential areas, it shows the continental climate effect on the mountains and slopes in the northern parts. The annual average temperature in the research area is 12.6 °C, the highest temperature is 34.0 °C in August and the lowest temperature is -8.2 °C in February (DMİ, 1995). Although brown forest soils are common in the watershed area, there are also alluvial and collivial soil types.

## 3. Method

### 3.1. Soil sampling

Soil samples were taken in forest areas to evaluate the physical and chemical properties of the soil and soil quality scores in pure stands of Black Pine (Çk), Red Pine (Çz), Beech (Kn), and Oak (M) tree species with development stages (b, bc, c, cd, d, de) and canopy closure classes (1, 2, and 3) in pure forest stands (Çkb2, Çkbc3, Çkc3, Çkcd2, Çkcd3, Çkd1, Çkd2, Çkd3, Çkde1, Çkde2, Çzb3, Çzbc3, Çzc2, Çzc3, Çzd1, Çzd2, Knb3, Knbc3, Knc3, Kncd2, Kncd3, Mb3, Mbc3) and in bonitet classes (1, 2, 3, and 5). A total of 360 soil samples (0-30 cm) were taken at 180 points with disturbed and undisturbed structures in three canopy closure classes and four tree species with fifteen replicates (3*4*15) in the karstic forest ecosystem.

### 3.1. Soil analyses

Soil bulk density was determined using the Blake and Hartge (1986) method, available water content was measured using pressure plates and the difference between field capacity and wilting point (Klute, 1986). Soil water-filled pore volume was calculated by dividing the volumetric water content of soil by the total porosity ratio. Aggregate stability was measured by wet sieving (Kemper and Rosenau, 1986). Total organic carbon was determined by the wet combustion method of Walkley-Black (Nelson and Sommers, 1982). Available P value was determined according to Watanabe and Olsen (1965) for calcareous and neutral soils and according to Bray and Kurtz (1945) for acidic soils. Available potassium (K) ion for plant uptake was extracted using 1 N ammonium acetate extraction solution (Jackson, 1958). Soil pH and electrical conductivity (EC) values were determined using a pH/EC meter according to Richards (1954).

### 3.2. Determination of soil quality

To determine the soil quality characteristics of the study area, the "Soil Management Assessment Framework" (SMAF), which is one of the soil quality assessment methods, was used. SMAF uses the physical, chemical, and biological properties of the soil to reveal the effects of management practices on soil functions. Currently, there are algorithms developed to score only 13 indicators consisting of physical, chemical, and biological properties of the soil in the SMAF method. SMAF includes indicators such as organic carbon content, aggregate stability, pH, electrical conductivity, sodium adsorption ratio, available phosphorus and potassium content for plants, available water content, water-filled pore volume, bulk density, beta-glucosidase enzyme activity, microbial biomass carbon, and potential mineralizable nitrogen (Andrews et al., 2004; Wienhold et al., 2011).

The SMAF method consists of three main stages: selecting indicators, interpreting indicator scores, and combining indicator scores into an index. In this study, indicators suitable for management and function purposes were selected by taking into account the indicators used in the SMAF method and the soil properties of the study area. Scoring curves developed by Karlen and Stott (1994) were used for interpreting soil indicators for the first time. Three basic scoring curves were used for interpreting soil indicators: "more is better", "less is better", and "the midpoint is optimal". The SMAF method uses an additive index calculation model. In this calculation model, the value for each indicator is added and divided by the number of indicators. The resulting score is multiplied by 100 to determine the soil quality percentage, which is defined as the capacity to show the specified function of the soil. Dividing the total value of the indicators by the number of indicators in the soil quality index calculation formula eliminates the problem that may arise when missing data occurs (Andrews et al., 2004).

$$\text{Soil Quality Index} = \left(\frac{\sum_{i=0}^{n} S_i}{n}\right) * 100 \qquad \text{(Eq. 1)}$$

The soil quality index percentage is calculated using the indicator value (S) scored in the formula above and the number of indicators (n).

### 3.3. Determination of plant species and bonitet class

According to the forest stand map created by the General Directorate of Forestry (OGM, 2006), beech, oak, fir, red pine, and black pine forests are found in pure and mixed forms within the watershed. However, fir forests were not included in the study due to their distribution not being fully compatible with the sampling patterns used in the study (*Table 1*).

