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Soil quality as related to sampling depth on semiarid and semihumid pastures

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Abstract

Soils in pastures vary significantly with depth due to the stronger interaction between soil and plants in the topsoil. However, research on soil resources in pastures has not yet reached a consensus on the appropriate soil depth to consider when evaluating soil quality (SQ). This study aimed to assess how SQ changes with soil depth in two distinct pasture systems. A semiarid site (Kurşunlu) and a semihumid site (Ilgaz) were selected, and representative sampling areas were designated in each. At both sites, soils at 0-10 and 10-20 cm depths were intensively sampled. The soil quality index (SQI) was calculated for 0-10, 10-20, and 0-20 cm (combining 0-10 and 10-20 cm) soil depths. The means of SQI related to depth and site were compared using one-way ANOVA. The SQI values ranged from 0.211 (± 0.002, 0-10 cm) to 0.556 (± 0.004, 10-20 cm) at Kurşunlu and from 0.230 (± 0.003, 0-10 cm) to 0.601 (± 0. 003, 10-20 cm) at Ilgaz. On both sites, the depth-related SQI means were significantly different, and in all cases, SQI was significantly higher at Ilgaz. The 0-10 cm soil depth proved more suitable than 10-20 or 0-20 cm depths for monitoring SQ. Results suggested that soil pH and bulk density were identified as potential early-warning indicators for soil degradation in the study pastures.

Keywords: Aggregate stability, bulk density, nutrient availability, soil depth, soil pH

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Introduction

Grasslands and pastures, which represent the largest terrestrial ecosystem on Earth and cover about 40% of the planet's land area, play a vital role in supporting essential ecosystem functions and services as well as the livelihoods of millions of people; however, they are increasingly threatened by degradation resulting from human activities and climate change (Abdalla et al., 2018; Li et al., 2013; Bogunovic et al., 2022; Sun et al., 2022). Degradation of grasslands is a complex social-ecological issue that can lead to a reduction in the connection between the structure and function of grasslands (Li et al., 2013; Zhou et al., 2023). Turkey's rangelands, approximately 82% of which are located in arid climate zones, have grazing capacities ranging from 0.3 to 3.9 AU (animal unit) per hectare, depending on regional climate conditions and grazing periods (Sayar et al., 2015). Extensive livestock rearing continues to be a major land use in many areas, and in the Mediterranean basin and Turkey, grasslands are increasingly degraded due to intensive grazing. Overgrazing and poor management have caused bush encroachment, soil erosion, loss of wildlife habitat, and a sharp decline in livestock productivity (Paz-Kagan et al., 2016; Karaca et al., 2021). Soil quality (SQ) is increasingly regarded as a core measure of soil health and ecosystem performance, integrating its physical, chemical, and biological characteristics to support plant growth, nutrient cycling, and the overall resilience of the environment (Sanad, 2024). This decline affects soil quality (SQ), which is vital for maintaining the health and productivity of grasslands. Soil quality acts as a reliable indicator of the overall health of the grassland ecosystem (Sánchez-Marañón et al., 2002). Strong links have been reported between SQ and productivity in grasslands (Paz-Kagan et al., 2016). Soil quality can be used to evaluate grassland degradation and guide restoration efforts (Dong et al., 2012).

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In pastures, soil properties vary significantly with depth, and grazing activities, including trampling and excreta deposition, exert distinct impacts on belowground soils at different soil layers (Recha et al., 2022). In a study (Bai et al., 2015), grazing differently affected root production and mortality in the 0-10 cm, 10-20 cm, and 20-30 cm soil layers. Results from Gilmullina et al. (2020) showed that SOC and N contents were nearly twice as high in the 0-10 cm soil depth compared to 20-30 cm on two permanent sown grasslands in Lusignan (southwest of France). Differences in the type, distribution, and abundance of roots by depth may lead to highly varying soil structures with depth, which influence other important soil quality variables like water holding capacity and hydraulic conductivity (Stott, 2019).

Choosing the appropriate soil depth is crucial when comparing SQI values or indicator weights, because key soil properties—such as organic matter, pH, phosphorus, and nitrogen—change with depth, and management practices like grazing can affect shallow and deeper layers differently, which in turn can influence the relative importance of soil quality indicators (Gong et al., 2025). The soil depth examined in studies on SQ has varied widely, which may lead to misleading comparisons of SQ data across different research. For instance, studies have used depths such as 0-5 cm (Gardi et al., 2002; Kamarudin, 2019), 0-20 cm (Budak et al., 2018; Wu et al., 2019), 0-15 cm (Paz-Kagan et al., 2016), 0-10 cm (Bogunovic et al., 2022), and 0-30 cm (Karaca et al., 2021) to assess SQ in pastures. This wide range of sampling depths creates methodological heterogeneity, which complicates cross-study comparisons of SQI and highlights the need for more standardized approaches in future research. This issue becomes even more important when considering soil degradation caused by grazing. Bai et al. (2015) reported that heavy grazing significantly impacted bulk density (BD) at soil depths of 0-10 and -10-20 cm but not in the 20-30 cm layer, with a greater negative effect in the 0-10 cm zone compared to 10-20 cm. They also found that grazing had a stronger negative influence on soil water content in the 0-10 cm depth than in 10-20 and 20-30 cm. Results from Dong et al. (2012) showed that grassland degradation affected the decline of organic carbon and total nitrogen stocks differently at depths of 0-4, 4-10, 10-20, and 0-20 cm. No study has fully addressed the relationship between soil quality and soil depth across various pasture systems.

This study was based on testing the following hypotheses: 1. Due to intense soil-vegetation interaction combined with external forces such as livestock grazing, SQ is expected to vary significantly with soil depth in pastures, and 2. Depth-related differences in SQ may vary in pastures with different vegetation, site factors, and climate. To test these hypotheses, this study aimed to: 1. Characterize changes in SQI related to soil depth on a semiarid and semi-humid pasture. 2. Determine the key soil properties to serve as early warning indicators for monitoring SQ on the study pastures. This study offers a comparative framework to assess how soil depth influences soil quality in contrasting pasture systems.

Material and Methods

Study sites

The Kurşunlu site is situated at approximately 40°50′36″ N and 33°16′12″ E, while the Ilgaz site is located near 41°02′24″ N and 33°38′00″ E. The current study evaluated SQ on 0-10, 10-20, and 0-20 cm depths (data for 0-10 and 10-20 cm were combined) across two different pasture ecologies: a semi-humid site (Ilgaz) and a semi-arid site (Kurşunlu) (Figure 1). The study locations differ greatly in vegetation (Appendix A), topography, climate, and soil. A representative sampling site was selected in each of these pastures.

The Kurşunlu pasture is situated on a mountain terrace that gradually ascends toward the north. The elevation of the study pasture is approximately 1,150 (MTL). The surrounding area mainly consists of grasslands, woodlands, and forests on highlands and sloping hills, with some highly eroded sites exposing bare land. Soils in the area have developed from in-place deposits The soils at the sampling site are classified as, suborder Ustorthents, according to Soil Taxonomy (Soil Survey Staff, 2014).

The Ilgaz pasture is located on the side of Mount Ilgaz. The elevation of the pasture is approximately 1400 meters from MTL. The macrotopography around the study site consists of hillslopes with varying aspects, steepness, and types, such as crests, head slopes, nose slopes, and base slopes. The soils in the study area are formed over colluvium transported from the side slope. The soils at the sampling site of the Ilgaz pasture are classified as Humustepts based on Soil Taxonomy (Soil Survey Staff, 2014).

The distance between the two pastures is approximately 30 km in a straight line. The Ilgaz pasture has a prevalent Dry-Subhumid Continental Central Anatolia Climate, while the Kurşunlu pasture has a Dry-Semiarid Continental Central Anatolia Climate type according to (Iyigun et al., 2013). Over a period of 20 years, the mean annual precipitation is 440 mm on the Kurşunlu site and 596 mm on the Ilgaz site. Additionally, the mean annual temperature is 9.4 °C on the Kurşunlu site and 6.5 °C on the Ilgaz site.

