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Effects of Soil Compaction on Vegetation and Soil Physicochemical Properties in Recreational Areas: A Case Study of Kastamonu

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Abstract

Aim of study: This study investigated the possible effects of soil penetration resistance on soil properties and tree physiology in recreational area soils.

Area of study: It was studied in Açık Maslak and Kadıdağı recreational areas in Kastamonu.

Material and methods: Some soil properties were determined in 395 soil samples from park, road, control, and picnic areas in each recreational area. At 61 points, soil penetration resistance was measured with a penetrometer. Some physiological properties were determined in fresh needle samples of 42 trees.

Main results: Soil penetration resistance in the control ranges from 1.6 MPa to 2.1 MPa, with medium compaction, while in other-use areas with high compaction ranged from 2.03 MPa to 3.75 MPa. The soil penetration resistance linearly decreased with increasing organic matter and permeability values. In contrast, the soil penetration resistance increased linearly with increasing soil bulk density. Additionally, the effects of all of tree's physiological properties on soil penetration resistance were not found to be statistically significant ($P>0.05$).

Research highlights: Depending on soil use, it was observed that soil penetration resistance was less effective for organic matter, permeability, bulk density and soil moisture content. However, some chemical compounds in trees did not show a significant trend in soil penetration resistance. Our findings show that moderate to high compaction in recreational area soils often significantly affects visitor density or trampling by visitors, which can lead to soil degradation.

Keywords: Soil Compaction, Nutrients, Pine Needle, Plant Physiology, Recreation

Rekreasyon Alanlarda Toprak Sıkışmasının Bitki ve Toprak Fizikokimyasal Özellikleri Üzerindeki Etkileri: Kastamonu Örneği

Öz

Çalışmanın amacı: Bu çalışmada rekreasyon alanı topraklarında, toprak penetrasyon direncinin toprak özellikleri ve ağaç fizyolojisi üzerindeki olası etkileri araştırılmıştır.

Çalışma alanı: Kastamonu'da bulunan Açık Maslak ve Kadıdağı rekreasyon alanlarda çalışılmıştır.

Materyal ve yöntem: Her bir rekreasyon alanı içerisinde park, yol, kontrol ve piknik alanların 395 toprak örneğinin bazı özellikleri belirlenmiştir. 61 noktada toprak penetrasyon direnci penetrometre ile ölçülmüştür. 42 ağacın taze ibre örneklerinde bazı fizyolojik özellikler belirlenmiştir.

Temel sonuçlar: Kontrol alanların toprak penetrasyon direnci orta derecede ve 1.6 MPa ile 2.1 MPa arasında değişirken, yüksek derecede sıkışmış diğer kullanım alanlarında 2.03 MPa ile 3.75 MPa arasında değişmektedir. Organik madde ve geçirgenlik değerlerinin artmasıyla toprağın penetrasyon direnci doğrusal olarak azalırken, hacim ağırlığının artmasıyla ile birlikte doğrusal olarak artmıştır. Ayrıca ağacın fizyolojik özellikleri toprak penetrasyon direncine etkisi istatistiksel olarak anlamsızdır ($P>0.05$).

Araştırma vurguları: Toprak kullanımına bağlı olarak, organik madde, permeabilite, hacim ağırlığı ve toprak nemi üzerinde toprak penetrasyon direncinin çok az da olsa etkili olduğu, ancak ağaçlardaki bazı kimyasal bileşiklerin toprak penetrasyon direncinde önemli bir eğilim göstermediği görülmüştür. Bulgularımız, rekreasyon alanı topraklarında orta ve yüksek derece sıkışmanın çoğunlukla ziyaretçilerin yoğunluğu ya da ziyaretçiler tarafından çiğnenmesinin önemli bir etkiye sahip olduğu ve bunun da toprağın bozulmasına yol açabileceğini göstermektedir.

Anahtar Kelimeler: Toprak Sıkışması, Besin Elementi, Çam İbresi, Bitki Fizyolojisi, Rekreasyon

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Introduction

Rural recreation areas are among the most critical places that meet the recreation needs of people in our present day (Turgut, 2012). In addition to the positive effects of recreational activities on people, they can also cause some negative impacts on the natural environment. The most important among these are humans' constant trampling of the soil surface. Pedestrian traffic, which is inevitable in recreational areas, can increase the mass density of the soil at significant levels, cause soil compaction, decrease the plant cover rate and species diversity, and shorten plant heights (Kissling et al., 2009; Mingyu et al., 2009). The intensive use of such areas by people causes compaction of forest surface soils. This compaction then affects some physical and chemical properties of soils as well as the physiological properties of plants.

Soil compaction causes changes in soil structure, the amount of available water and physical properties of the soil, such as (1) an increase in soil bulk density; (2) disintegration of soil aggregates; (3) a reduction in soil porosity; (4) loss of pore continuity; (5) decreased infiltration capacity; and (6) increased water erosion (Hargreaves et al., 2019; Wang et al., 2020; Bremer et al., 2021; Schäffer, 2022; Vistro et al., 2022). These changing soil properties restrict the growth and development of wood-like plants, reducing shoot growth at significant levels (Chiapperini & Donnelly, 1978). Recreational areas limit the rooting area of plants and slow down or stop root penetration (Materechera et al., 1991). These limiting factors allow roots to spread laterally and develop only for short distances (Tirado-Corbalá & Slater, 2010). The number of macropores decreases, and the number of micropores increases during soil compaction (Huang et al., 1996). Regarding water permeability, as the soil bulk density increases (and the pore size decreases in this context), the infiltration rate of rainwater decreases. Slow infiltration causes water deficits in the soil, runoff, and erosion (Kramer & Boyer, 1995; Sarıyıldız & Küçük, 2005). Lutz (1945) reported that soil permeability, exposed to heavy recreational use in State Park, was lower than that of undisturbed soil, and the water infiltration rate varied according to the soil type. Compaction also indirectly affects the chemical properties of soils. Oxygen deficiency occurs due to soil compaction, and decreased macroporosity is detected. For this reason, nitrogen mineralization and nitrogen loss in compacted soils are decreased (Closa & Goicoechea, 2010).

Negativities may occur in the uptake of water and nutrients, growth hormones needed for meristem tissues, and carbohydrate synthesis with the physiological dysfunction of plants grown in compacted soils (Turgut, 2012). It also negatively impacts plant growth and performance (Alameda & Villar, 2012). Chlorosis problems occur because of the insufficient chlorophyll content in the leaves, which can directly limit photosynthetic pigment synthesis (Kobaissi et al., 2013). Smiley et al. (2006) reported that the chlorophyll contents of plants are significantly lower in compacted soils than in non-compacted soils. Mariotti et al. (2020) reported that soil compaction causes decreased rates of photosynthesis. The first response of plants to these stresses is the change in the water content of their tissues, membrane permeability, chlorophyll content, and gas exchange parameters (Ripley et al., 2007). Exposure of roots to oxygen deficiency in excess water causes changes in subsoil respiration and increased carbohydrate utilization and synthesis of antioxidants (Couée et al., 2006; Sun et al., 2015), which, in turn, decreases growth, increases membrane damage, decreases stomatal conductivity, and photosynthesis as the first response of plants to environmental stresses (Ripley et al., 2007). The purpose of this study was to uncover the changes in the properties of some soil types and the physiological properties of tree leaves as a result of the pressure of visitors to the control (non or less-compacted) and parks, roads, and picnic areas in the recreational areas in the city of Kastamonu.