***Table 1. Some dominant plant species in the study area***

| | **Latin** |
|---|---|
| **Plant species** | *Pinus brutia Ten.* |
| | *Pinus nigra J. F. Arnold* |
| | *Cedrus libani A. Rich.* |
| | *Abies cilicicasubsp. Cilicica* |
| | *Pinus pinea L.* |
| | *Juniperus oxycedrus L.* |
| | *Juniperus excelsasubsp. Excelsa* |
| | *Juniperus communis L.* |
| | *Robinia pseudoacacia L.* |
| | *Cupressus sempervirens L.* |
| | *Quercus cerris L.* |
| | *Quercus infectoria Oliv.* |
| | *Fagus orientalis Lipsky* |
| | *Carpinus orientalis Mill.* |
| | *Platanus orientalis L.* |
| | *Juglans regia L.* |
| | *Salix sp.* |
| | *Cerasus mahalep Mill.* |
| | *Castanea sativaMill.* |
| | *Alnus glutinosa Gaertn.* |
| | *Populusalba L.* |
| **Shrub Types** | *Crataegus sp.* |
| | *Prunus x domestica L.* |
| | *Pyrus elaeagnifolia Pall.* |
| | *Rosa sp.* |
| | *Phillyrealatifolia L.* |
| | *Paliurusspina-christi P. Mill.* |
| | *Styrax officinalis L.* |
| | *Pistacia terebinthus L.* |
| | *Arbutus andrachne L.* |
| **Herbaceous Plants** | *Rubus fruticosus* |
| | *Thymus sp.* |
| | *Colutea arborescens L.* |
| | *Verbascum sp.* |
| | *Plantagolanceolata L.* |
| | *Viscum albüm L.* |
| | *Ruscus aculeatus L.* |
| | *Pteridium sp.* |
| | *Astragalus sp.* |
| | *Fragari avesca L.* |
| | *Urtica dioica L.* |
| | *Euonymus europaeus L.* |
| | *Menthapulegium L.* |
| | *Centaurealy copifoliaBoiss. &Kotschy* |
| | *Geranium glaberrimum Boiss. &Heldr.* |
| | *Fraxinus ornus L.* |
| | *Salviapilifera Montbret & Aucherex Benth.* |
| | *Ferulalongi pedunculata Peşmen* |
| | *Thecocarpus carvifolius Hedge &Lamond* |
| | *Salvia recognitaFisch. &C.A.Mey.* |
| | *Johrenia selinoides Boiss. & Balansa* |
| | *Astragalus vaginans DC.* |
| | *Diplopilosaflava Dvorak* |

Bonitet is a measure of the actual yield capacity of a forest stand. Good bonitet means high yield, while poor bonitet means low yield (Günel, 1981). Different bonitet classes (1, 2, 3, 4, and 5) are present in the study area (OGM, 2006). The soil properties of the soils found in four different bonitet classes (1, 2, 3, and 5) were used to determine soil quality. However, the soils found in the fourth bonitet class were not included in the study due to their distribution not being fully compatible with the sampling patterns used in the study (*Figure 3*).

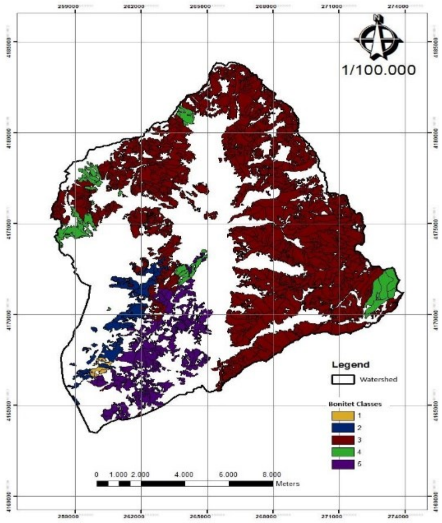

***Figure 3. Bonitet map of the study area (OGM, 2006)***

### *3.4. Statistical analyses*

The statistical analyses of the data obtained from the research area were conducted using the SPSS 20 software package. Descriptive statistics of soil properties for different tree species (Scots pine, Red pine, Beech, and Oak) and bonitet classes (1, 2, 3, and 5) within the forest ecosystem were calculated, including minimum, maximum, mean, mean standard error, standard deviation, coefficient of variation, skewness, and kurtosis. Additionally, descriptive statistics were performed for the indicator index and soil quality index values obtained. Furthermore, grouping was conducted, and comparisons of means were made using the Duncan test.

## 4. RESULTS and DISCUSION

### *4.1. Soil Properties in Forest Ecosystems*

#### *4.1.1. Soil Properties According to Tree Types and Bonitet Classes*

Descriptive statistics and Duncan test results of aggregate stability, water-filled pore volume, bulk density, available water amount, total carbon, available P, potassium, pH and EC values of soil physical and chemical properties of the upper layers (0-30) of Karasu watershed soils were determined according to tree species. According to Duncan homogeneity test results on tree species, aggregate stability and total C ratios were in the same groups, while water-filled pore volume, bulk density, available water amount, available P, potassium and EC values were found in different groups. However, while pH values were found in the same group in black pine, red pine and oak tree species, it was determined that the beech tree species was in a different group (Table 2).

The available P content of the soils was 6.13 mg/kg in black pine (Ck) soils, 7.57 mg/kg in red pine (Cz) soils, 10.64 mg/kg in beech (Kn) soils and 8.30 mg/kg in oak (M) soils. According to Ülgen and Ateşalp (1972), The available P content of the soils is in the middle class. The pH values of the soils were determined as 7.55 in black pine soils, 7.90 in red pine soils, 7.12 in beech soils and 7.60 in oak soils. According to Jackson (1962) classification, the pH values of the soils are alkalescence in soils on black pine and oak tree species, neutral in soils on beech tree species and medium alkaline in soils on red pine tree species. The electrical conductivity of the soils was determined as 0.15 dS/m in black pine soils, 0.17 dS/m in red pine soils, 0.13 dS/m in beech soils and 0.19 dS/m in oak soils. According to Anonymous (2008), when the electrical conductivity of the soils was examined, it was determined that the electrical conductivity values of the soils on black pine, red pine, beech and oak were in the saltless class (0-2) (*Table 2*).