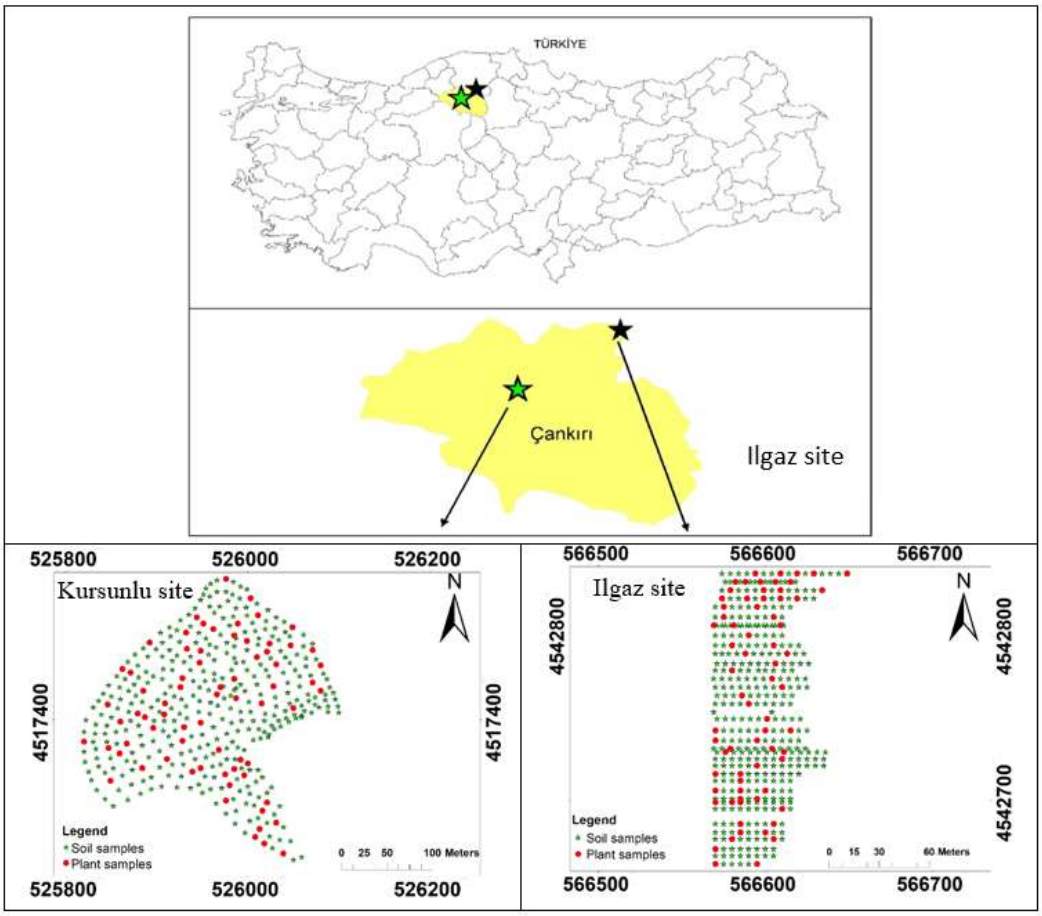


Figure 1. The location of study pastures on the Turkish map and the sampling schemes used. The red dots indicate both soil and plant sampling sites, with data provided in Appendix A, while stars represent only soil sampling sites.

Experimental design and soil sampling

Soil samples were collected in May 2016 from 0–10 cm and 10–20 cm depths at 400 points per study site (totaling 1,600 samples) within 1×1 m plots spaced 1 m apart. At each plot, five cores (four corners and center) were composited for analysis, following a systematic 1×1m grid design (Figure 1). In both cases, we sampled a field site with an approximately 6% slope that appeared flat and topographically uniform, being free of rills and rocks.

Soil samples were analyzed for sand, silt, and clay content (Gee and Bauder, 1986); aggregate stability index (ASI) (Kemper and Rosenau, 1986); field capacity (FC, volumetric), permanent wilting point (PWP, volumetric) (Cassel and Nielsen, 1986); organic matter (OM) content (Nelson and Sommers, 1996); cation exchange capacity (CEC) (Rhoades, 1982); pH (1:2.5, soil:water) and electrical conductivity (EC) (Pansu and Gautheyrou, 2007); and $CaCO_3$ content (McLean, 1982). Plant-available phosphorus (P_{av}) was determined using the modified Olsen's method, with extraction performed in 0.5 M $NaHCO_3$ solution at pH 8.5 (Kuo, 1996). Exchangeable potassium (K), calcium (Ca), and magnesium (Mg)-hereafter referred to as exchangeable Ca, K, and Mg-were determined with an atomic absorption spectrophotometer (Thomas, 1982). DTPA-extracted micronutrients (Fe, Cu, Mn, and Zn-here after DTPA-extracted Fe, Cu, Mn, and Zn) were measured following the method described by Lindsay and Norvell (1978). Soil bulk density (BD) (Blake and Hardge, 1986) and FC were measured on undisturbed soil samples collected using 100 cm^3 steel rings. Penetration resistance (PR) was measured on-site during sampling, with measurements adjusted to the water content of the soils at the time of sampling. Plant-available water content (PAWC) was calculated by subtracting PWP from FC.

Developing minimum datasets

We measured 19 soil properties for each of the 1600 samples. The SQIs were chosen based on the "key soil indicators" for soil quality assessment (Arshad and Coen, 1992; Pierce et al., 1983; Larson and Pierce, 1994; Crepin and Johnson, 1993; Sánchez-Navarro et al., 2015; Paz-Kagan et al., 2016). To identify the most relevant soil variables for SQ evaluation, principal component analysis (PCA) was performed on the datasets (Andrews and Carroll, 2001; Andrews et al., 2002; Paz-Kagan et al., 2016; Yu et al., 2018; Nehrani et al., 2020).

Soil quality indexing

The evaluation of the SQ was conducted using the general approach of the SQI, which involves scoring functions for each of the SQ indicators (Andrews et al., 2004). These scoring functions were established within a straightforward framework. Each soil property was processed through a scoring algorithm to produce a unitless score (0 to 1) that indicates its level of function in the system, allowing the scores to be combined into a single value (Andrews and Carroll, 2001, Andrews et al. 2002; Li et al. 2013, Paz-Kagan et al. 2016). The "optimal range" functions were applied for pH and EC (Andrews et al., 2004; Rahmanipour et al., 2014). A threshold value of 7.0 was used for pH, while an optimal range of 0.2-2.0 dS m^{-1} was used for EC (Andrews et al., 2004; Rahmanipour et al., 2014).

Statistical analysis

Soil depth- and site-related differences in soil properties and SQI values were examined using one-way ANOVA, and the means were grouped with the least significant difference (LSD) method. First, we assessed depth-related differences in soil properties and SQIs at each site, and then we compared the mean SQI values between sites. A significance level of 0.05 was used in all cases.

Results

Descriptive statistics of soil properties

Soil properties showed similar mean values in most cases across the 0–10 cm, 10–20 cm, and combined 0–20 cm soil depths at both sites. For the 0–20 cm layer, soil samples collected from the 0–10 and 10–20 cm depths were combined and thoroughly homogenized prior to laboratory analyses to obtain a composite sample representing the 0–20 cm soil depth. (Table 1 and Appendix B). However, the mean soil property values were mostly significantly different between the study sites. At the Kurşunlu site, values for BD, PR, pH, and contents of $CaCO_3$, K, Ca, and P_{av} were significantly higher ($P<0.05$) compared to the Ilgaz site. Conversely, the Ilgaz site had significantly higher values for FC, PWP, PAWC, EC, and contents of silt, OM, Mg, Fe, Cu, Mn, and Zn.

Table 1. Results of ANOVA and subsequent LSD test for soil variables across soil depths and between study pastures

Variable	Pasture					
	Kurşunlu Soil depth (cm)			Ilgaz Soil depth (cm)		
	0-10	10-20	0-20	0-10	10-20	0-20
Sand (%)	56.82±0.68a	57.76±0.68a	57.22±0.70a	53.62±0.68b	53.20±0.35b	53.41±0.55b
Silt (%)	15.42±0.34a	14.71±0.35b	15.04±0.35a	19.77±0.34c	19.19±0.23c	19.48±0.29c
Clay (%)	27.77±0.49a	27.57±0.47a	27.63±0.48a	26.64±0.47b	27.66±0.25a	27.15±0.39a
BD (Mg m^{-3})	1.24±0.006a	1.24±0.004a	1.24±0.009a	1.19±0.005b	1.19±0.005b	1.19±0.004b
PR (MPa)	2.84±0.02a	2.84±0.012a	2.83±0.02a	2.59±0.03b	2.60±0.03b	2.60±0.02b
FC (%)	25.08±0.34a	24.84±0.35a	24.93±0.37a	32.83±0.35b	32.88±0.26b	32.86±0.27b
PWP (%)	14.20±0.34a	13.95±0.24a	14.06±0.29a	15.51±0.24b	15.46±0.22b	15.48±0.20b
PAWC (%)	10.88±0.24a	10.89±0.25a	10.87±0.18a	17.32±0.33b	17.42±0.31b	17.37±0.23b
ASI (%)	48.70±0.17a	48.44±0.17a	48.51a±0.12	48.69±0.21a	48.46±0.23a	48.58±0.16a
$CaCO_3$ (%)	2.26±0.051a	2.38±0.05a	2.32±0.03a	1.38±0.05b	1.25±0.05b	1.32±0.04b
OM (%)	1.31±0.027a	1.18±0.03b	1.24±0.02b	4.35±0.05c	4.08±0.06d	4.21±0.04c
pH	7.56±0.017a	7.52±0.02a	7.53±0.01a	6.43±0.03b	6.46±0.02b	6.45±0.01b
EC (µS mm^{-1})	146.18±6.83a	126.57±5.66b	136.19±4.44a	324.25±8.21c	268.63±8.55d	296.44±6.01c
CEC (cMol kg^{-1})	19.96±0.240a	19.85±0.24a	19.88±0.17a	19.39±0.13b	19.89±0.13a	19.64±0.09a
*K (mg kg^{-1})	102.94±3.40a	91.22±3.33a	96.95±2.39a	85.38±2.61b	76.56±2.39b	80.97±1.77b
*Ca (mg kg^{-1})	279.16±3.16a	275.58±3.04a	277.02±2.19a	193.15±6.71b	185.24±6.67b	189.19±4.73b
*Mg (mg kg^{-1})	40.68±0.530a	40.89±0.54a	40.73±0.37a	47.09±1.58b	48.81±1.76b	47.95±1.19b
P_{av} (mg kg^{-1})	0.23±0.005a	0.21±0.01b	0.22±0.002a	0.21±0.001b	0.20±0.003b	0.20±0.002b
**Fe (mg kg^{-1})	1.75±0.067a	1.69±0.07b	1.72±0.05b	25.20±0.99c	27.02±0.98d	26.11±0.70d
**Cu (mg kg^{-1})	0.80±0.038a	0.84±0.05b	0.82±0.03a	1.13±0.03c	1.15±0.03c	1.14±0.02c
**Mn (mg kg^{-1})	10.56±0.576a	9.07±0.58b	9.80±0.41a	13.43±0.61c	13.92±1.05c	13.68±0.61c
**Zn (mg kg^{-1})	2.87±0.359a	2.47±0.34b	2.67±0.25a	11.67±0.33c	10.50±0.31d	11.09±0.23c

BD: Bulk density, PR: Penetration resistance, FC: Field capacity, PWP: Permanent wilting point, PAWC: Plant available water content, ASI: Aggregate stability index, EC: Electrical conductivity, CEC: Cation exchange capacity. P_{av}: Plant available P.
*Exchangeable nutrients, ** DTPA-extracted soil micronutrients.