Materials and Methods

Description of the Study Areas and Sampling

This study was conducted in 2 urban parks in Kastamonu, located in northern Türkiye (Figure 1). The first study area, Şehit

Şerife Bacı Nature Park (Kadıdağı), is 12 km away from the city center and is commonplace for the people of the city (41°15'44" N, 33°46'57" E, Figure 1). The study area has an area of 10 hectares. Approximately 33,600 people visited the park in 2019, and 38,400 people visited the park in 2020. The second study area, the Şehit Dursun Erdoğan recreational area (Açık Maslak), is 8 km away from the city center (41°22'35" N, 33°44'10" E, Figure 1). The park covers an area of approximately 6 hectares and is a popular entertainment place for the city's citizens. Approximately 35,000 people visited the park in 2019 and approximately 40,000 in 2020.

Figure 1. The location of the study areas and a) Control (non-compacted) in the Açık Maslak recreational area, b) Park in the Kadıdağı recreational area, c) Road in the Açık Maslak recreational area, d) Picnic area in the Kadıdağı recreational area

The bedrock of the recreational areas mainly developed from sedimentary rocks, medium-thick bedded, heavily jointed, gray-beige colored, massive structure (Atalay, 2006), and Eocene neritic limestone (fossil $CaCO_3$) (Akbaş et al., 2011). The soil texture of the Kadıdağı recreational area is sandy loam (in the park), loamy sand (in the control), and sandy clay loam (in the road and picnic area). The soil texture in the Açık Maslak recreational area is sandy loam (in the park, control, and picnic areas) and sandy clay loam (road). The area's average temperature is 10.4°C, and the total annual precipitation is 623.6 mm (Savacı & Öksüz, 2020). The study areas have a humid, microthermal climate. The highest temperature is 29.9°C in August. The lowest temperature is -4.0°C in January (Öksüz, 2019). The study areas have similar environmental conditions. The dominant tree species in the Açık Maslak recreational area are Scots pine (*Pinus sylvestris* L.) and black pine (*Pinus nigra* Arnold), and in the Kadıdağı recreational area are only Scots pine (*Pinus sylvestris* L.) trees. The parks and roads of both recreational areas are usually covered with existing soil cover. In addition, it is possible to see the protrusions of tree roots on the measuring roads (Figure 1). Soil sampling was performed to measure the soil compaction of children's playgrounds (park), roads, picnic areas (places trampled by visitors), and control areas (natural vegetation not trampled by visitors) in each urban park (Figure 1) and to examine some physical and chemical properties of the soils. Soil samples nondisturbed were taken from 20 m x 20 m = 400 m^2 surrounding areas at six different soil depth levels (0-5 cm, 5-10 cm, 10-15 cm, 15-20 cm, 20-25 cm, and 20-30 cm), and a total of 395 (8 soil use × 6 soil depth × 8 repetition = 384 soil samples + 11 extra cylinder samples were taken when 25-30 cm depths could not be reached in heavily compacted soils) soil samples were taken from recreational areas. The compaction values in the soils of 61 points were checked with the help of a 30º manual penetrometer (Vicksberg Penetrometer - Proving Ring Penetrometer). Penetrometer measurements of compaction values in the Açık Maslak recreational area soil were made from 11 points of the park, 8 points of the road, 6 points of the picnic area, and 6 points of the control. Penetrometer measurements of compaction values in the Kadıdağı recreational area were made from 10 points of the park, 8 points of the road, 6 points of the picnic area, and 6 points of the control. The penetrometer measurements were recorded at depth intervals of 5 cm using a manual (hand-pushed) penetrometer at 6 soil depths. The classification of soil penetration resistance is presented in Table 1.

Table 1. The classes of penetration resistance (USDA, 1993)

Penetration Resistance (MPa)	Class
<0.01	Extremely low
0.01-0.1	Very low
0.1-1.0	Low
1.0-2.0	Moderate
2.0-4.0	High
4.0-8.0	Very high
<8.0	Extremely high

Eighteen disturbed soil samples were taken from the 0-30 cm depth level to analyze the soil texture. The soil samples were separated from stones and pebbles greater than 2 mm in diameter by passing through a sieve of 2 mm mesh for soil analysis.

Soil Analysis

The soil bulk density and moisture content were analyzed in undisturbed soil samples. The soil was sampled at six depths: 0–5 cm, 5-10 cm, 10-15 cm, 15-20 cm, 20-25 cm, and 25–30 cm. Nondisturbed soil samples were collected into 100 cm^3 Kopecky cylinders (5 cm in height and diameter) and dried at 105ºC until constant weight (Orzech et al., 2021). The permeability in soil samples was determined by applying a formula based on Darcy's law using Equation 1 (Schwab, 1966).

$$P = ((Q/A) \times (Hs/Hs + Hw)) \quad (1)$$

Here, P refers to the permeability (cm hour^{-1}), Q refers to the amount of water passing at a particular time point (cm hour^{-1}), A refers to the cross-sectional area of the soil sample (cm^2), Hs refers to the height of the soil sample (cm), and Hw refers to the water column height (cm).

Having calculated the soil moisture content (SMC), the soil samples used in permeability analyses and saturated with water were subsequently subjected to free drainage (approximately 30 minutes) on a sloping surface, weighed, and then saturated weights were determined. These were then dried in an oven at 105ºC for 24 hours and weighed, and the soil moisture content

(SMC) was determined in Equation 2 (Luo et al., 2023).

$$\% \, Soil\ moisture\ content\ (\theta m) = \left(\frac{weight\ of\ most\ soil - weight\ of\ dry\ soil}{weight\ of\ dry\ soil}\right) \times 100 \quad (2)$$

After drying the cylindrical soil samples in an oven at 105ºC for 24 hours, the bulk density of each soil sample over the oven-dried weight was determined in g cm^{-3} with the help of the formulas. Sand (2.0 – 0.05 mm in diameter), silt (0.05 – 0.002 mm), and clay (less than 0.002 mm) ratios at 0-30 cm depth soil samples were determined with the Bouyoucos Hydrometer Method (Bouyoucos, 1936). The amount of organic matter in the soils was estimated with the loss of ignition (LOI) method after burning at 550ºC for 5 h (Bojko & Kabala, 2014). Additionally, some macronutrients (Ca, Mg, P, K) and micronutrients (Mn and Na) of the soil were determined with the Spectro Xepos II model XRF device.

Analysis of the Needle Leaf Samples

To determine the peroxidase dismutase (POD) and superoxide dismutase (SOD) enzyme activities and some physiological properties (i.e., photosynthetic pigment amounts (chlorophyll a, chlorophyll b, chlorophyll a:b, total chlorophyll and carotenoid amount), proline, protein in fresh needle leaf samples collected from 4 different points in the field (picnic area, park, roadside, and control) and the amount of nitrate, glucose, and sucrose), and needle leaf samples were taken from approximately 42 trees and randomly from the top of the tree. After being brought to the laboratory, needle samples were dried at 60ºC for 24-48 hours, cut into small pieces in a grinding machine, and prepared for analysis. The Arnon equation (Arnon, 1949) was used to determine the total amount of chlorophyll, and the number of carotenoids was determined according to the Jaspars formula (Witham et al., 1971). Chlorophyll and carotenoid concentrations in fresh needle leaves were analyzed using a UV–visible spectrophotometer (PG Instruments Ltd., Alma Park, Wibtoft, Leicestershire, England).