***Table 2. Descriptive statistics and Duncan test results of the physical and chemical properties of the soils of the study area according to tree species***

| N=180 | Tree Species | Min. | Max. | Mean | S. E. | S. D. | C. V. | S | K |
|---|---|---|---|---|---|---|---|---|---|
| **Aggregate Stability (%)** | **Black pine (Ck)** | 65.52 | 92.97 | 85.20 | 1.25 | 6.84 | 8.03 | -1.19 | 0.87 |
| | **Red pine (Cz)** | 68.29 | 92.39 | 84.98 | 1.12 | 6.14 | 7.22 | -1.08 | 0.76 |
| | **Beech (Kn)** | 70.42 | 92.60 | 84.32 | 1.11 | 6.06 | 7.19 | -0.56 | -0.57 |
| | **Oak (M)** | 74.27 | 92.23 | 85.69 | 0.71 | 3.87 | 4.52 | -1.32 | 2.71 |
| **Water-Filled Pore Volume (%)** | **Black pine (Ck)** | 19.74 | 61.93 | 35.86a | 2.12 | 11.60 | 32.34 | 0.85 | -0.22 |
| | **Red pine (Cz)** | 13.00 | 77.38 | 46.11b | 2.66 | 14.59 | 31.65 | -0.15 | 0.30 |
| | **Beech (Kn)** | 28.91 | 78.18 | 48.45d | 2.05 | 11.23 | 23.17 | 0.84 | 0.42 |
| | **Oak (M)** | 36.77 | 57.92 | 47.29c | 1.07 | 5.88 | 12.43 | 0.11 | -0.81 |
| **Bulk Density (gr/cm3)** | **Black pine (Ck)** | 0.99 | 1.66 | 1.31a | 0.03 | 0.16 | 12.21 | 0.30 | 0.04 |
| | **Red pine (Cz)** | 1.01 | 1.84 | 1.41b | 0.04 | 0.20 | 14.18 | -0.07 | -0.49 |
| | **Beech (Kn)** | 1.03 | 1.69 | 1.31a | 0.03 | 0.16 | 12.56 | 0.62 | 0.01 |
| | **Oak (M)** | 1.09 | 1.60 | 1.29a | 0.02 | 0.11 | 8.53 | 1.02 | 1.68 |
| **Available Water Amount (%)** | **Black pine (Ck)** | 2.89 | 11.20 | 6.68a | 0.35 | 1.90 | 28.38 | -0.08 | 0.04 |
| | **Red pine (Cz)** | 3.77 | 11.74 | 7.66b | 0.31 | 1.71 | 22.30 | -0.27 | 0.59 |
| | **Beech (Kn)** | 8.90 | 13.10 | 11.76d | 0.20 | 1.08 | 9.19 | -1.08 | 0.72 |
| | **Oak (M)** | 7.26 | 11.31 | 9.49c | 0.14 | 0.76 | 8.01 | -0.44 | 1.81 |
| **Total Carbon (%)** | **Black pine (Ck)** | 1.26 | 9.01 | 2.87 | 0.30 | 1.65 | 57.47 | 2.28 | 5.97 |
| | **Red pine (Cz)** | 0.51 | 11.65 | 3.49 | 0.53 | 2.88 | 82.26 | 1.26 | 0.76 |
| | **Beech (Kn)** | 0.75 | 5.62 | 2.78 | 0.23 | 1.26 | 45.09 | 0.73 | -0.12 |
| | **Oak (M)** | 1.71 | 8.43 | 3.72 | 0.29 | 1.57 | 42.07 | 1.34 | 2.19 |
| **Available P(mg/kg)** | **Black pine (Ck)** | 3.15 | 13.80 | 6.13a | 0.44 | 2.39 | 39.02 | 1.25 | 2.19 |
| | **Red pine (Cz)** | 1.81 | 19.74 | 7.57ab | 0.79 | 4.32 | 56.94 | 1.60 | 2.45 |
| | **Beech (Kn)** | 3.62 | 23.30 | 10.64c | 0.94 | 5.16 | 48.54 | 0.52 | -0.50 |
| | **Oak (M)** | 3.98 | 15.71 | 8.30b | 0.55 | 3.00 | 36.09 | 0.61 | -0.04 |
| **Potassium (meq/100)** | **Black pine (Ck)** | 0.33 | 1.14 | 0.62a | 0.04 | 0.22 | 35.06 | 0.86 | 0.25 |
| | **Red pine (Cz)** | 0.19 | 0.96 | 0.53a | 0.04 | 0.20 | 36.84 | 0.15 | -0.57 |
| | **Beech (Kn)** | 0.34 | 1.02 | 0.58a | 0.03 | 0.17 | 28.82 | 0.56 | -0.05 |
| | **Oak (M)** | 0.47 | 1.22 | 0.78b | 0.03 | 0.18 | 22.33 | 0.22 | -0.11 |
| **pH** | **Black pine (Ck)** | 6.41 | 8.73 | 7.55b | 0.12 | 0.65 | 8.65 | -0.01 | -0.84 |
| | **Red pine (Cz)** | 6.91 | 8.73 | 7.90b | 0.11 | 0.60 | 7.57 | -0.02 | -1.42 |
| | **Beech (Kn)** | 5.52 | 8.29 | 7.12a | 0.13 | 0.73 | 10.25 | -0.40 | -0.27 |
| | **Oak (M)** | 6.24 | 8.69 | 7.60b | 0.11 | 0.60 | 7.86 | -0.31 | -0.27 |
| **Electrical Conductivity (dS/m)** | **Black pine (Ck)** | 0.07 | 0.44 | 0.15ab | 0.01 | 0.07 | 46.67 | 2.71 | 9.57 |
| | **Red pine (Cz)** | 0.06 | 0.29 | 0.17bc | 0.01 | 0.06 | 35.29 | -0.15 | -0.57 |
| | **Beech (Kn)** | 0.06 | 0.22 | 0.13a | 0.01 | 0.04 | 30.77 | 0.69 | -0.45 |
| | **Oak (M)** | 0.10 | 0.30 | 0.19c | 0.01 | 0.05 | 26.32 | 0.09 | -0.34 |