Values labelled with different letters in the same row are significantly different at significance level of 0.05The variability of soil characteristics plays a crucial role in identifying soil quality indicators. Soil texture components showed medium variability in most cases according to Mulla and McBratney (2002), who classified soil attributes with coefficients of variation (CV) less than 15% as slightly variable, between 15% and 36% as moderately

variable, and greater than 36% as highly variable (Appendix B). Bulk density, ASI, and PAWC were identified as important soil physical quality indicators across both study sites because they exhibited high loading and communality values in the principal component analysis, indicating their strong contribution to the overall soil quality variation (Table 2). Bulk density and ASI consistently showed low variability at both sites, while PAWC generally exhibited medium variability at Ilgaz and high variability at Kurşunlu. Contents of Fe, Cu, Mn, Zn, K, and $CaCO_3$ demonstrated high variability across all depths at both sites, whereas Ca and Mg consistently showed medium variability at Kurşunlu and high variability at Ilgaz. Plant-available P typically showed medium variability at Ilgaz and high variability at Kurşunlu. Soil OM content and CEC exhibited moderate variability, and EC mostly displayed high variability (see Appendix B for more details).

Minimum datasets

Soil variables relevant to SQ were identified using PCA. The PCA results are provided in Appendix C, and the weights for the soil quality indicators are summarized in Table 2. Soil Mn concentration and BD were the most consistent indicators across all six cases, followed by Mg content, ASI, and pH, which were common to five of six cases. Besides Mg content, BD, PAWC, pH, and the contents of Mn, Ca, and Mg were the most significant soil quality indicators on the Ilgaz site. Soil BD had a greater influence on SQ at the Kurşunlu site compared to the Ilgaz site, as shown by the higher weights assigned to BD in the former (Table 2). Similarly, pH appeared more influential on the Ilgaz site. Interestingly, OM content was relatively insignificant in soil quality assessments at both sites (Table 2).

Table 2. Weights calculated for soil quality indicators in different soil depths on Kurşunlu and Ilgaz site

Variable	Site/depth (cm)					
	Kurşunlu			Ilgaz		
	0-10	10-20	0-20	0-10	10-20	0-20
BD (Mg m^{-3})	0.07	0.176	0.114	0.082	0.0629	0.062
PR (MPa)	0.11			0.142	0.0774	
PAWC (%)		0.102		0.0689	0.0632	0.0593
ASI (%)	0.08	0.088	0.086	0.0743		0.0611
$CaCO_3$ (%)	0.08		0.0899		0.0867	0.0706
OM (%)	0.09					
pH	0.07	0.094		0.142	0.151	0.148
EC (µS mm^{-1})						
CEC ($cmol_c$ kg^{-1})				0.0651	0.151	
*K (mg kg^{-1})		0.126	0.111		0.0868	
*Ca (mg kg^{-1})				0.0869	0.0852	0.0805
*Mg (mg kg^{-1})	0.07		0.0766	0.0869	0.0852	0.0805
P_{av} (mg kg^{-1})	0.08		0.0714		0.0852	0.0685
**Fe (mg kg^{-1})		0.134	0.0910	0.0787		0.148
**Cu (mg kg^{-1})	0.09	0.134	0.091			0.148
**Mn (mg kg^{-1})	0.08	0.134	0.0910	0.0718	0.0670	0.072
**Zn (mg kg^{-1})	0.07		0.0750	0.0995		

BD: Bulk density, PR: Penetration resistance, FC: Field capacity, PWP: Permanent wilting point, PAWC: Plant available water content, ASI: Aggregate stability index, EC: Electrical conductivity, CEC: Cation exchange capacity, P_{av}: Plant available P. *Exchangeable nutrients, **DTPA-extracted soil micronutrients

Soil quality index

Table 3 shows the SQI values calculated for different soil depths at each site. The mean SQI for the 0-10 cm depth was significantly lower than that for the 10-20 cm and 0-20 cm depths at Kurşunlu, and lower than those for the 10-20 cm and 0-20 cm depths at the Ilgaz site. This suggests that SQI varied with depth on both pastures. The ANOVA and LSD tests also indicated that SQI was consistently higher at the Ilgaz site than at Kurşunlu across all three depths (0-10, 10-20, and 0-20 cm).

Table 3. Result of ANOVA test and exploratory statistics for soil quality indicators at different soil depths on Kurşunlu and Ilgaz sites

Site	Depth	Mean	Max	Min	SD	CV	Skewness	Kurtosis
Kurşunlu	0-10	*0.341±0.002a	0.515	0.211	0.046	13.429	0.637	0.722
	10-20	0.360±0.004bc	0.565	0.224	0.090	24.908	2.031	6.541
	0-20	0.344±0.002abc	0.470	0.258	0.039	11.448	0.482	-0.001
Ilgaz	0-10	0.391±0.003d	0.601	0.230	0.065	16.666	0.305	-0.308
	10-20	0.423±0.003e	0.578	0.230	0.057	13.475	-0.139	-0.275
	0-20	0.414±0.002e	0.587	0.269	0.047	11.225	0.086	0.295

*Numbers following ± represent standard error of mean. Values labelled with different letters in the same row are significantly different at the level of 0.05. SD: Standard deviation, CV: Coefficient of variation

Discussion

The SQIs differed considerably between the Kurşunlu and Ilgaz sites. At the Kurşunlu site, BD, ASI, Cu, and Mn were the most relevant SQ indicators across all three depths (0-10 cm, 10-20 cm, and 0-20 cm). Conversely, at the Ilgaz site, Ca and Mg contents, along with BD, PAWC, and pH, were the common SQ indicators. Overall, soil quality at the Kurşunlu pasture was limited by deficiencies in macro elements and microelements, as well as high BD and pH levels. Although high BD also caused soil quality issues at the Ilgaz site, the impact was less severe compared to Kurşunlu. Our results showed that BD consistently influenced soil quality in both pastures (Table 2). The primary reason for this significant effect of BD is likely improper grazing. Soil BD is often recognized as a key SQI in pastures (Biswas et al., 2017; Yu et al., 2018; Karaca et al., 2021; Recha et al., 2022), with grazing intensity strongly linked to soil BD (Steffens et al., 2008; Abdalla et al., 2018; Recha et al., 2022; Bogunovic et al., 2022). A decrease in water content caused by increased BD has been identified as a main response of soil physical properties to alpine grassland degradation (Dong et al. 2012). Pasture management practices can greatly influence BD. Gardi et al. (2002) documented significant differences in BD values at a soil depth of 0-5 cm among pastures managed under different regimes. Our data indicated that, despite similar grazing practices, soil BD was notably lower at the Ilgaz site, possibly partly due to its higher OM content. This was supported by a significant negative correlation between OM and BD ($r=-0.04$, $p<0.05$) at Ilgaz, and $r=-0.12$ ($p<0.05$) at the other site. Steffens et al. (2008) reported a significant negative correlation between organic carbon and BD in grassland soils.

The aggregate stability index emerged as the second most influential soil physical property, impacting SQ on both research sites. Our findings indicated no significant difference in ASI between the sites or across different soil depths within the sites (one-way ANOVA with LSD, $P > 0.05$). Additionally, the weights computed for ASI were remarkably consistent in magnitude across depths and between the study sites, indicating a consistently influential role of ASI on SQ at the research sites. Dissimilarly to our findings, in a study (Gardi et al., 2002), values for ASI differed significantly across five contrasting pastures in Northern Italy. In addition, Bogunovic et al. (2022) reported significant differences in water-stable aggregates between ungrazed and heavily grazed grassland parcels.

Inadequate soil aggregate stability can cause negative effects such as reduced water infiltration, increased water runoff, and higher soil sediment loss (Kairis et al., 2021). The stability of soil aggregates, which is heavily influenced by clay and organic matter content, plays a crucial role in soil slaking. As a result, the Aggregate Stability Index (ASI) has been widely used in soil quality assessments across various land uses (Karlen and Stott, 1994; Gardi et al., 2002; Moebius-Clune et al., 2011; Budak et al., 2018; Karaca et al., 2021). Plant available water content proved to be a more relevant SQ indicator at the Ilgaz site compared to the Kurşunlu site. The higher PAWC at Ilgaz may partly result from greater OM content. Plant available water content has often been reported as a key SQI across various land uses (Shao et al., 2020; Karaca et al., 2021). In Mediterranean conditions, soil porosity and water availability are considered critical SQIs (Kairis et al., 2021).