In needle samples, the amount of proline was determined according to the methods used by Bates et al. (1973), and the amount of protein was determined by Bradford (1976). The light absorption of the toluene phase was estimated at 520 nm using a UV–visible spectrophotometer (Terzi et al., 2014). The total proline content was expressed as μmol g^{-1} fresh weight (FW) of leaves. The needle leaf samples were measured spectrophotometrically at 595 nm. The Anthron method (Pearson et al., 1976) was used to quantify glucose and sucrose. SOD (enzyme commission number [EC] 1.15.1.1) enzyme activity was determined according to the method of Cakmak (2002), POD ([EC 1.12.1.1) enzyme activity was determined according to the method of Angelini et al. (1990). Ascorbate peroxidase ([EC] 1.11.1.11) enzyme activity was determined according to Nakano & Asada (1981). The nitrate content in the needles was determined according to the method of Cataldo et al. (1975) and the rapid colorimetric method. Additionally, macro- and micronutrient elements of needle samples were determined with the Spectro brand Xepos II model XRF device on the samples taken from 4 different points (park, road, control, and picnic areas) where jamming was observed in the recreational areas and natural control areas.

Data Analysis

The data conformity to the normal distribution was checked with the one-sample Kolmogorov–Smirnov (K-S) test. The soil data showed a normal distribution ($P>0.05$), and the physiological and nutritional element data of the needles did not show a normal distribution ($P<0.05$). The Kruskal–Wallis ANOVA test, one of the nonparametric tests, was used since the needle data did not show a normal distribution. Dunn's Bonferroni correction (Dunn, 1964) was used for pairwise comparisons of the groups. Since nonparametric statistical methods were used, the findings and discussion section evaluations were based on medians instead of arithmetic means (Küçük & Yener, 2019). Statistical calculations on soil properties have been shown separately for each recreation area. However, since the physicochemical properties of tree needles in both recreation areas were close, the values of the two recreation areas were combined and are shown according to their median values.

The data were evaluated with SPSS 20.0, the package program, variance analysis was applied, and homogeneous groups were obtained by applying the Duncan test for soil data to the values with significant differences at a 95% confidence interval level (IBM Corp., 2011). Statistical variations in soil properties (soil penetration resistance, pH, bulk density, permeability, organic matter, soil moisture content, Ca, Mg, P, K, Mn, and Na concentrations) among six depths and four soil uses (park, road, picnic area, and control) were analyzed by univariate ANOVA with a general linear model in two recreational areas. When the means exhibited significant differences, the data were analyzed using the Duncan test (P<0.05) to assess variations between the four soil uses. The relationship between soil penetration resistance and soil properties was investigated using univariate linear regression analysis for every recreational area. No statistically significant difference was observed in soil properties according to soil depth in recreational areas, and statistical values were not given (P>0.05).

Results

Soil Penetration Resistance and Soil Properties

The mean soil penetration resistance of recreational areas with different soil uses (park, road, picnic area, and control) and soil depths are given in Figure 2. Penetration resistance in control area soils ranges from 1.6 MPa to 2.1 MPa, and soils generally have medium compaction. The control in each recreational area at all depths had the lowest soil penetration resistance values (Figure 2). The penetration resistance values of the road, park, and picnic area soils in both areas are between 2.0 MPa and 4.0 MPa (Figure 2). According to the soil penetration resistance classification, high compaction was observed in the park, road, and picnic area soils. In the Açık Maslak recreational area, especially in parks, roads, and picnic areas, soil compaction was most observed at the 20-25 cm and 25-30 cm soil depth levels (3.7 MPa). In the Kadıdağı recreational area, the soils under the parks (3.38 MPa) were compressed the most, followed by roads (3.07 MPa), picnic areas (2.61 MPa), and control (1.76 MPa), respectively. Similarly, in the Açık Maslak recreational area, the soils under the park (3.34 MPa) were the most compacted, followed by the road (3.06 MPa), picnic areas (3.02 MPa) and control (2.03 MPa), respectively.

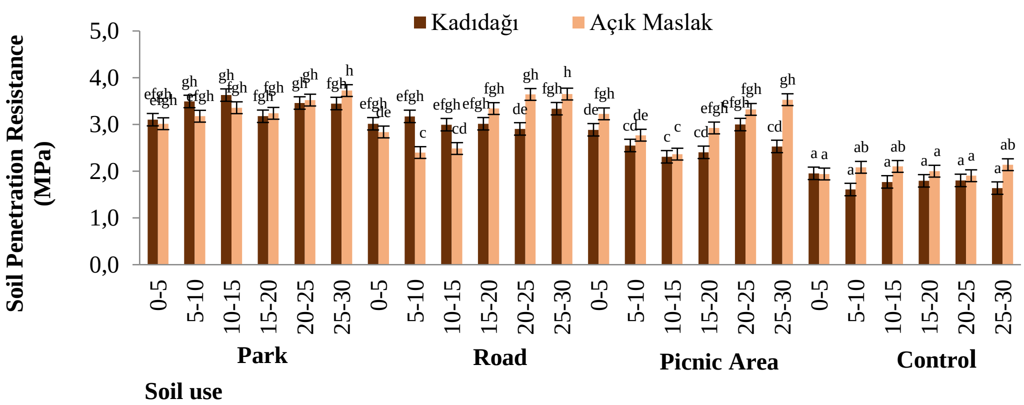


Figure 2. Mean values and Duncan test results based on soil penetration resistance. Mean values followed by different letters for the same area indicate significant differences at P<0.05 by Duncan's test.

The soil texture of the recreational areas at 0-30 cm soil depth is given in Figure 3. The results showed no significant variations (P>0.05) in the recreational areas. The soil textures in Kadıdağı park, road, picnic area, and control were sandy loam, sandy clay loam, loamy sand, and sandy clay loam, respectively. While the park, control, and picnic areas in the Açık Maslak recreational area are sandy loam, the soils on the road have sandy clay loam soils. The silt percentage of both recreational areas generally showed similar soil properties. There was no statistically significant difference in sand and clay percentages in the Açık Maslak recreation area soil according to soil use (P>0.05). No statistically significant difference was observed in the sand percentage in the park and control lands in the Kadıdağı recreation area (Figure 3).

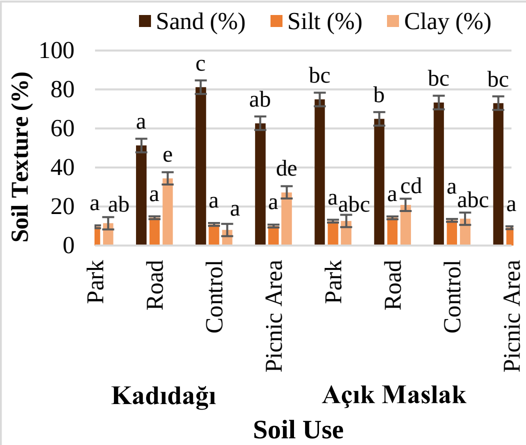


Figure 3. Soil texture in recreational areas Mean values followed by different letters for the same area indicate significant differences at P <0.05 by Duncan's test.