Min.= Minimum, Max.= Maximum, S. E.=Standard Error, Std. S. D.= Standard Deviation, C. V.= Coefficient of Variation, S.=Skewness, K.=Kurtosis Note=The letters next to the mean values of soil properties indicate group differences

***Table 3. Descriptive statistics and Duncan test results of the physical and chemical properties of the soils of the study area according to bonitet classes***

| N=180 | Bonitet Class | Min. | Max. | Mean | S. E. | S. D. | C. V. | S | K |
|---|---|---|---|---|---|---|---|---|---|
| **Aggregate Stability (%)** | **1** | 71.60 | 92.18 | 86.51 | 3.12 | 7.64 | 8.83 | -2.01 | 4.24 |
| | **2** | 68.29 | 92.39 | 84.36 | 1.61 | 6.44 | 7.63 | -1.14 | 1.16 |
| | **3** | 65.52 | 92.97 | 84.95 | 0.59 | 5.71 | 6.72 | -0.97 | 0.63 |
| | **5** | 81.94 | 89.74 | 83.96 | 1.39 | 3.42 | 4.07 | -0.91 | -1.46 |
| **Water-Filled Pore Volume (%)** | **1** | 20.95 | 77.38 | 49.42 | 8.02 | 19.63 | 39.73 | -0.05 | -0.14 |
| | **2** | 27.12 | 56.22 | 45.23 | 1.97 | 7.86 | 17.39 | -0.62 | 0.24 |
| | **3** | 13.00 | 78.18 | 43.63 | 1.29 | 12.33 | 28.26 | 0.13 | 0.16 |
| | **5** | 31.84 | 62.29 | 49.56 | 4.79 | 11.72 | 23.66 | -0.59 | -1.02 |
| **Bulk Density (gr/cm3)** | **1** | 1.01 | 1.66 | 1.32 | 0.10 | 0.25 | 18.81 | 0.03 | -1.33 |
| | **2** | 1.16 | 1.71 | 1.37 | 0.04 | 0.17 | 12.71 | 0.63 | -0.69 |
| | **3** | 0.99 | 1.84 | 1.32 | 0.02 | 0.16 | 12.17 | 0.70 | 0.56 |
| | **5** | 1.09 | 1.56 | 1.35 | 0.07 | 0.17 | 12.86 | -0.67 | -0.69 |
| **Available Water Amount (%)** | **1** | 6.20 | 9.32 | 8.01 | 0.47 | 1.16 | 14.44 | -0.64 | -0.46 |
| | **2** | 5.59 | 11.74 | 8.17 | 0.41 | 1.62 | 19.88 | 0.27 | 0.24 |
| | **3** | 2.89 | 13.19 | 9.14 | 0.27 | 2.59 | 28.35 | -0.45 | -0.44 |
| | **5** | 5.06 | 11.20 | 8.36 | 0.81 | 1.99 | 23.84 | -0.46 | 1.94 |
| **Total Carbon (%)** | **1** | 1.90 | 11.65 | 7.16b | 1.36 | 3.33 | 46.46 | -0.50 | 0.58 |
| | **2** | 0.51 | 7.34 | 3.63a | 0.49 | 1.96 | 53.90 | 0.60 | -0.27 |
| | **3** | 0.57 | 9.01 | 2.96a | 0.17 | 1.59 | 53.85 | 1.51 | 2.81 |
| | **5** | 1.39 | 3.15 | 2.17a | 0.31 | 0.75 | 34.56 | 0.61 | -1.78 |
| **Available P(mg/kg)** | **1** | 1.81 | 19.74 | 10.02 | 2.60 | 6.37 | 63.61 | 0.43 | -0.26 |
| | **2** | 3.48 | 13.32 | 7.34 | 0.71 | 2.82 | 38.49 | 0.72 | -0.42 |
| | **3** | 2.97 | 23.38 | 8.33 | 0.45 | 4.29 | 51.47 | 1.19 | 1.08 |
| | **5** | 4.69 | 8.11 | 5.98 | 0.49 | 1.20 | 20.07 | 1.17 | 1.78 |
| **Potassium (meq/100)** | **1** | 0.44 | 0.74 | 0.55 | 0.05 | 0.12 | 21.91 | 0.75 | -0.92 |
| | **2** | 0.19 | 1.03 | 0.61 | 0.06 | 0.24 | 39.93 | 0.14 | -0.81 |
| | **3** | 0.20 | 1.22 | 0.65 | 0.02 | 0.22 | 33.25 | 0.33 | -0.30 |
| | **5** | 0.37 | 0.67 | 0.57 | 0.04 | 0.11 | 19.12 | -1.35 | 2.09 |
| **pH** | **1** | 7.26 | 8.73 | 8.14b | 0.26 | 0.65 | 7.94 | -0.81 | -1.77 |
| | **2** | 6.95 | 8.73 | 7.84ab | 0.16 | 0.63 | 8.07 | -0.04 | -1.36 |
| | **3** | 5.52 | 8.73 | 7.45a | 0.07 | 0.69 | 9.33 | -0.38 | -0.14 |
| | **5** | 7.22 | 8.65 | 7.70ab | 0.21 | 0.51 | 6.58 | 1.59 | 2.99 |
| **Electrical Conductivity (dS/m)** | **1** | 0.12 | 0.29 | 0.22b | 0.02 | 0.06 | 26.82 | -1.00 | 1.30 |
| | **2** | 0.06 | 0.23 | 0.18ab | 0.01 | 0.05 | 27.52 | -1.53 | 1.67 |
| | **3** | 0.06 | 0.44 | 0.15a | 0.01 | 0.06 | 40.74 | 1.47 | 4.26 |
| | **5** | 0.08 | 0.19 | 0.14a | 0.02 | 0.04 | 30.13 | -0.35 | -1.17 |