Soil pH proved to be one of the most influential chemical properties affecting soil quality at both research locations. At the Kurşunlu site, high soil pH was a factor that lowered soil quality, whereas the opposite was true at the Ilgaz site. Soil pH has been widely recognized as a key Soil Quality Indicator (SQI) in many cases (e.g., Shao et al., 2020; Recha et al., 2022). An optimal pH range of 6.5 to 7.0 enhances the availability of nitrogen, phosphorus, and potassium in pastures (Dong et al., 2012). The greater importance assigned to pH at the Ilgaz site suggests that soil pH was a more significant SQI there than at Kurşunlu. Although soil pH differed significantly between the two study sites, it did not change with soil depth within the sites. In contrast, Gardi et al. (2002) reported minimal influence of soil depth on pH in various pastures in northern Italy, and Recha et al. (2022) found no significant difference in soil pH between 0-15 cm and 15-45 cm depths across grasslands in Kenya, Tanzania, and Uganda.

Soil $CaCO_3$ content was an important SQ indicator at both sites. No significant differences were found in $CaCO_3$ means across soil depths at either site. Similar findings have been reported elsewhere (Gardi et al., 2002). Like our study, soil $CaCO_3$ content has been recognized as a SQI in pastures across Eastern (Karaca et al., 2021) and Southeastern (Budak et al., 2018) Türkiye.

The results show that OM content has little effect on SQ at the research sites. Unlike our findings, OM content has often been recognized as a SQI (Gardi et al., 2002; Li et al., 2013; Paz-Kagan et al., 2016; Yu et al., 2018; Karaca et al., 2021). Karaca et al. (2021) reported a significant impact of OM on SQ in the Lake Van pasturelands in Eastern Türkiye, and Li et al. (2013) noted that OM content could indicate grazing effects on soils in Qinghai Province, China. Dong et al. (2012) found that the organic carbon content in the 0-4 cm layer

was mainly affected by grassland degradation from erosion-induced topsoil loss, which caused soil texture to change from loam to sandy loam, led to decreases in vegetation cover, and altered vegetation composition. However, similar to our study, OM content was not included in MDS in some cases (e.g., Budak et al., 2018; Shao et al., 2020).

Table 1 shows that the average values for most SQIs are mostly similar across different depths at both study sites. However, Table 3 indicates that the SQI in the 0-10 cm layer differs significantly from that in the 10-20 cm layer on both sites. This difference may be due to the method used to calculate SQI. The SQI is determined by considering both the extent and variability of soil quality indicators. When calculating the SQI, the choice of SQ indicators and their weights largely depend on the correlation between indicators and the interactions among these correlations. The weight assigned to each indicator is based on the eigenvector it belongs to and the proportion of the total variability in the dataset that this eigenvector explains. Therefore, the contribution of a specific indicator to the SQI is influenced by both its assigned weight and the magnitude of its score.

The nutrient status of grasslands is essential for producing nutritious and high-quality animal feed (Kumaresan et al., 2010). Nutrient deficiencies are a primary concern in grasslands, affecting the quantity and quality of meat and milk production (Masters and White, 1996; Kao et al., 2020), and micronutrient deficiencies are often seen in both the herbage and livestock within pasture systems (Thomas et al., 2021). Means for K and Ca contents were significantly higher at the Kurşunlu site. Meanwhile, means for P_{av} and Mg contents were significantly greater at the Ilgaz site. Exchangeable K represents a small portion of total K in soils and is the best indicator of soil K supply; it has been used in fertility assessments (Shao et al., 2020). In arable soils, exchangeable K ranges from 40 to 400 mg K kg^{-1} (Mengel, 2007). Our data indicated that K was adequate in soil at both sites (Appendix B). Additionally, mean values for exchangeable Ca indicated that the soils were sufficient in Ca supply according to Tisdale et al. (1993) (Appendix B). Similarly, mean values for exchangeable Mg suggested that Mg deficiency might not be an issue at either site, based on several sources (Tisdale et al., 1993; Whitehead, 2000; Merhaut, 2007; Dudek et al., 2020). Conversely, P_{av} was insufficient at both Kurşunlu and Ilgaz sites, as per Tisdale et al. (1993), Whitehead (2000), and Marijanušić et al. (2017). Depth-related variations in P_{av} are notable at Kurşunlu but not at Ilgaz. In grasslands, P_{av}, Ca, and K contents were identified as indicators of SQ (e.g., Li et al., 2013).

Values for DTPA-extracted Fe, Mn, Zn, and Cu were notably higher at the Ilgaz site compared to the Kurşunlu site, which aligns with the common occurrence of micronutrient deficiencies in plants due to calcareous and/or alkaline soils (Tisdale et al., 1993). The higher micronutrient levels at the Ilgaz site were attributed to greater organic matter content and lower soil pH (Römheld and Nikolic, 2007). Soil Mn content was the most influential micronutrient affecting soil quality across all studied depths at both sites (Table 2). The negative effects of Cu and Zn on soil quality were more significant in Kurşunlu, while Fe and Mn had equally important roles at both locations (Table 2). Soils with Zn levels above 1.0 mg kg^{-1} are considered sufficient for Zn supply (Tisdale et al., 1993), and levels exceeding 4.43 mg kg^{-1} are deemed adequate for most grasses (Marijanušić et al., 2017). Depth-related differences were notable for all four micronutrients in Kurşunlu and for Fe and Zn on the Ilgaz site. Similarly, Recha et al. (2022) reported that average values for Mn, Cu, Fe, and Zn differed significantly between 0-15 and 15-45 cm soil depths across grasslands in Kenya, Uganda, and Tanzania. Consistent with our findings, soil Fe, Mn, Zn, and Cu contents were identified as key variables influencing soil quality in Eastern Türkiye (Karaca et al., 2021). The mean PR was slightly higher in Kurşunlu, averaging around 2.8 MPa, compared to approximately 2.6 MPa in Ilgaz. The relatively higher PR values recorded in Kurşunlu are likely associated with its coarser soil texture, limited organic matter, and comparatively drier climate, which together lead to increased soil strength and reduced pore connectivity. The variation of PR with depth was minor at both sites, suggesting that surface factors such as grazing pressure, evaporation, and organic matter depletion play a more significant role in soil compaction than subsurface processes. Similar patterns have been documented in previous studies. Sağlam and Dengiz (2017) reported that soils with coarse texture and low organic matter generally show higher penetration resistance, especially under dry conditions. Likewise, Arshad et al. (1997) as well as Hamza and Anderson (2005) emphasized that soil penetration resistance increases as soil moisture and organic matter decline, highlighting the key role of organic carbon in maintaining soil structural stability.

Studies conducted in grazed rangelands of Central Anatolia have also shown that continuous grazing and reduced vegetation cover lead to surface compaction and increased penetration resistance (Ozgöz et al., 2012). These results support the present findings, indicating that both soil physical characteristics and land use practices strongly influence PR dynamics under different environmental conditions. The findings of this study indicated that careful consideration is necessary when interpreting soil quality data for pastures in

relation to nutrient adequacy. Therefore, to improve fertility assessments, nutrient analyses that consider soil depth should be used alongside the Soil Quality Index (SQI), since SQI values alone may not fully reflect nutrient constraints at different depths. In addition, indicators such as available phosphorus (Pav), manganese (Mn), and bulk density (BD) may act as useful early-warning signals for detecting changes in soil quality in pasture ecosystems. However, site-related SQI values showed consistency between SQ and nutrient status. For example, both SQI and nutrient availability were significantly higher at the Ilgaz site than at the Kurşunlu site. Therefore, these results are very important for providing a clear understanding of whether SQ in pastures truly reflects soil fertility.

Conclusion

This study tested two hypotheses. The first was that, due to rapid changes in plant-soil interactions and grazing-induced soil degradation with depth, soil quality can vary accordingly in pastures. The findings supported this hypothesis, revealing that soil quality was significantly lower at the 0-10 cm depth compared to the 10-20 cm depth in both study pastures. The second hypothesis suggested that the variation in soil quality with depth differs across different pasture ecosystems. The data upheld this hypothesis as well: at the semiarid pasture, soil quality at the 0-10 cm depth differed significantly from the 10-20 cm depth but not from the 0-20 cm depth, whereas it was significantly different from both the 10-20 cm and 0-20 cm depths on semi-humid pasture.

Several soil variables, including bulk density, plant-available water content, aggregate stability index, pH, and DTPA-extracted nutrients such as Mn and Zn, exchangeable Mg, Ca, and plant-available P, were included in the minimum data sets for both pastures. Soil bulk density and Mn content were common soil quality indicators across all three soil depths on both sites. The results have two main implications. First, the soil quality index calculated using data from soil samples taken at 0-10 cm depth better reflects soil degradation than data from 0-20 or 10-20 cm depths. These results indicate that bulk density (BD) and manganese (Mn) at the 0–10 cm soil depth may function as sensitive early-warning indicators of pasture degradation. Incorporating these parameters into regular soil monitoring schemes could enhance the early detection of structural and chemical deterioration in pasture soils, thereby supporting more effective and timely management decisions. Using samples from 0-20 cm may overestimate the soil quality of the 0-10 cm layer. Therefore, sampling confined to the 0–10 cm soil layer appears sufficient for detecting the effects of grazing on soil quality. Second, by monitoring pH and bulk density—or more practically, penetration resistance, given the strong correlation between bulk density and penetration resistance in our data—one can anticipate changes in soil quality in advance. This is likely because changes in surface pH and bulk density are more sensitive to grazing pressure, whereas the inclusion of deeper layers can mask these signals through the dilution effect of improved subsoil conditions or reduced compaction bias. Additional studies across different conditions are necessary to ensure these findings are applicable to a variety of soil and environmental settings. These insights provide methodological reference for Mediterranean and Central Anatolian grassland restoration programs.