The average pH, bulk density, permeability, organic matter, soil moisture content, Ca, Mg, P, K, Mn, and Na concentrations in the soils of parks, roads, control, and picnic areas in Kadıdağ and Açık Maslak recreational areas are given in Table 2.

There was no statistically significant difference in soil pH according to soil use in the Açık Maslak recreational area (P>0.05). In contrast, a statistically significant difference was found in the Kadıdağı recreational area (P<0.05). The highest soil pH was found in the Açık Maslak recreational area, and the pH values varied between 7.9 and 8.2. In the Kadıdağı recreational area, the lowest pH is in the picnic area soils, and pH values varied between 6.2 and 7.5. Soils showed slightly alkaline soil properties in the Açık Maslak recreational area, while soils showed slightly acidic and neutral soil properties in the Kadıdağı recreational area. Bulk density was highest with 1.51 g cm^{-3} in road soils at Açık Maslak and 1.47 g cm^{-3} in road soils at Kadıdağı and lowest with 0.83 g cm^{-3} in control soils at Açık Maslak and 0.86 g cm^{-3} in control soils at Kadıdağı. No statistically significant difference was found since the bulk density values were close in the areas with the same land use in both recreational areas. However, a statistically significant difference was found between different land uses (park, road, picnic area, and control). In the Açık Maslak recreational area, the highest soil permeability was observed in the picnic area (30.9 cm h^{-1}) and control soils (44.5 cm h^{-1}), and a statistically significant difference was found between these two soil uses. In the Kadıdağı recreational areas, the highest permeability values were found in the control soils (49.0 cm h^{-1}), and no statistically significant difference was found between the other soil uses except for the control soils. The soil organic matter content was highest in the control soils, with 13.8% in the Açık Maslak recreational areas and 19.5% in the Kadıdağı recreational areas, while it was low in the other areas. While there was no statistically significant difference in organic matter contents in the park and road soils, significant differences were observed in the picnic area and control soils. The soil moisture content was highest in control soils (32.8%), and a statistically significant difference was found only in control soils according to other soil uses in the Açık Maslak recreational area. However, a statistically significant difference was found in the park with the lowest soil moisture content (18.3%) in the Kadıdağı recreational area (Table 2).

The highest calcium (Ca) concentration was observed in the soil under all soil uses of the Açık Maslak recreational area and varied between 88.6 g kg^{-1} (picnic area) and 115.6 g kg^{-1} (road). The lowest Ca concentrations were between 16 g kg^{-1} (picnic area) and 23.8 g kg^{-1} (road) in the Kadıdağı recreational area. There were statistically significant differences in the Ca concentrations in soil uses in the Açık Maslak recreational area. The magnesium (Mg) concentration was the highest, with 13.8 g kg^{-1} in the park soils at

Kadıdağı, followed by 11.7 g kg^{-1} in the road soils at Açık Maslak, 11.4 g kg^{-1} in the park soils, 11.3 g kg^{-1} in the picnic area soils, and 11.2 g kg^{-1} in the control soils at Açık Maslak. There were no statistically significant differences in the Mg concentrations in any soil use in the Açık Maslak recreational area (Table 2). The phosphorus (P) concentration had the highest value in Kadıdağı control soils (0.78 g kg^{-1}), and a statistically significant difference was found between soil uses. It was observed that P concentration decreased in high compaction soils (road). The potassium (K) concentration was highest in picnic area soils with 12.4 g kg^{-1}, followed by 11.7 g kg^{-1} in road, 11.3 g kg^{-1} in control, and 10.9 g kg^{-1} in park soils in the Açık Maslak recreational area. However, the K concentrations in soil uses in the Kadıdağı recreational area were very close, and no statistically significant difference was found. While the manganese (Mn) concentration had the lowest value (mean 0.35 g kg^{-1}) in the Açık Maslak recreational area, it was approximately four times higher (mean 1.29 g kg^{-1}) in the Kadıdağı recreational area. There was no statistically significant difference between Mn concentrations according to soil use in the Açık Maslak recreational area, and a statistically significant difference was found between some soil uses in the Kadıdağı recreational area. The sodium (Na) concentration was highest in the park soil (17.1 g kg^{-1}) and lowest in the picnic area soil (8.0 g kg^{-1}) in the Kadıdağı recreational area, and a statistically significant difference was found only in the park soil (Table 2).

Table 2. Mean values and Duncan test results based on other soil properties and soil use

Recreation Area	Soil Properties	Soil Use Areas			
		Park	Road	Picnic Area	Control
		M±SE	M±SE	M±SE	M±SE
Açık Maslak (n=167)	pH	8.1^{e}±.04	8.2^{e}±.07	8.2^{e}±.04	7.9^{e}±.06
	BD (g cm^{-3})	1.12^{c}±.03	1.51^{d}±.04	0.99^{b}±.03	0.83^{a}±.02
	Permeabillity	11.9^{a}±1.1	8.8^{a}±1.9	30.9^{b}±3.1	44.5^{c}±4.9
	OM (%)	5.8^{a}±.3	5.9^{a}±.3	9.2^{b}±.4	13.8^{c}±.4
	SMC (%)	19.7^{a}±.9	17.4^{a}±1.8	22^{a}±1.8	32.8^{b}±1.5
	Ca (g kg^{-1})	113.4^{d}±2.6	115.6^{d}±4.5	88.6^{b}±4.5	103.5^{c}±5
	Mg (g kg^{-1})	11.4^{c}±.1	11.7^{c}±.2	11.3^{c}±.4	11.2^{c}±.6
	P (g kg^{-1})	0.59^{bc}±.0	0.57^{b}±0.0	0.67^{de}±.03	0.68^{e}±0.0
	K (g kg^{-1})	10.9^{c}±.1	11.7^{d}±.5	12.4^{e}±.3	11.3^{cd}±.2
	Mn (g kg^{-1})	0.35^{a}±0.0	0.35^{a}±.01	0.37^{a}±.0	0.34^{a}±0.0
	Na (g kg^{-1})	9.3^{cd}±.1	8.5^{abc}±.2	8.2^{ab}±.4	9.9^{d}±.2
Kadıdağı (n=228)	pH	7.5^{d}±.04	6.9^{c}±.07	6.2^{a}±.07	6.5^{b}±0.1
	BD (g cm^{-3})	1.09^{c}±.02	1.47^{d}±.02	1.07^{bc}±.03	0.86^{a}±.03
	Permeability	6.7^{a}±.5	10.2^{a}±.7	12.6^{a}±1.3	49.0^{c}±5.5
	OM (%)	5.4^{a}±.3	5.3^{a}±.4	9.9^{b}±.6	19.5^{d}±.7
	SMC (%)	18.3^{a}±1.1	35.7^{bc}±1.1	34^{bc}±2.6	37.4^{c}±1.4
	Ca (g kg^{-1})	22.9^{a}±.5	23.8^{a}±.3	16.0^{a}±.5	19.2^{a}±1.4
	Mg (g kg^{-1})	13.8^{d}±.4	9.8^{b}±.08	8.8^{a}±.2	8.6^{a}±.2
	P (g kg^{-1})	0.63^{cd}±.0	0.47^{a}±.0	0.55^{b}±.03	0.78^{f}±.01
	K (g kg^{-1})	9.2^{b}±.1	9.5^{b}±0.1	8.6^{a}±.3	9.15^{ab}±.1
	Mn (g kg^{-1})	1.39^{c}±.02	1.27^{b}±.2	1.23^{b}±.0	1.26^{b}±.02
	Na (g kg^{-1})	17.1^{e}±.5	9.0^{bcd}±.06	8.0^{a}±.03	8.4^{abc}±.4

The standard error of the mean is shown next to it. Small letters that differ in vertical columns indicate that the means differ significantly from each other (*P*<0.05, n=395). BD: Bulk density, OM:Organic matter, SMC: Soil moisture content, Ca: calcium, Mg:magnesium, P: phosphorus, K:potassium, Mn: manganese, Na:sodium, Rec.: Recreational, M±SE: Mean± Standard Error.