Min.= Minimum, Max.= Maximum, S. E.=Standard Error, Std. S. D.= Standard Deviation, C. V.= Coefficient of Variation, S.=Skewness, K.=Kurtosis Note=The letters next to the mean values of soil properties indicate group differences

Descriptive statistics and Duncan test results of aggregate stability, water-filled pore volume, bulk density, available water amount, total carbon, available P, potassium, pH and EC values from soil physical and chemical properties of the upper layers of soils (0-30) were determined according to bonitet classes.

According to Duncan homogeneity test results performed on the bonitet classes, while aggregate stability, water-filled pore volume, bulk density, available water amount, available P and potassium ratios were in the same groups, it was determined that the total C, pH and EC values were in different groups (Table 3).

The available P content of the soils was found to be 10.02 mg/kg in the 1st bonitet, 7.34 mg/kg in the 2nd bonitet, 8.33 mg/kg in the 3rd bonitet and 5.98 mg/kg in the 5th bonitet according to bonitet classes. According to Ülgen and Ateşalp (1972), the available P contents of the soils were in the middle group in the first, second and third bonitets, while it was in the low group in the fifth bonitet. The pH value of the soils was determined as 8.14 in the 1st bonitet, 7.84 in the 2nd bonitet, 7.45 in the 3rd bonitet and 7.70 in the 5th bonitet according to the bonitet classes. According to Jackson (1962) classification, the soils on the second, third and fifth bonitets were found to be alkalescence, while the soils on the first bonitet were medium alkaline. The electrical conductivity of the soils was determined as 0.22 dS/m in the 1st bonitet, 0.18 dS/m in the 2nd bonitet, 0.15 dS/m in the 3rd bonitet and 0.14 dS/m in the 5th bonitet according to bonitet classes. According to Anonymous (2008), the electrical conductivity values of the soils on the first, second, third and fifth bonitets were determined to be in the saltless class (0-2) (*Table 3*).

## 4.2. Soil Quality Assessment in Forest Ecosystems

### 4.2.1. Soil Quality According to Tree Species and Bonitet Classes

Descriptive statistics and Duncan test results of soil quality indicator values of the watershed area were determined according to tree species. Soils did not show similar functions among tree species in terms of capacity. While there were similarities in the aggregate stability scores of the soils, the scores of the total organic carbon, pH, available P, bulk density, electrical conductivity, available water amount, potassium and water-filled pore volume indicators were not similar according to tree species. When soil indicators are examined according to tree species, while the aggregate stability indicator has the highest scores, the available water amount indicator has the lowest scores (*Table 4*).

Soil quality index of the soil in terms of tree species was determined as 69.42% in black pine tree species, 76.06% in beech tree species, 77.31% in oak tree species and 71.52% in red pine tree species. According to the results of Duncan homogeneity test performed in terms of soil quality indices on tree species, it was determined that black pine, red pine, beech and oak tree species were in the same groups (Table 4; Figure 4).

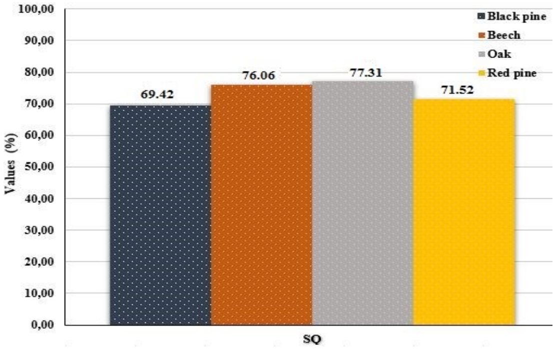

*Figure 4. Soil quality values change of soils according to tree species*

Descriptive statistics and Duncan test results of soil quality indicator values of the watershed were determined according to bonitet classes. Soils showed similar functions in terms of capacity among bonitet classes. While the scores of the total organic carbon, aggregate stability, available P, bulk density, electrical conductivity, available water amount and potassium indicators of soils were similar, the scores of the pH and water-filled pore volume indicators did not show similarity according to bonitet classes. When soil indicators are examined according to bonitet classes, while the aggregate stability indicator has the highest scores, the available water amount indicator has the lowest scores (Table 5).