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References

Abdalla, M., Hastings, A., Chadwick, D.R., Jones, D.L., Evans, C.D., Jones, M.B., Rees, R.M., Smith, P., 2018. Critical review of the impacts of grazing intensity on soil organic carbon storage and other soil quality indicators in extensively managed grasslands. *Agriculture, Ecosystems and Environment* 253: 62–81.

Andrews, S., Karlen, D., Cambardella, C., 2004. The soil management assessment framework. *Soil Science Society of America Journal* 68(6): 1945-1962.

Andrews, S., Karlen, D., Mitchell, J., 2002. A comparison of soil quality indexing methods for vegetable production systems in Northern California. *Agriculture, Ecosystems & Environment* 90(1): 25–45.

Andrews, S.S., Carroll, C.R., 2001. Designing a soil quality assessment tool for sustainable agroecosystem management. *Ecological Applications* 11(6): 1573-1585.

Arshad, M.A., Coen, G.M., 1992. Characterization of soil quality: Physical and chemical criteria. American Journal of Alternative Agriculture 7(1/2): 25–31.

Arshad, M.A., Lowery, B., Grossman, B., 1997. Physical tests for monitoring soil quality. In: Methods For Assessing Soil Quality Vol. 49. Doran, J.W., Jones, A.J. (Eds.). Soil Science Society of America, Inc. Madison, Wisconsin, USA. pp.123-141.

Bai, R., Xi, D., He, J., Hu, H., Fang, Y., Zhang, L., 2015. Activity, abundance and community structure of anammox bacteria along depth profiles in three different paddy soils. *Soil Biology and Biochemistry* 91: 212–221.

Biswas, S., Hazra, G.C., Purakayastha, T.J., Saha, N., Mitran, T., Roy, S.S., Basak, N., Mandal, B., 2017. Establishment of critical limits of indicators and indices of soil quality in rice-rice cropping systems under different soil orders. *Geoderma* 292: 34–48.

Blake, G.R., Hardge, K.H., 1986. Bulk Density. In: Methods of Soil Analysis: Part 1. Physical and Mineralogical Methods, Klute, A., (Ed.). American Society of Agronomy-Soil Science Society of America, Madison, Vol 5, pp. 363–375.

Bogunovic, I., Kljak, K., Dugan, I., Grbeša, D., Telak, L.J., Duvnjak, M., Kisic, I., Solomun, M.K., Pereira, P., 2022. Grassland management impact on soil degradation and herbage nutritional value in a temperate humid environment. *Agriculture* 12(7): 921.

Budak, M., Gunal, H., Celik, I., Yildiz, H., Acir, N., Acar, M., 2018. Soil quality assesment of upper Tigris basin. *Carpathian Journal of Earth and Environmental Sciences* 13: 301-316.

Cassel, D., Nielsen, D., 1986. Field capacity and available water capacity. In: Methods of Soil Analysis: Part 1. Physical and Mineralogical Methods, Klute, A., (Ed.). American Society of Agronomy-Soil Science Society of America, Madison, Vol 5, pp. 901–926.

Crepin, L., Johnson, R.L., 1993. Soil sampling and environmental assessment, In: Soil Sampling and Methods of Analysis, Carter, M.R., (Ed.). Lewis Publishers, Boca Raton, pp. 5–18.

Dong, S.K., Wen, L., Li, Y.Y., Wang, X.X., Zhu, L., Li, X.Y., 2012. Soil-quality effects of grassland degradation and restoration on the Qinghai-Tibetan Plateau. *Soil Science Society of America Journal* 76: 2256–2264.

Dudek, T., Wolański, P., Rogut, K., 2020. The content of macro- and micro minerals in the sward of different types of semi-natural meadows of temperate climate in SE Poland. *Agronomy* 10(2): 273.

Gardi, C., Tomaselli, M., Parisi, V., Petraglia, A., Santini, C., 2002. Soil quality indicators and biodiversity in northern Italian permanent grasslands. *European Journal of Soil Biology* 38: 103–110.

Gee, G., Bauder, J., 1986. Particle-size analysis, In: Methods of Soil Analysis: Part 1. Physical and Mineralogical Methods, Klute, A., (Ed.). Vol.5, American Society of Agronomy and Soil Science Society of America, Madison, pp. 383–411.

Gilmullina, A., Rumpel, C., Blagodatskaya, E., Chabbi, A., 2020. Management of grasslands by mowing versus grazing–impacts on soil organic matter quality and microbial functioning. *Applied Soil Ecology* 156: 103701.

Gong, D., Wang, Z., Zhang, Y., Wei, B., Zhang, B., Hu, X., Gu, C. 2025. Preliminary study to determine the key limiting ındicator of cropland soil quality on the Tibetan Plateau. *Agriculture* 15(12): 1252.

Hamza, M.A., Anderson, W.K., 2005. Soil compaction in cropping systems: A review of the nature, causes and possible solutions. *Soil and Tillage Research* 82(2): 121-145.

Iyigun, C., Türkeş, M., Batmaz, İ., Yozgatligil, C., Purutçuoğlu, V., Koç, E.K., Öztürk, M.Z., 2013. Clustering current climate regions of Turkey by using a multivariate statistical method. *Theoretical and Applied Climatology* 114: 95–106.

Kairis, O., Aratzioglou, C., Filis, A., Mol, M., 2021. The effect of land management practices on soil quality indicators in Crete. *Sustainability* 13(15): 8619.

Kamarudin, K., 2019. Comparison of soil spatial variability and geostatistical characteristics between different vegetation types in Nara Park (Japan). Master thesis. Kindai University.

Kao,P.T., Darcha,T., McGrathc,S.P., Kendalld,N.R., Bussb,H.L.,Warrene, H.,Lee, M.R.F., 2020. Factors influencing elemental micronutrient supply from pasture systems for grazing ruminants. *Advances in Agronomy* 164:161-219.

Karaca, S., Dengiz, O., Demirağ, T., Özkan, B., Dedeoğlu, M., Gülser, F., Sargin, B., Demirkaya, S., Ay, A., 2021. An assessment of pasture soils quality based on multi-indicator weighting approaches in semi-arid ecosystem. *Ecological Indicators* 121: 107001.

Karlen, D.L., Stott, D.E., 1994. A framework for evaluating physical and chemical indicators of soil quality. In: Defining Soil Quality for a Sustainable Environment. Doran, J.W., Coleman, D.C., Bezdicek, D.F., Steaward, B.A., (Eds.). American Society of Agronomy-Soil Science Society of America, Madison, SSSA Special Publication Number 35, pp. 53-72.

Kemper, W.D., Rosenau, R.C., 1986. Aggregate stability and size distributlon, In: Methods of Soil Analysis: Part 1. Physical and Mineralogical Methods, Klute, A., (Ed.). Vol.5, American Society of Agronomy and Soil Science Society of America, Madison, pp. 425–442.

Kumaresan, A., Bujarbaruah, K.M., Pathak, K.A., Brajendra, Ramesh, T., 2010. Soil–plant–animal continuum in relation to macro and micro mineral status of dairy cattle in subtropical hill agro ecosystem. *Tropical Animal Health and Production* 42: 569–577.

Kuo, S., 1996. Phosphorus. In: Methods of Soil Analysis: Part 3 Chemical Methods, 5.3. Sparks, D.L. Page, A.L., Helmke, P.A., Loeppert, R.H., Soltanpour, P.N., Tabatabai, M.A., Johnston, C.T., Sumner, M.E. (Eds.). SSSA Book Series No. 5. ASA-SSSA Madison WI, USA, pp. 869 - 919.

Larson, W.E., Pierce, F.J., 1994. The dynamics of soil quality as a measure of sustainable management. In: Defining Soil Quality for a Sustainable Environment. Doran, J.W., Coleman, D.C., Bezdicek, D.F., Steaward, B.A., (Eds.). American Society of Agronomy-Soil Science Society of America, Madison, SSSA Special Publication Number 35, pp. 37-51.

Li, Y., Dong, S., Wen, L., Wang, X., Wu, Y., 2013. Assessing the soil quality of alpine grasslands in the Qinghai-Tibetan Plateau using a modified soil quality index. *Environmental Monitoring and Assessment* 185: 8011–8022.

Lindsay, W.L., Norvell, W.A., 1978. Development of a DTPA soil test for zinc, iron, manganese, and copper. *Soil Science Society of America Journal* 42(3):421–428.

Marijanušić, K., Manojlović, M., Bogdanović, D., Čabilovski, R., Lombnaes, P., 2017. Mineral composition of forage crops in respect to dairy cow nutrition. *Bulgarian Journal of Agricultural Science* 23(2): 204-212.

Masters, D.G., White, C.L., 1996. Detection and treatment of mineral nutrition problems in grazing sheep, detection and treatment of mineral nutrition problems in grazing sheep. Canberra, Australia. 195 p. Available at [Access date: 06.07.2025]: https://www.aciar.gov.au/sites/default/files/legacy/node/2211/mn37_pdf_14863.pdf

McLean, E.O., 1982. Soil pH and Lime Requirement. In. Methods of soil analysis, Part 2- Chemical and Microbiological Properties. Page, A.L., Keeney, D. R., Baker, D.E., Miller, R.H., Ellis, R. Jr., Rhoades, J.D. (Eds.). Soil Science Society of America. Madison, Wisconsin, USA. pp. 199-224.