The statistical significance of the soil penetration resistance and the single and combined effects of soil depth and soil use on some soil properties (pH, bulk density, permeability, organic matter, soil moisture content, Ca, Mg, P, K, Mn, and Na) are listed in Table 3. There were significant effects of soil use on soil penetration resistance variables in all recreational areas (*P*<0.001). Two-way (soil depth × soil use) interactions were not significant for soil penetration resistance (*P*>0.05). There were significant effects of soil use (*P*<0.01) on the soil pH, bulk density, permeability, organic matter, moisture content, Ca, P, K, Mn, and Na concentrations in all recreational areas. The effects of soil depth and two-way (soil depth × soil use) interactions on Ca (*P*<0.01), P (*P*<0.001), K (*P*<0.001), and Mn (*P*<0.001) use, or soil depth × soil use in the Açık Maslak recreational area (*P*>0.05). The soil moisture content was significantly correlated with soil depth (*P*<0.01), soil use (*P*<0.001), and soil depth × soil use (*P*<0.05) in the Kadıdağı recreational area. Soil penetration resistance, soil pH, bulk density, permeability, organic matter, and soil moisture content were only significantly concentrations were significant in the Açık Maslak recreational area. However, the effects of soil depth × soil use on the Ca, Mg, P, Mn, and Na concentrations (P>0.05) were not significant in the Kadıdağı recreational area. The Mg concentration was not significantly correlated with soil depth, soil correlated with soil use (*P*<0.05) at the Açık Maslak recreational area. Therefore, since soil depth was statistically nonsignificant in all soil properties (except for Ca, P, K, and Mn concentrations in the Açık Maslak and soil moisture content in the Kadıdağı), no evaluation was made according to soil depth (Table 3).

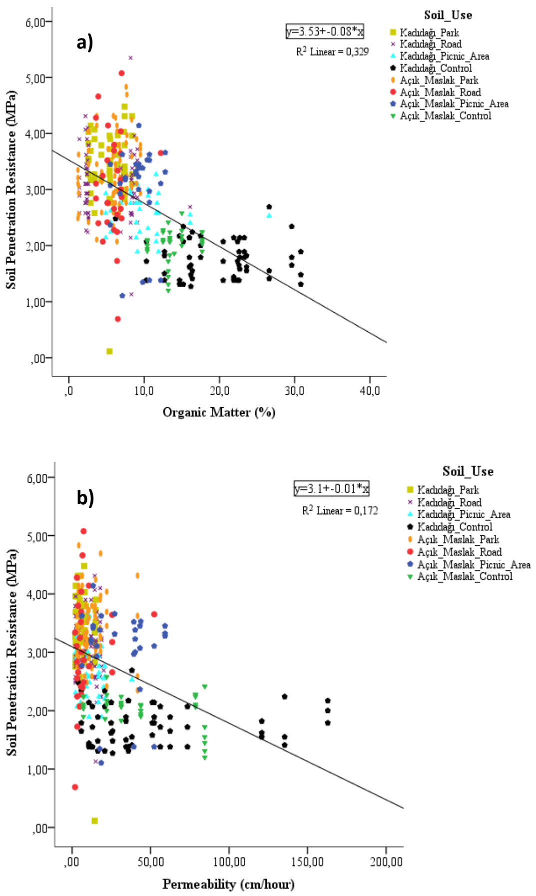
Table 3. Univariate Analysis by General Linear Model for Recreational Areas

Rec. Area	Soil Properties	Soil Depth (SD)		Soil Use (SU)		SD*SU	
		F test	P value (Sig.)	F test	P value (Sig.)	F test	P value (Sig.)
Açık Maslak (n=167)	SPR	4.992	.149 (**NS**)	38.701	.448(***)	1.495	.136 (**NS**)
	pH	.118	.004 (**NS**)	4.049	.078(**)	.111	.011 (**NS**)
	BD	.313	.011 (**NS**)	49.381	.509(***)	.601	.059 (**NS**)
	Permea.	.590	.020 (**NS**)	35.003	.423(***)	.386	.039 (**NS**)
	OM	.238	.008 (**NS**)	106.246	.690 (***)	.138	.014 (**NS**)
	SMC	.236	.008 (**NS**)	19.481	.290 (***)	.450	.045 (**NS**)
	Ca	4.390	.133 (**)	9.845	.171 (***)	2.213	.188 (**)
	Mg	.260	.009 (**NS**)	.351	.007 (**NS**)	1.247	.116 (**NS**)
	P	3.768	.116 (**)	31.842	.400 (***)	5.967	.385 (***)
	K	5.047	.150 (***)	8.434	.150 (***)	3.538	.271 (***)
	Mn	6.506	.185 (***)	6.506	.120 (***)	4.208	.306 (***)
	Na	2.845	.090 (**NS**)	13.371	.219 (***)	1.886	.165 (*)
Kadıdağı (n=228)	SPR	.583	.014 (**NS**)	110.691	.619 (***)	1.465	.097 (**NS**)
	pH	.952	.023 (**NS**)	33.862	.332 (***)	.805	.056 (**NS**)
	BD	.777	.019 (**NS**)	144.113	.679 (***)	.420	.030 (**NS**)
	Permea.	334	.008 (**NS**)	44.609	.396 (***)	.991	.068 (**NS**)
	OM	.153	.004 (**NS**)	161.815	.704 (***)	.453	.032 (**NS**)
	SMC	4.178	.093 (**)	42.532	.385 (***)	1.931	.124 (*)
	Ca	.474	.011 (**NS**)	15.878	.189 (***)	1.105	.075 (**NS**)
	Mg	.150	.004 (**NS**)	80.317	.542 (***)	.963	.066 (**NS**)
	P	1.534	.036 (**NS**)	78.481	.536 (***)	1.660	.109 (**NS**)
	K	.188	.005 (**NS**)	6.087	.082 (**)	2.063	.132 (*)
	Mn	.396	.010 (**NS**)	12.320	.153 (***)	.746	.052 (**NS**)
	Na	.481	.012 (**NS**)	148.550	.686 (***)	.600	.042 (**NS**)

Asterisks represent severity: *, *P*<0.05, **, *P*<0.01, ***, *P*<0.001, NS: Not significant, Rec., Recreational, SPR: Soil Penetration Resistance, pH: Soil reaction, BD: Bulk density, Permea.: Permeability, OM: Organic matter, SMC: Soil moisture content, Ca: calcium, Mg: magnesium, P: phosphorus, K: potassium, Mn: manganese, Na: sodium

The Relationship Between Soil Penetration Resistance and Soil Properties

The variations in soil penetration resistance as a function of soil properties are presented in Figure 4. The soil penetration resistance linearly decreased with increasing organic matter and permeability values (Figures 4a and 4b). In contrast, the soil penetration resistance increased linearly with increasing soil bulk density and moisture content (Figures 4c and 4d). The regression between soil penetration resistance and organic matter and permeability when performed across all soil uses gave a poor and even negative relationship (R^2=0.329 and R^2=0.172, respectively). In addition, the relationship within each soil use was very poor and positive, with R^2 values of 0.096 and 0.101 for bulk density and soil moisture content, respectively. The relationships were significant at the 5% probability level.