***Table 4. Descriptive statistics and Duncan test results of soil quality indicator values of the study area according to tree species***

| N=180 | Tree Species | Min. | Max. | Mean | S. E. | S. D. | C. V. | S | K |
|---|---|---|---|---|---|---|---|---|---|
| **Aggregate Stability** | **Black pine (Ck)** | 1.00 | 1.00 | 1.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| | **Beech (Kn)** | 1.00 | 1.00 | 1.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| | **Oak (M)** | 1.00 | 1.00 | 1.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| | **Red pine (Cz)** | 1.00 | 1.00 | 1.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| **Water-Filled Pore Volume** | **Black pine (Ck)** | 0.58 | 0.96 | 0.84a | 0.02 | 0.09 | 11.33 | -0.64 | 0.25 |
| | **Beech (Kn)** | 0.62 | 0.95 | 0.89b | 0.01 | 0.07 | 7.53 | -2.67 | 8.47 |
| | **Oak (M)** | 0.88 | 0.97 | 0.95c | 0.00 | 0.02 | 2.47 | -1.46 | 1.86 |
| | **Red pine (Cz)** | 0.55 | 0.97 | 0.88b | 0.02 | 0.12 | 13.20 | -1.79 | 2.30 |
| **Bulk Density** | **Black pine (Ck)** | 0.32 | 0.99 | 0.84bc | 0.04 | 0.22 | 26.02 | -1.27 | 0.09 |
| | **Beech (Kn)** | 0.26 | 0.99 | 0.64a | 0.05 | 0.25 | 39.22 | -0.01 | -1.27 |
| | **Oak (M)** | 0.48 | 0.99 | 0.90c | 0.03 | 0.17 | 18.40 | -1.68 | 1.39 |
| | **Red pine (Cz)** | 0.29 | 0.99 | 0.77b | 0.05 | 0.26 | 33.93 | -0.80 | -1.04 |
| **Available Water Amount** | **Black pine (Ck)** | 0.06 | 0.82 | 0.33a | 0.03 | 0.16 | 47.25 | 1.15 | 2.35 |
| | **Beech (Kn)** | 0.41 | 0.72 | 0.63c | 0.01 | 0.08 | 12.05 | -0.95 | 0.87 |
| | **Oak (M)** | 0.31 | 0.83 | 0.56bc | 0.02 | 0.13 | 23.91 | 0.60 | -0.76 |
| | **Red pine (Cz)** | 0.13 | 0.75 | 0.54b | 0.03 | 0.18 | 32.73 | -0.95 | -0.17 |
| **Total Carbon** | **Black pine (Ck)** | 0.80 | 1.00 | 0.98b | 0.01 | 0.05 | 4.81 | -3.33 | 10.68 |
| | **Beech (Kn)** | 0.38 | 1.00 | 0.96ab | 0.02 | 0.12 | 13.05 | -3.82 | 16.29 |
| | **Oak (M)** | 0.94 | 1.00 | 1.00b | 0.00 | 0.01 | 1.10 | -5.48 | 30.00 |
| | **Red pine (Cz)** | 0.32 | 1.00 | 0.92a | 0.03 | 0.17 | 18.28 | -2.69 | 6.94 |
| **Phosphorus** | **Black pine (Ck)** | 0.12 | 0.93 | 0.46a | 0.04 | 0.23 | 49.62 | 0.21 | -0.91 |
| | **Beech (Kn)** | 0.17 | 0.98 | 0.71c | 0.05 | 0.26 | 37.29 | -0.80 | -0.76 |
| | **Oak (M)** | 0.21 | 0.95 | 0.65bc | 0.04 | 0.22 | 33.88 | -0.63 | -0.69 |
| | **Red pine (Cz)** | 0.02 | 0.97 | 0.54ab | 0.05 | 0.26 | 48.55 | 0.04 | -0.78 |
| **Potassium** | **Black pine (Ck)** | 0.76 | 1.00 | 0.94b | 0.01 | 0.08 | 8.17 | -1.30 | 0.59 |
| | **Beech (Kn)** | 0.89 | 1.00 | 0.98c | 0.01 | 0.03 | 3.35 | -1.71 | 1.63 |
| | **Oak (M)** | 0.89 | 1.00 | 0.98c | 0.01 | 0.03 | 2.87 | -2.35 | 5.42 |
| | **Red pine (Cz)** | 0.55 | 1.00 | 0.88a | 0.02 | 0.13 | 15.16 | -1.27 | 1.01 |
| **pH** | **Black pine (Ck)** | 0.60 | 1.00 | 0.86b | 0.02 | 0.12 | 13.84 | -0.75 | -0.12 |
| | **Beech (Kn)** | 0.72 | 1.00 | 0.92b | 0.02 | 0.08 | 9.19 | -1.09 | 0.27 |
| | **Oak (M)** | 0.61 | 1.00 | 0.86b | 0.02 | 0.11 | 12.62 | -0.60 | -0.71 |
| | **Red pine (Cz)** | 0.60 | 0.98 | 0.80a | 0.02 | 0.14 | 16.94 | -0.22 | -1.55 |
| **Electrical Conductivity** | **Black pine (Ck)** | 0.45 | 1.00 | 0.81a | 0.03 | 0.17 | 20.99 | -0.49 | -1.09 |
| | **Beech (Kn)** | 0.39 | 1.00 | 0.77a | 0.03 | 0.19 | 24.04 | -0.13 | -1.16 |
| | **Oak (M)** | 0.65 | 1.00 | 0.95b | 0.02 | 0.10 | 10.02 | -2.17 | 3.78 |
| | **Red pine (Cz)** | 0.39 | 1.00 | 0.86a | 0.04 | 0.21 | 24.88 | -1.36 | 0.40 |
| **SQ** | **Black pine (Ck)** | 60.56 | 79.98 | 69.42a | 0.91 | 4.97 | 7.16 | 0.30 | -0.33 |
| | **Beech (Kn)** | 59.69 | 82.68 | 76.06b | 1.02 | 5.61 | 7.37 | -1.15 | 1.11 |
| | **Oak (M)** | 68.33 | 83.80 | 77.31b | 0.68 | 3.74 | 4.84 | -0.73 | 0.21 |
| | **Red pine (Cz)** | 50.45 | 80.94 | 71.52a | 1.35 | 7.37 | 10.31 | -1.18 | 1.39 |