Mengel, K., 2007. Potassium, In: Handbook of Plant Nutrition, Barker, A., Pilbeam, D., (Eds.). CRC Press, Boca Raton, pp. 91–120.

Merhaut, D.J., 2007. Magnesium, In: Handbook of Plant Nutrition, Barker, A. V., Pilbeam, D.J. (Eds.). CRC Press, Boca Raton, pp. 149–171.

Moebius-Clune, B.N., van Es, H.M., Idowu, O.J., Schindelbeck, R.R., Kimetu, J.M., Ngoze, S., Lehmann, J., Kinyangi, J.M., 2011. Long-term soil quality degradation along a cultivation chronosequence in western Kenya. *Agriculture, Ecosystems and Environment* 141: 86–99.

Mulla, D.J., McBratney, A.B., 2002. Soil spatial variability, In: Soil Physics Companion, Warrick, A.W., (Ed.). CRC Press, Boca Raton, pp. 343–373.

Nehrani, S.H., Askari, M.S., Saadat, S., Delavar, M.A., Taneri, M., Holden, N.M., 2020. Quantification of soil quality under semi-arid agriculture in the northwest of Iran. *Ecological Indicators* 108: 105770.

Nelson, D.W., Sommers, L.E., 1996. Total carbon organic carbon and organic matter. In: Methods of Soil Analysis: Part 3 Chemical Methods, 5.3. Sparks, D.L. Page, A.L., Helmke, P.A., Loeppert, R.H., Soltanpour, P.N., Tabatabai, M.A., Johnston, C.T., Sumner, M.E. (Eds.). SSSA Book Series No. 5. ASA-SSSA Madison WI, USA, pp. 961–1010.

Ozgöz, E., Akbş, F., Çetin, M., Erşahin, S., Günal, H., 2007. Spatial variability of soil physical properties as affected by different tillage systems. *New Zealand Journal of Crop and Horticultural Science* 35(1): 1-13.

Pansu, M., Gautheyrou, J., 2007. Handbook of Soil Analysis: Mineralogical, Organic and Inorganic Methods. Springer Berlin, Heidelberg. 993p.

Paz-Kagan, T., Ohana-Levi, N., Herrmann, I., Zaady, E., Henkin, Z., Karnieli, A., 2016. Grazing intensity effects on soil quality: A spatial analysis of a Mediterranean grassland. *Catena* 146: 100–110.

Pierce, F.J., Larson, W.E., Dowdy, R.H., Graham, W.A.P., 1983. Productivity of soils: assessing long-term changes due to erosion. *Journal of Soil and Water Conservation* 38(1): 39–44.

Rahmanipour, F., Marzaioli, R., Bahrami, H.A., Fereidouni, Z., Bandarabadi, S.R., 2014. Assessment of soil quality indices in agricultural lands of Qazvin Province, Iran. *Ecological Indicators* 40: 19–26.

Recha, J.W., Olale, K.O., Sila, A.M., Ambaw, G., Radeny, M., Solomon, D., 2022. Measuring soil quality indicators under different climate-smart land uses across East African Climate-Smart Villages. *Agronomy* 12(2): 530.

Rhoades, J.D., 1982. Soluble salts, In. Methods of soil analysis, Part 2- Chemical and Microbiological Properties. Page, A.L., Keeney, D. R., Baker, D.E., Miller, R.H., Ellis, R. Jr., Rhoades, J.D. (Eds.). ASA-SSSA, Madison, Wisconsin, USA. pp. 167–179.

Römheld, V., Nikolic, M., 2007. Iron, In: Handbook of Plant Nutrition, Barker, A. V., Pilbeam, D.J. (Eds.). CRC Press, Boca Raton, pp. 329–350.

Sağlam, M., Dengiz, O., 2017. Spatial variability of soil penetration resistance in an alluvial delta plain under different land uses in middle Black Sea Region of Turkey. *Archives of Agronomy and Soil Science* 63(1): 60-73.

Sanad, H., Moussadek, R., Mouhir, L., Oueld Lhaj, M., Dakak, H., El Azhari, H., Zouahri, A., 2024. SQI and geostatistical approach: A case study of the Mnasra Region, Gharb Plain, Morocco. *Agronomy* 14(6): 1112.

Sánchez-Marañón, M., Soriano, M., Delgado, G., Delgado, R., 2002. Soil quality in Mediterranean mountain environments: effects of land use change. *Soil Science Society of America Journal* 66(3): 948-958.

Sánchez-Navarro, A., Gil-Vázquez, J.M., Delgado-Iniesta, M.J., Marín-Sanleandro, P., Blanco-Bernardeau, A., Ortiz-Silla, R., 2015. Establishing an index and identification of limiting parameters for characterizing soil quality in Mediterranean ecosystems. *Catena* 131: 35–45.

Sayar, M. S., Han, Y., Başbağ, M., Gül, İ., Polat, T., 2015. Rangeland improvement and management studies in Southeastern Anatolia Region of Turkey. *Pakistan Journal of Agricultural Sciences* 52(1): 9-18.

Shao, G., Ai, J., Sun, Q., Hou, L., Dong, Y., 2020. Soil quality assessment under different forest types in the Mount Tai, central Eastern China. *Ecological Indicators* 115: 106439.

Soil Survey Staff, 2014. Keys to soil taxonomy. Government Printing Office, Washington. Available at [Access date: 06.07.2025]: https://nrcs.app.box.com/s/xi57bj6zyo601eokr7v715mkdpeaa81h/file/1147478400323

Steffens, M., Kölbl, A., Totsche, K., Kögel-Knabner, I., 2008. Grazing effects on soil chemical and physical properties in a semiarid steppe of Inner Mongolia (P.R. China). *Geoderma* 143: 63–72.

Stott, D., 2019. Recommended soil health indicators and associated laboratory procedures. Soil Health Technical Note No. 450-03 76. U.S. Department of Agriculture, Natural Resources Conservation Service (NRCS), Washington, D.C.

USA. Available at [Access date: 06.07.2025]: https://www.naptprogram.org/files/napt/publications/method-papers/2019-nrcs-technote-450-03.pdf

Sun J., Wang Y., Piao S., Liu M., Han G., Li J., Liang E., Lee T.M., Liu G., Wilkes A., Liu S., Zhao W., Zhou H., Yibeltal M., Berihun M.L., Browning D., Fenta A.A., Tsunekawa A., Brown J., Willms W., Tsubo M. 2022. Toward a sustainable grassland ecosystem worldwide. *The Innovation* 3(4): 100265.

Thomas, C.L., Darch, T., Harris, P., Beaumont, D.A., Haefele, S.M., 2021. The distribution of soil micro-nutrients and the effects on herbage micro-nutrient uptake and yield in three different pasture systems. *Agronomy* 11(9): 1731.

Thomas, G.W., 1982. Exchangeable cations, In. Methods of soil analysis, Part 2- Chemical and Microbiological Properties. Page, A.L., Keeney, D. R., Baker, D.E., Miller, R.H., Ellis, R. Jr., Rhoades, J.D. (Eds.). ASA-SSSA, Madison, Wisconsin, USA. pp. 159–165.

Tisdale, S., Nelson, W., Beaton, J., Havlin, J., 1993. Soil Fertility and Fertilizers, 5th ed. Macmillan Inc., New York. 634p.

Whitehead, D.C., 2000. Nutrient elements in grassland: soil-plant-animal relationships, Introduction. In: Nutrient Elements in grassland: soil-plant-animal relationships. Whitehead, D.C. (Ed.). CABI Publishing. pp. 1–14.

Wu, C., Liu, G., Huang, C., Liu, Q., 2019. Soil quality assessment in Yellow River Delta : Establishing a minimum data set and fuzzy logic model. *Geoderma* 334: 82–89.

Yu, P., Han, D., Jia, H., 2018. Soil quality assessment under different land uses in an alpine grassland. *Catena* 171: 280–287.

Zhou, H., Yang, X., Zhou, C., Shao, X., Shi, Z., Li, H., Su, H., Qin, R., Chang, T., Hu, X., Yuan, F., Li, S., Zhang, Z., Ma, L., 2023. Alpine grassland degradation and its restoration in the Qinghai–Tibet Plateau. *Grasses* 2(1): 31-46.