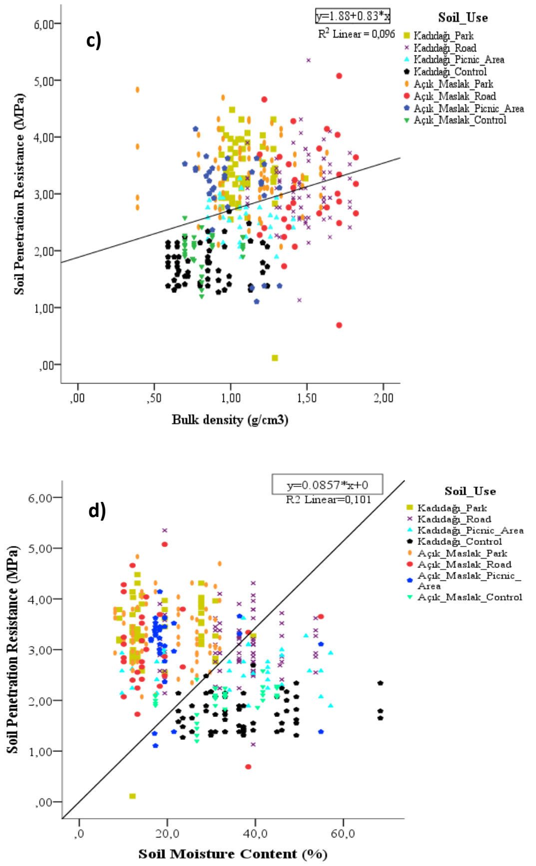
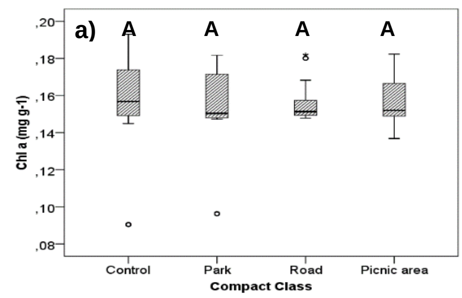


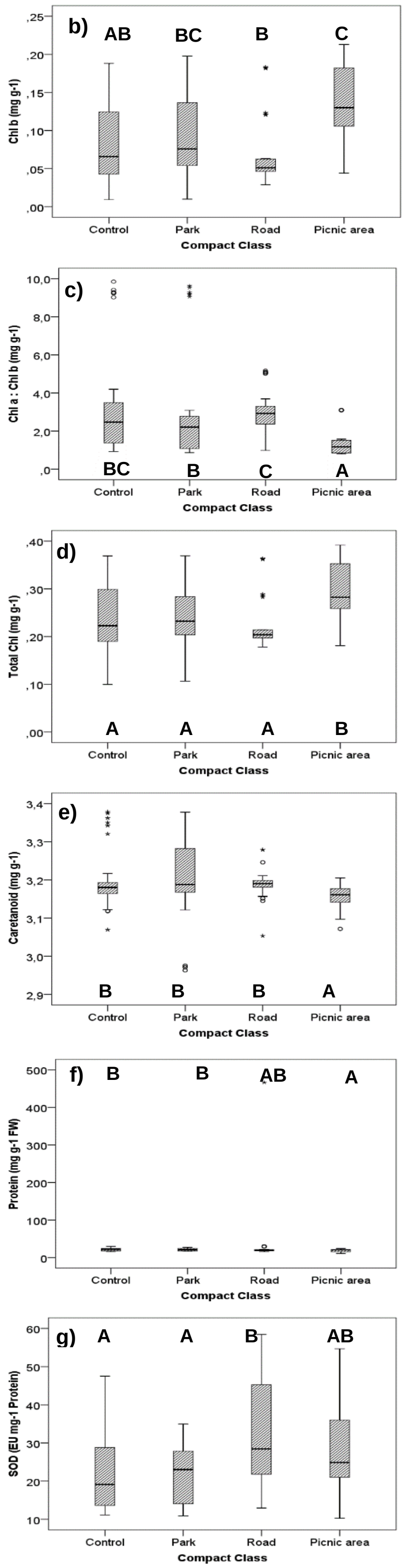
Figure 4. The relationship between soil penetration resistance and soil properties: a) organic matter, b) permeability, c) bulk density, d) soil moisture content

Soil Penetration Resistance and Physiological Properties of Trees

The box plot of the photosynthetic pigments, protein, antioxidant enzyme activities, nitrate, proline, glucose, sucrose, and nutrition elements in the needles of the trees in different compaction areas is shown in Figure 5. According to the compaction classes, the amount of chlorophyll a, one of the photosynthetic pigments in the needles of the trees showed similar mean values. It did not show significant differences in the four areas (Fig. 5a). Higher chlorophyll b content was observed at significant levels in the tree needles in the picnic area compared to other areas. The lowest amount of chlorophyll b, 0.0693 mg g^{-1}, was measured in highly compacted (road) areas (Fig. 5b). Significant differences (P<0.001) were detected in the chlorophyll a:b ratio of tree needles in 4 different areas (Fig. 5c). The lowest Chl a: Chl b ratio was found in the picnic area trees.

The highest ratio was found in the needles of the control and roadside trees. Variations in chlorophyll a: chlorophyll b ratios were in the highest control area plot (Fig. 5c). Significant differences were detected in the trees in the highest picnic area with a total chlorophyll content of 0.296 mg g^{-1} ($P<0.001$). Only the control, park, and roadside trees had similar mean values. There were no significant differences (Fig. 5d). The carotenoid value was lowest in the picnic area and highest in the park area plots. Significant differences were observed only in the needles of the trees in the picnic area (Fig. 5e). The protein content in the tree needles in the control and park areas showed similar mean values and did not show significant differences. However, the protein content of the needles in picnic areas and roadsides showed significant differences (Fig. 5f). SOD enzyme activity was at the highest levels in the road and picnic areas. It was at the lowest levels in the needles of the trees in the park. SOD enzyme activity in the control and park areas showed similar mean values and did not have significant differences (Fig. 5g). POD enzyme activity showed different mean values and significant differences only in picnic area trees (Fig. 5h). The nitrate in the needles was at the highest level at the roadside and lowest in the control areas (Fig. 5i). The highest amounts of proline and sucrose were found in the parks, and the lowest was found in the controls (Fig. 5j. and 5l.). However, nitrate, proline, and sucrose values showed similar mean values in all four areas and had no significant differences. The glucose contents showed similar mean values in the control, park, and picnic areas, and the lowest was found in the parks (Fig. 5k).