Min.= Minimum, Max.= Maximum, S. E.=Standard Error, Std. S. D.= Standard Deviation, C. V.= Coefficient of Variation, S.=Skewness, K.=Kurtosis, SQ= Soil Quality Note= The letters next to the mean values of the soil quality indicator values show the group differences

***Table 5. Descriptive statistics and Duncan test results of soil quality indicator values of the study area according to bonitet classes***

| N=180 | Bonitet Class | Min. | Max. | Mean | S. E. | S. D. | C. V. | S | K |
|---|---|---|---|---|---|---|---|---|---|
| **Aggregate Stability** | **1** | 1.00 | 1.00 | 1.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| | **2** | 1.00 | 1.00 | 1.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| | **3** | 1.00 | 1.00 | 1.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| | **5** | 1.00 | 1.00 | 1.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| **Water-Filled Pore Volume** | **1** | 0.58 | 0.95 | 0.83a | 0.06 | 0.15 | 18.62 | -1.13 | -0.43 |
| | **2** | 0.80 | 0.97 | 0.94b | 0.01 | 0.04 | 4.62 | -2.45 | 7.09 |
| | **3** | 0.55 | 0.97 | 0.88ab | 0.01 | 0.09 | 10.41 | -1.57 | 2.33 |
| | **5** | 0.85 | 0.97 | 0.93b | 0.02 | 0.04 | 4.46 | -1.51 | 2.98 |
| **Bulk Density** | **1** | 0.48 | 0.99 | 0.83 | 0.09 | 0.21 | 25.32 | -1.22 | 0.04 |
| | **2** | 0.34 | 0.99 | 0.83 | 0.06 | 0.25 | 29.91 | -1.25 | -0.31 |
| | **3** | 0.26 | 0.99 | 0.78 | 0.03 | 0.24 | 31.24 | -0.81 | -0.76 |
| | **5** | 0.35 | 0.99 | 0.73 | 0.12 | 0.31 | 41.83 | -0.50 | -2.31 |
| **Available Water Amount** | **1** | 0.30 | 0.73 | 0.61 | 0.06 | 0.16 | 26.17 | -1.94 | 3.99 |
| | **2** | 0.23 | 0.75 | 0.59 | 0.04 | 0.16 | 26.81 | -1.07 | 0.43 |
| | **3** | 0.06 | 0.83 | 0.49 | 0.02 | 0.18 | 35.53 | -0.43 | -0.54 |
| | **5** | 0.19 | 0.82 | 0.54 | 0.10 | 0.24 | 45.28 | -0.34 | -1.52 |
| **Total Carbon** | **1** | 1.00 | 1.00 | 1.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| | **2** | 0.32 | 1.00 | 0.95 | 0.04 | 0.17 | 17.79 | -3.95 | 15.70 |
| | **3** | 0.38 | 1.00 | 0.97 | 0.01 | 0.10 | 10.65 | -4.14 | 19.02 |
| | **5** | 0.78 | 1.00 | 0.95 | 0.04 | 0.09 | 9.03 | -2.15 | 4.79 |
| **Phosphorus** | **1** | 0.02 | 0.97 | 0.66 | 0.15 | 0.36 | 54.80 | -1.29 | 1.36 |
| | **2** | 0.16 | 0.92 | 0.57 | 0.06 | 0.24 | 41.22 | -0.01 | -1.31 |
| | **3** | 0.10 | 0.98 | 0.60 | 0.03 | 0.27 | 44.26 | -0.24 | -1.21 |
| | **5** | 0.31 | 0.71 | 0.48 | 0.06 | 0.14 | 29.40 | 0.70 | 0.61 |
| **Potassium** | **1** | 0.86 | 1.00 | 0.92 | 0.03 | 0.06 | 6.94 | 0.30 | -2.43 |
| | **2** | 0.55 | 1.00 | 0.90 | 0.03 | 0.13 | 14.11 | -1.63 | 2.74 |
| | **3** | 0.56 | 1.00 | 0.96 | 0.01 | 0.08 | 8.60 | -2.85 | 9.34 |
| | **5** | 0.80 | 1.00 | 0.94 | 0.03 | 0.07 | 7.90 | -1.86 | 3.83 |
| **pH** | **1** | 0.60 | 0.94 | 0.74a | 0.06 | 0.15 | 20.22 | 0.75 | -1.82 |
| | **2** | 0.60 | 0.98 | 0.81ab | 0.03 | 0.14 | 17.00 | -0.28 | -1.32 |
| | **3** | 0.60 | 1.00 | 0.88b | 0.01 | 0.11 | 12.44 | -0.81 | -0.25 |
| | **5** | 0.62 | 0.95 | 0.85b | 0.05 | 0.12 | 14.08 | -1.90 | 3.96 |
| **Electrical Conductivity** | **1** | 0.78 | 1.00 | 0.96 | 0.04 | 0.09 | 9.32 | -2.45 | 6.00 |
| | **2** | 0.39 | 1.00 | 0.92 | 0.05 | 0.19 | 20.74 | -2.27 | 4.17 |
| | **3** | 0.39 | 1.00 | 0.83 | 0.02 | 0.18 | 21.88 | -0.76 | -0.60 |
| | **5** | 0.52 | 1.00 | 0.84 | 0.08 | 0.21 | 24.43 | -1.03 | -0.93 |
| **SQ** | **1** | 68.26 | 79.73 | 74.75 | 1.89 | 4.62 | 6.18 | -0.28 | -1.57 |
| | **2** | 54.81 | 83.80 | 74.25 | 1.88 | 7.51 | 10.11 | -1.32 | 1.84 |
| | **3** | 50.45 | 82.68 | 73.45 | 0.67 | 6.46 | 8.79 | -0.78 | 0.50 |
| | **5** | 65.55 | 76.84 | 72.54 | 1.73 | 4.23 | 5.83 | -0.87 | 0.15 |