Appendix A

Plants diagnosed in Kurşunlu and Ilgaz pastures during the study

Kurşunlu site				Ilgaz site	
Scientific name	Common name	Scientific name	Common name	Scientific name	Common name
Achillea biebersteinii	Yarrow	*Knautia orientalis*	Knautia	*Achillea millefolium*	Common yarrow
Achillea coarctata	Achillea	*Lapsana communis*	Nipplewort	*Agropyron cristatum*	Crested wheatgrass
Achillea teretifolia	Achillea	*Lotus corniculatus*	Birdfoot deervetch	*Agropyron repens*	Quackgrass
Achillea fraasii	Filigree yarrow	*Marrubium astracanicum*	Horehound	*Alyssum pateri*	Madwort
Adonis Flammea	Pheasant's eye	*Marrubium globosum*	Horehound	*Anthemis tinctoria*	Yellow chamomile
Agropyron cristatum	Crested wheatgrass	*Marrubium parviflorum*	Horehound	*Anthemis cretica ssp. anatolica*	Anatolian mountain chamomile
Agropyron elongatum	Tall wheatgrass	*Medicago falcata*	Yellow alfalfa	*Astragalus cymbostegius*	Astragale
Agropyron intermedium	Intermediate wheatgrass	*Medicago papillosa*	Papillose medick	*Bromus inermis*	Smooth brom
Alyssum pateri	Madwort	*Medicago truncatula*	Barrel medic	*Bromus japonicus*	Japanese brom
Anchusa azurea	Italian bugloss	*Melilatus indica (indicus)*	Indian meliot	*Capsella bursa-pastoris*	Sheepherd's purse
Anthemis tinctoria	Golden chamomile	*Onobrychis altissima*	Sainfoin	*Centaurea depressa*	Dark blue bottle
Artemisia absinthium	Absinthium	*Onobrychis argaea*	Sainfoin	*Cicer anatolicum*	Chick-pea
Artemisia austriaca	Sagebrush	*Onobrychis araxina*	Sainfoin	*Dactylis glomerata*	orchardgrass
Astragalus aduncus	Milk-vetch	*Paronychia chionaea*	Thyme leowod	*Digitalis ferruginea*	Foxglove
Astragalus andrachneifolius	Astragale	*Phleum pratense*	Timothy	*Euphorbia seguieriana*	Spurge
Astragalus christianus	Astragale	*Phlomis pungens*	Jerusalem sage	*Euphorbia petrophila*	Spurge
Astragalus cymbostegius	Astragale	*Picnomon arcana*	Soldier thistle	*Eryngium campestre*	Field eryngo
Astrgalus depressus	Milk-vetch	*Plantago atrata*	Plantain	*Festuca arundinacea*	Tall fescue
Astragalus onobrychis	Sainfoin milk-vetch	*Plantago lagopus*	Round-headed plantain	*Festuca pratensis*	Meadow fescue
Ballota acetabulosa	Foetid-horsebound	*Potentilla argentea*	Silvery cinquefoil	*Festuca ovina*	Sheep fescue
Bromus arvensis	Field brome	*Potentilla recta*	Sulphur cinquefoil	*Inula oculus-christi L.*	Hoary flea bane
Centaurea virgata	Sguarrose knapweed	*Ruta chalepensis*	Fringed rue	*Lotus corniculatus*	Birdfoot deervetch
Centaurea carduiformi	Conflower	*Salvia aethiopis*	Mediterranean sage	*Medicago falcata*	Yellow alfalfa
Centaurea depressa	Dark blue bottle	*Salvia fruticosa*	Triloba sag	*Medicago papillosa*	Papillose medick
Convolvulus arvensis	Field bindweed	*Sanguisorba minor*	Small burnet	*Melissa officinalis*	Lemon balm
Convolvulus lineatus	Bindweed	*Senecio vernalis*	Ragwort	*Nepeta nuda*	Hairless cat mint
Cynodon dactylon	Bermudagrass	*Sideritis montana*	Field iron wort	*Onobrychis altissima*	Sainfoin
Dactylis glomerata	Orchardgrass	*Sisymbrium altissimum*	Tall tumble mustard	*Onobrychis hypargyrea*	Sainfoin
Daucus carota	Carrot	*Stachys cretica*	Cretan hedgenettle	*Phleum pratense*	Timothy
Descurainia sophia	Fixweed	*Stachys iberica*	Woundwort	*Pilosella hoppeana*	Mouse-ear hawkweed
Digitalis ferruginea	Foxglove	*Taeniatherum caput-medusae*	Medusa head	*Plantago lagopus*	Round-headed plantain
Eryngium bithynicum	Field eryngo	*Trifolium pratense*	Red clover	*Poa longifolia*	Mountain bluegrass
Eryngium campestre	Field eryngo	*Trifolium repens*	White clover	*Potentilla argentea*	Silvery cinquefoil
Eryngium creticum	Syrian eryngo	*Trifolium scabrum*	Clover	*Ranunculus kotschyi*	Buttercup
Erysimum alpestre	Alpen erysimum	*Turgenia latifolia*	Bur-parsley	*Ranunculus polyanthemos*	Buttercup
Erodium cicutarium	Common storks bill	*Verbascum blattaria*	Moth mullein	*Sisymbrium elatum*	Tumblemustard
Euphorbia denticulata	Bluish spurge	*Veronica multifida*	Speedwell	*Taeniatherum caput-medusae*	Medusa head
Euphorbia petrophila	Spurge	*Vicia cracca*	Bird vetch	*Trifolium pratense*	Red clover
Euphorbia seguieriana	Spurge	*Vicia grandiflora*	Big flower vetch	*Trifolium repens*	White clover
Festuca ovina	Sheep fescue	*Xeranthemum annum*	Immortelle	*Trifolium subterraneum*	Subterranean clover
Galium floribundum	Bedstraw	*Inula oculus-christi*	Hoary fela bane	*Urtica pilulifera*	Roman nettle
Geranium collinum	Geranium	*Helichrysum arenarium*	Sandy everlasting	*Verbascum blattaria*	Moth mullein
Hordeum murinum	Mouse barley	*Helictotrichon pratense*	Meadow oat-grass		

Appendix B

Results of exploratory data analysis for 0-10, 10-20 and 0-20 cm soil depths at Kurşunlu and Ilgaz study sites

Descriptive statistics for soil variables in 0-10 cm depth on Kurşunlu site

Variable	Mean	Min	Max	SD	CV	Skewness	Kurtosis
Sand (%)	56.82	13.90	82.30	13.71	24.14	1.25	0.38
Silt (%)	15.42	2.50	57.50	6.95	45.10	0.89	0.13
Clay (%)	27.77	13.40	66.10	9.58	34.50	0.93	0.25
BD (Mg m^{-3})	1.24	1.00	1.65	0.09	7.39	0.95	-0.41
PR (MPa)	2.84	1.60	3.22	0.41	14.62	0.97	-0.39
FC (%)	25.08	11.72	44.16	6.77	26.99	0.94	-0.43
PWP (%)	14.20	3.66	33.84	4.67	32.91	1.44	0.59
PAWC (%)	10.88	1.08	27.31	4.87	44.78	6.34	60.51
ASI (%)	48.70	34.86	56.17	3.39	6.95	6.39	61.44
$CaCO_3$ (%)	2.26	0.30	7.09	1.02	45.08	4.88	39.13
OM (%)	1.31	0.12	3.03	0.55	42.08	2.00	6.89
pH	7.56	7.00	8.25	0.35	4.62	2.12	7.82
EC (µS cm^{-1})	146.18	21.20	1104.00	136.50	93.38	2.07	7.56
CEC (cMol kg^{-1})	19.96	12.76	39.11	4.78	23.97	1.64	1.71
*K (mg kg^{-1})	102.94	11.20	602.00	68.16	66.21	1.62	1.61
*Ca (mg kg^{-1})	279.16	1.34	493.21	63.32	22.68	1.95	2.40
*Mg (mg kg^{-1})	40.68	16.56	113.44	10.61	26.08	1.74	2.02
P_{av} (mg kg^{-1})	0.23	0.08	0.57	0.09	39.24	3.58	12.71
**Fe (mg kg^{-1})	1.75	0.01	7.63	1.35	77.42	3.15	9.49
**Cu (mg kg^{-1})	0.80	0.01	5.44	0.76	94.77	2.64	6.13
**Mn (mg kg^{-1})	10.56	0.05	39.87	11.45	108.44	1.98	2.79
**Zn (mg kg^{-1})	2.87	0.03	44.37	7.18	250.06	3.63	12.95

BD: Bulk density, PR: Penetration resistance, FC: Field capacity, PWP: Permanent wilting point, PAWC: Plant available water content, ASI: Aggregate stability index, EC: Electrical conductivity, CEC: Cation exchange capacity, SD: Standard deviation, CV: Coefficient of variation

* Exchangeable.

** DTPA-extracted.

Descriptive statistics for soil variables in 10-20 cm depth on Kurşunlu site.

Variable	Mean	Min	Max	SD	CV	Skewness	Kurtosis
Sand (%)	57.76	16.40	82.30	13.75	23.80	-0.87	0.41
Silt (%)	14.71	2.50	45.00	6.92	47.02	1.06	1.96
Clay (%)	27.57	11.10	63.60	9.45	34.28	1.28	1.80
BD (Mg m^{-3})	1.24	1.00	1.43	0.09	7.12	-1.28	1.07
PR (MPa)	2.84	1.19	3.35	0.44	15.42	-1.55	1.47
FC (%)	24.84	9.30	45.68	6.90	27.79	0.42	-0.37
PWP (%)	13.95	4.97	33.73	4.85	34.72	1.20	1.60
PAWC (%)	10.89	1.17	32.93	5.02	46.10	0.68	0.77
ASI (%)	48.44	35.17	56.76	3.44	7.10	-0.96	2.01
$CaCO_3$ (%)	2.38	0.30	6.94	1.12	46.90	1.13	2.18
OM (%)	1.18	0.14	3.03	0.57	48.17	0.22	-0.97
pH	7.52	7.01	8.21	0.35	4.68	0.12	-1.40
EC (µS cm^{-1})	126.57	28.70	912.00	113.11	89.37	3.55	15.99
CEC (cMol kg^{-1})	19.85	11.61	37.86	4.73	23.81	1.28	1.80
*K (mg kg^{-1})	91.22	21.50	550.00	66.60	73.01	2.68	10.79
*Ca (mg kg^{-1})	275.58	20.23	466.01	60.82	22.07	-0.03	1.73
*Mg (mg kg^{-1})	40.89	10.63	112.43	10.80	26.42	0.81	4.58
P_{av} (mg kg^{-1})	0.21	0.08	0.94	0.11	51.88	2.78	11.43
**Fe (mg kg^{-1})	1.69	0.02	15.36	1.46	86.53	3.41	23.36
**Cu (mg kg^{-1})	0.84	0.02	9.07	0.93	110.87	3.52	19.79
**Mn (mg kg^{-1})	9.07	0.01	50.31	11.63	128.23	1.64	1.23
**Zn (mg kg^{-1})	2.47	0.00	50.44	6.77	273.76	4.29	20.05

BD: Bulk density, PR: Penetration resistance, FC: Field capacity, PWP: Permanent wilting point, PAWC: Plant available water content, ASI: Aggregate stability index, EC: Electrical conductivity, CEC: Cation exchange capacity, SD: Standard deviation, CV: Coefficient of variation

* Exchangeable.