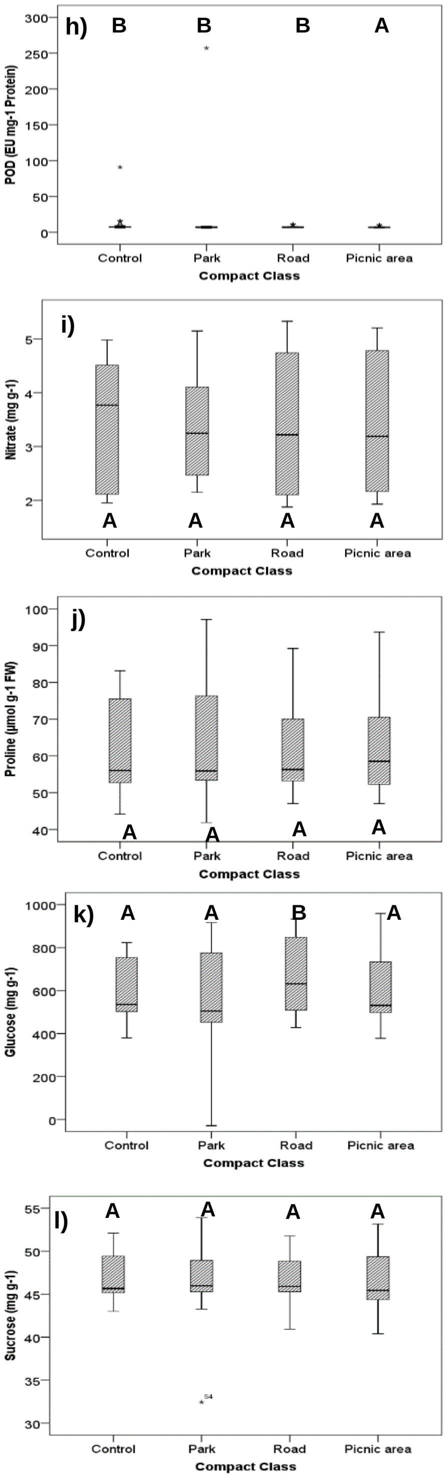


Figure 5. Box plots and the results of the Kruskal–Wallis test (different letters represent a significant difference at $P<0.05$; the upper hanging bar represents the high edge; the lower hanging bar is the lower edge, and the upper and lower box lines indicate quartiles 3 and 1, respectively. Finally, the line inside the box is the median.)

Discussion

Effects of Soil Compaction on Some Soil Properties

The results of the study presented here revealed that soil use ($P<0.001$) had only a statistically significant effect on the soil penetration resistance of parks, roads, picnic areas, and control soils in both recreational areas (Figure 2 and Table 3). However, soil depth did not have a statistically significant effect on the soil penetration resistance (Table 3). Generally, the soil penetration resistance value tended to increase or decrease with soil depth in recreational areas and was intermediate (between 1.6 MPa and 2.0 MPa) to high (between 2.1 MPa and 3.7 MPa) compaction was observed. This situation leads to increased visits to recreational areas, the loss and exposure of organic soil, and the compaction of the underlying mineral soil as the plant and organic matter trampled by the visitors are crushed (Marion, 2016). Our findings show that compaction increases significantly in soils under continuously visited roads and parks. It was observed during the fieldwork that both recreational areas were visited intensively annually by 30,000 to 40,000 people of the city or visitors from other cities, and activities, e.g., cycling, ATV driving, restaurants, cafe places, outdoor sports, and entertainment, were performed intensively. Similar results were obtained by Andrés-Abellán et al. (2005), who reported that the most frequented areas (e.g., car parks, children’s parks, restaurants, and forest paths also had the most significant bare ground. In conclusion, the density and activities of visitors to recreational areas have been associated with a negative impact on soil compaction. According to the literature, the highest soil compaction was usually recorded in activity sites where most visitor activity occurred (Andrés-Abellán et al., 2005; Marion, 2016; Mallikage et al., 2021). Alkan (2014) stated that as the number of people increases, soil fertility decreases as land is used more intensively.

In this study, soil pH did not vary with soil depth, while pH was affected by soil use status, and there was a decrease from very compacted park soils to very slightly compacted areas (Tables 2 and 3). The effect of 4 different soil uses on pH in Açık Maslak recreational areas is very small. Since the pH values are close to each other, no statistically significant difference was found. However, it was observed that the pH of the Kadıdağı recreational area soil was 33.2% of soil use had an effect (Tables 2 and 3). The park and road had higher soil pH in all recreational areas. This situation may have increased due to the very high compacted soil under children's playgrounds (parks) constantly trampled or crushed by visitors (Figure 1b). Malmivaara-Lämsä et al. (2008) reported that soil pH was significantly higher in compacted areas than in controls. In contrast, Ma et al. (2016) found that soil pH gradually increased as the degree of disturbance from tourism activities decreased. However, control soils in the Açık Maslak recreational area showed a very low pH (7.9), while picnic area soils in the Kadıdağı recreational area showed a very low pH (6.2). Andrés-Abellan et al. (2005) found a relationship between the density of visitors in recreational areas and increased soil pH. The soil organic matter ratio was low in areas with high soil compaction, and the pH values were high (Figure 4a). Lockaby & Dunn (1984) speculated in their studies that there might be high pH values in heavily used areas (for example, parking lots, main roads, and caves), as in our study. It is possible to argue that the pH value in the study areas was higher in roads and parks, similar to the results of the other studies mentioned above. Additionally, depending on the visitor density (Cakir et al., 2010), the existing calcareous main material (Bolan et al., 2023) in deeper layers may effectively increase the soil pH value.

The soil bulk density of the Kadıdağı and Açık Maslak recreational areas were 67.9% and 50.9% of soil use, respectively (Table 3). The relationship within each soil use was very poor and positive, with R^2 values of 0.096 for bulk density (Figure 4c). The soil bulk density in the Açık Maslak and Kadıdağı recreational areas was the highest in the road (1.51 g cm^{-3} and 1.47 g cm^{-3}) and park (1.12 g cm^{3} and 1.09 g cm^{-3}) soils, respectively, compared to the control and picnic areas (Table 2), with high visitor density showing a positive regression with soil penetration resistance and bulk density (Figure 4c). Similarly, Sujetovienė & Baranauskienė (2016) reported in their study that the soil bulk density of Kaunas Park increased at a rate of 79% and 64% when compared to the control and increased at a rate of 51% and 39%, respectively, in Alytus Park. Cakir et al. (2010) found that the soil bulk density (1.58 g cm^{-3}) and fine soil bulk density (1.51 g cm^{-3}) in the picnic area were higher than those in the nondisturbed areas. Lei (2004) also reported that soil bulk density in disturbed areas increased significantly compared to control areas. The reason for these high values was increased soil compaction and bulk density with the effect of visitors (Sarah & Zhevelev, 2007). Kozlowski (1999) reported that visitors' trampling of the soil causes increased bulk density and hardness in recreational areas. It is possible to argue that the tighter the soil structure is, the lower the water infiltration and the higher the soil bulk density.