Min.= Minimum, Max.= Maximum, S. E.=Standard Error, Std. S. D.= Standard Deviation, C. V.= Coefficient of Variation, S.=Skewness, K.=Kurtosis, SQ= Soil Quality Note= The letters next to the mean values of the soil quality indicator values show the group differences

Soil quality index in terms of bonitet classes of soils was determined as 74.75% in the first bonitet, 74.25% in the second bonitet, 73.45% in the third bonitet and 72.54% in the fifth bonitet. According to the Duncan homogeneity test results, soil quality indices of four different bonitets (1, 2, 3 and 5) were in the same group (*Table 5, Figure 5*).

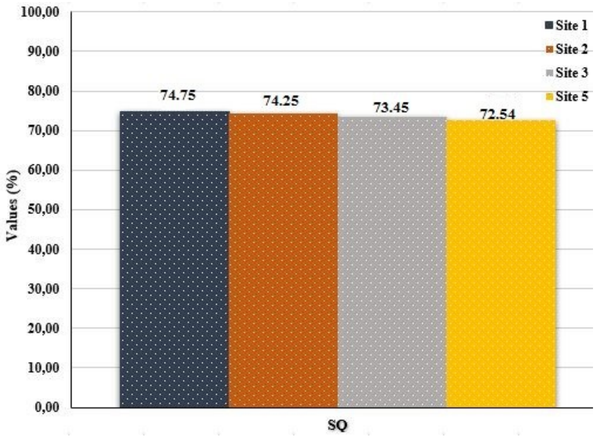

***Figure 5. Soil quality values change of soils according to bonitet classes***

When the soil quality was evaluated according to bonitet classes in the watershed, the lowest soil quality index was determined in the soils located on the fifth bonitet. The presence of karstic areas in the fifth bonitet and the soil degradation as a result of silvicultural practices caused the soils to have lower quality scores (Figure 6). The selection and implementation of managements that include protection and improvement targets on the soils on forest ecosystems will increase the soil quality by increasing the capacities of soil functions. According to the results obtained, it was understood that the bonitet classes of forest ecosystems have the potential to be used as a function of soil quality. The soils of the karst areas are shallower and lowered the general soil quality score. The dynamic properties of the soil lose its productivity functions by being exposed to intense human activities (Günal et al. 2015). Although the soil quality scores in the fifth bonitet are not very low in general, the reason why it scores lower than other bonitets is the soil erosion caused by silvicultural interventions. Erosion reduces soil fertility by causing loss of soil nutrients. Nutrient depletion and loss of soil fertility are major causes of low productivity in many developing countries. The use of organic materials, recycling of organic by-products including urban waste, is a useful strategy to increase soil fertility and improve structural stability or aggregates (Lal, 2015).

***Figure 6. Karst areas and silvicultural practices in forest ecosystems***

## 5. Conclusions

The Soil Quality Index has been determined, exhibiting variations across different tree species. It has been established that decomposition processes and stand dynamics significantly influence this variation. The study identified the highest Soil Quality Index in soils within broadleaf stands. Furthermore, it was determined that soil bonitet classes do not significantly affect the Soil Quality Index. The absence of a difference between soil quality and bonitet indices has been attributed to the karstic characteristics of the study areas. Although the soils in these areas are concentrated in karstic pockets, they are shallow in certain locations. Despite the generally high soil quality in karstic ecosystems, absolute soil depth remains one of the most critical factors limiting plant growth.

In the region, karstic-origin formations restrict soil depth, which poses challenges for the restoration of fragile forest ecosystems, particularly those requiring deep soils. Soil erosion, especially in areas with low stand canopy closure, leads to the loss of a significant portion of plant nutrients in surface soils. Consequently, soil functions deteriorate, adversely affecting soil quality. In the sustainable management of soils, which are among our essential natural resources, the use of the Soil Management Assessment Framework (SMAF) as a method for calculating the Soil Quality Index requires specific parameters, particularly for karstic ecosystems. This will enable land managers to develop management plans aimed at improving low-productivity areas.

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### Ethical Statement

There is no need to obtain permission from the ethics committee for this study.

### Conflicts of Interest

The authors declare that they have no confict of interest.

### Authorship Contributions Statement

Concept: Reis, A.; Design: Reis, A., Dindaroğlu, T.; Data Collection or Processing: Reis, A.; Statistical Analyses: Reis, A.; Literature Search: Reis, A.; Writing, Review and Editing: Reis, A., Acir, N., Dindaroğlu, T.

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