These results showed that soil permeability increased depending on soil use, from highly compacted soils to less compacted soils ($P<0.001$), but nonsignificant differences were observed between soil depths ($P>0.05$) (Table 3). The soil permeability values of the Açık Maslak and Kadıdağı recreational areas were 42.3% and 39.6% of soil use, respectively (Table 3). The results showed a negative regression between soil penetration resistance and permeability (Figure 4b). This can be explained by factors such as the trampling of roads, parks, and picnic areas by intense visitors and the amount of organic matter in the soils of these areas. In this respect, soil permeability is negatively affected. In short, soil permeability may vary depending on the density and duration of visitors' soil tramping and the amount of organic matter (Deng et al., 2003).

Soil organic matter gradually decreased with increasing trampling intensity but did not change statistically with soil depth (Table

3). The soil organic matter of the Açık Maslak and Kadıdağı recreational areas was 69.0% and 70.4% of soil use, respectively (Table 3). The organic matter in the soil varied between 5.3% and 19.5% (Table 2). Although the highest organic matter was observed in the control areas, the organic matter in the soil taken from the park and road was relatively low (Figures 1b and 1c). The results showed a negative regression between soil penetration resistance and organic matter, similar to other researchers' findings (Cakir et al., 2010; Korkanç, 2014). In some previous studies, a reduction in organic matter accumulation was found in the organic matter (e.g., leaves, twigs) and humus layer on the mineral topsoil because of frequent trampling and low organic matter ingress into the soil (Andrés-Abellán et al., 2005; Kutiel et al., 2000). Litterfall, such as leaves, enters the topsoil, thereby increasing the organic matter in the soil (Yuejin et al., 2022). In this respect, it was observed that the amount of organic matter in the park and road soils of both recreational areas was low, visitors trampled the soil, and the employees of the recreational area operator constantly cleaned the organic materials spilled from the trees around.

The soil moisture content varied with soil depth in the Kadıdağı recreational area ($P<0.01$) and did not vary with soil depth in the Açık Maslak recreational area ($P>0.05$) (Table 3). However, the regression between soil penetration resistance and soil moisture content, when performed across all soil depths, gave a very poor and even positive relationship ($R^2=0.101$) (Figure 4c). Amrein et al. (2005) and Yuejin et al. (2022) found that the soil moisture content in a disturbed area was significantly reduced. A combination of higher organic matter content in the mineral topsoil may have caused this. The decreased macropore space in this soil layer is likely to be observed at a low value in the soil moisture content.

The results showed no regression between soil penetration resistance and Ca, Mg, P, Mn, and Na concentrations. However, there were significant effects of soil use ($P<0.01$) on the Ca, P, K, Mn, and Na concentrations in all recreational areas (Table 3). Mg and Ca concentrations in the soil increase parallel with soil compaction (park and road) in all recreational areas (Table 2). These values are likely to be high because of the increased soil pH, continuous exposure of the surface soil to pressure, low amount of organic matter, and since the present calcareous bedrock in the subsoil rises to the surface, reflecting its properties to the soil more. The present study showed significant reductions in P uptake in firmly compacted soils in high bulk-density soils (Table 2). Similarly, the low P concentration in soils was mainly related to the root system of trees because of the relative inertness of this element and its effects on P uptake due to soil compaction (Lipiec & Stępniewski, 1995). Kristoffersen & Riley (2005) reported that a high organic matter content provides weaker bonds between phosphorus ions and soil particles. In this way, more phosphorus is released into the soil solution. Sodium has a physical property that brings soil particles closer, reduces the macropore size, and prevents soil from water penetration (Reginato et al., 1983). In this way, it can be argued that the increased sodium concentration is a result of the decreased macro pore space in the soil layer of the over-compacted areas, the low value of the soil moisture content, the low permeability, and the increased sodium concentration in the soil.

Effects of Soil Compaction on Some Physical Properties of the Needle

Some physiological properties and nutrient elements that changed depending on the soil penetration resistance were determined according to the Kruskal–Wallis analyses, which are given in Figure 5. As a result, it was not found that all of the plant physiological properties had a statistically significant effect on soil penetration resistance (Fig. 5). In the studies conducted, it was suggested that the increased SOD enzyme activity in the plant has an important role in coping with oxidative stress caused by biotic and abiotic stress and contributes to the survival of plants under stress conditions (Aravind & Prasad, 2003; Aydin et al., 2012). Koç & Nzokou (2022) stated that pine has higher drought tolerance in resisting water stress through reduced photosynthetic activity and growth mechanism, as well as its ability to minimize water loss and increase water uptake. It is already known that nitrate has a more significant effect on leaf growth than other macronutrients (Mulholland et al., 1999). The increase in the amount of nitrate (NO_3^-) affects the structure, vitality, and characteristics of individual trees, along with the ability of the nitrogen in its structure to tolerate environmental stress (Shukor et al., 2015). Manganese activates vital enzymes, especially the SOD enzyme (Bolat & Kara, 2017). The reasons for the decreased manganese availability in plants with increasing soil pH values have been widely investigated (Schwab & Lindsay, 1983; Smiley et al., 1986). Three reactions affect the availability of Mn. Manganese complexes with organic matter and manganese oxides are formed, and manganese precipitates with calcium carbonate. In these complexes, decomposition is dependent on soil pH. The lower the soil pH is, the more Mn is available (Smiley et al., 1986).

For this reason, the present study determined that the soils were very compacted and had high pH (7.26-7.84) and low organic matter (5.45-5.68%) but low manganese concentrations. As a result, the progression and growth of tree roots grow in soils where compaction slows down, and the supply of air, water, and nutrients needed by the roots can be prevented because of poor aeration and drainage. Additionally, the plant begins to develop defense mechanisms against this abiotic stress, and an increase in the production of factors such as nitrate in its body may be adequate to tolerate this environmental stress. We can associate the decreased amount of this element because of soil compaction, as the SOD enzyme activity increases in the plant against oxidative stress and decreases in the manganese concentration, which is effective in the structure of this enzyme.

Conclusion

This study determined that soil use status influenced soil penetration resistance. The lowest soil penetration resistance values were observed in the soils under the control and picnic areas, and the highest values were observed under the park and road. In all soil use situations in recreational areas, the highest soil compaction is in 25-30 cm depth soils. In contrast, the soils of the four different soil uses taken from the recreational area were moderate to highly compacted, and these soil properties did not show a significant change according to the soil depth.

According to soil use, soil penetration resistance was effective on soil organic matter, permeability, bulk density and soil moisture content. It has been observed that while soil compaction affects the organic matter content of the soil and the permeability of the soil, it has little effect on the bulk density of the soil. In addition, soil penetration resistance was statistically insignificant and did not affect some physiological properties of Scots pine and black pine needles in all recreational areas.

Finally, a study with more sampling areas or a more extensive sampling size will contribute to generating data to represent better the effects on soil properties or the amount of soil compaction. Long-term measurements are needed to collect these baseline data and keep records of social and biophysical changes in the recreational area.

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Ethics Committee Approval

N/A

Peer-review

Externally peer-reviewed.

Author Contributions

Conceptualization: G.S.; Investigation: G.S. and K.M.M.A.; Material and Methodology: G.S. and K.M.M.A.; Supervision: G.S. and K.M.M.A.; Visualization: G.S. and K.M.M.A; Writing-Original Draft: G.S.; Writing review & Editing: G.S. All authors have read and agreed to the published version of the manuscript.

Conflict of Interest

The authors have no conflicts of interest to declare.

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