** DTPA-extracted.

Descriptive statistics for soil soil variables in 0-20 cm soil depth on the Kurşunlu site

Variable	Mean	Min	Max	SD	CV	Skewness	Kurtosis
Sand (%)	57.22	24.35	78.55	9.70	16.95	-0.64	-0.03
Silt (%)	15.04	2.50	35.00	4.92	32.68	0.88	1.58
Clay (%)	27.63	12.25	56.90	6.74	24.37	0.89	0.87
BD (Mg m^{-3})	1.24	01.02	1.48	0.07	5.79	-1.89	12.37
PR (MPa)	2.83	1.50	3.21	0.34	12.13	-1.45	1.89
FC (%)	24.93	7.87	37.73	4.87	19.54	0.22	-0.16
PWP (%)	14.06	4.42	28.81	3.40	24.21	0.87	0.94
PAWC (%)	10.87	1.80	25.29	3.51	32.29	0.47	0.57
ASI (%)	48.51	25.00	54.88	2.76	5.69	-2.15	13.22
$CaCO_3$ (%)	2.32	0.74	4.80	0.74	31.73	0.63	0.51
OM (%)	1.24	0.30	2.31	0.39	31.09	0.11	-0.43
pH	7.53	7.16	8.15	0.32	4.24	-4.69	56.88
EC (µS cm^{-1})	136.19	40.15	592.30	84.40	61.97	2.28	6.62
CEC (cMol kg^{-1})	19.88	9.16	37.24	4.38	22.03	1.31	2.04
*K (mg kg^{-1})	96.95	25.15	545.00	59.61	61.49	2.63	12.03
*Ca (mg kg^{-1})	277.02	134.49	468.46	50.49	18.23	0.48	0.53
*Mg (mg kg^{-1})	40.73	18.98	75.97	7.60	18.67	0.27	1.28
P_{av} (mg kg^{-1})	0.22	0.09	0.70	0.07	33.39	1.94	6.63
**Fe (mg kg^{-1})	1.72	0.02	8.09	0.99	57.69	1.61	5.87
**Cu (mg kg^{-1})	0.82	0.12	4.74	0.60	72.86	2.34	8.30
**Mn (mg kg^{-1})	9.80	0.23	37.05	8.04	82.07	0.99	0.15
**Zn (mg kg^{-1})	2.67	0.09	29.27	4.95	185.36	2.78	7.51

BD: Bulk density, PR: Penetration resistance, FC: Field capacity, PWP: Permanent wilting point, PAWC: Plant available water content, ASI: Aggregate stability index, EC: Electrical conductivity, CEC: Cation exchange capacity, SD: Standard deviation, CV: Coefficient of variation

* Exchangeable.

** DTPA-extracted.

Descriptive statistics for soil variables in 0-10 cm soil depth on the Ilgaz site

Variable	Mean	Min	Max	SD	CV	Skewness	Kurtosis
Sand (%)	53.62	34.10	80.00	6.76	12.60	0.33	0.68
Silt (%)	19.77	4.10	35.00	4.71	23.84	-0.07	0.39
Clay (%)	26.64	10.90	50.90	4.95	18.59	0.43	2.02
BD (Mg m^{-3})	1.19	1.00	1.30	0.10	8.51	-0.70	-1.03
PR (MPa)	2.59	1.55	3.21	0.52	20.21	-0.67	-1.05
FC (%)	32.83	11.27	48.70	4.89	14.88	-0.42	0.67
PWP (%)	15.51	3.16	28.26	4.56	29.43	-0.08	0.17
PAWC (%)	17.32	1.49	39.14	6.51	37.61	0.18	-0.27
ASI (%)	48.69	36.29	59.43	4.16	8.53	-0.57	0.75
$CaCO_3$ (%)	1.38	0.15	8.86	1.11	80.49	2.71	9.94
OM (%)	4.35	2.17	6.23	1.02	23.38	0.01	-1.10
pH	6.43	4.99	7.86	0.53	8.24	0.36	-0.33
EC (µS cm^{-1})	324.25	51.90	1036.00	164.09	50.61	1.01	1.57
CEC (cMol kg^{-1})	19.39	11.51	31.51	2.48	12.77	0.43	2.02
*K (mg kg^{-1})	85.38	2.80	232.10	52.12	61.05	0.62	-1.03
*Ca (mg kg^{-1})	193.15	0.50	666.82	134.09	69.42	-0.03	-0.93
*Mg (mg kg^{-1})	47.09	1.77	338.84	31.57	67.03	2.88	18.77
P_{av} (mg kg^{-1})	0.21	0.09	1.52	0.09	43.35	7.74	102.50
**Fe (mg kg^{-1})	25.20	0.14	91.80	19.78	78.51	1.00	-0.15
**Cu (mg kg^{-1})	1.13	0.07	4.59	0.68	60.60	1.29	2.17
**Mn (mg kg^{-1})	13.43	0.38	100.65	12.25	91.21	3.06	15.42
**Zn (mg kg^{-1})	11.67	0.02	31.83	6.51	55.80	0.39	-0.08

BD: Bulk density, PR: Penetration resistance, FC: Field capacity, PWP: Permanent wilting point, PAWC: Plant available water content, ASI: Aggregate stability index, EC: Electrical conductivity, CEC: Cation exchange capacity, SD: Standard deviation, CV: Coefficient of variation

* Exchangeable.

** DTPA-extracted.

Descriptive statistics for soil variables in 10-20 cm soil depth on the Ilgaz site

Variable	Mean	Min	Max	SD	CV	Skewness	Kurtosis
Sand (%)	53.20	31.00	83.40	7.01	13.19	0.37	1.65
Silt (%)	19.19	2.05	35.60	4.64	24.18	-0.39	1.43
Clay (%)	27.66	11.60	45.90	5.01	18.13	0.34	0.97
BD (Mg m^{-3})	1.19	0.97	1.39	0.10	8.55	-0.72	-0.95
PR (MPa)	2.60	1.45	3.65	0.53	20.56	-0.69	-0.97
FC (%)	32.88	17.68	56.30	5.05	15.36	-0.19	0.95
PWP (%)	15.46	2.95	26.66	4.39	28.43	-0.06	0.15
PAWC (%)	17.42	2.67	35.47	6.21	35.66	-0.04	-0.40
ASI (%)	48.46	32.25	59.97	4.60	9.50	-0.96	1.92
$CaCO_3$ (%)	1.25	0.15	8.42	0.94	75.20	3.23	15.99
OM (%)	4.08	2.00	6.35	1.23	30.19	-0.04	-1.28
pH	6.46	5.32	8.22	0.49	7.54	0.45	-0.16
EC (µS cm^{-1})	268.63	21.20	2654.00	170.82	63.59	7.16	94.64
CEC (cMol kg^{-1})	19.89	11.86	29.01	2.51	12.60	0.34	0.97
*K (mg kg^{-1})	76.56	2.80	219.70	47.78	62.41	0.91	-0.50
*Ca (mg kg^{-1})	185.24	0.22	554.70	133.42	72.03	-0.05	-1.29
*Mg (mg kg^{-1})	48.81	6.01	413.07	35.34	72.41	4.39	36.58
P_{av} (mg kg^{-1})	0.20	0.08	1.02	0.07	37.09	4.43	42.17
**Fe (mg kg^{-1})	27.02	0.11	89.02	19.64	72.72	0.80	-0.42
**Cu (mg kg^{-1})	1.15	0.01	3.44	0.65	56.64	1.03	1.03
**Mn (mg kg^{-1})	13.92	0.80	202.21	20.99	150.71	6.26	46.92
**Zn (mg kg^{-1})	10.50	0.12	33.67	6.18	58.83	0.63	0.43

BD: Bulk density, PR: Penetration resistance, FC: Field capacity, PWP: Permanent wilting point, PAWC: Plant available water content, ASI: Aggregate stability index, EC: Electrical conductivity, CEC: Cation exchange capacity, SD: Standard deviation, CV: Coefficient of variation

* Exchangeable.

** DTPA-extracted.

Descriptive statistics for soil variables in 0-20 cm soil depth on the Ilgaz site

Variable	Mean	Min	Max	SD	CV	Skewness	Kurtosis
Sand (%)	53.41	40.50	67.85	4.62	8.66	0.26	0.51
Silt (%)	19.48	7.85	27.80	3.23	16.56	-0.26	0.24
Clay (%)	27.15	16.70	38.40	3.38	12.45	0.26	0.30
BD (Mg m^{-3})	1.19	1.01	1.31	0.07	6.08	-0.45	-0.65
PR (MPa)	2.60	1.61	3.23	0.37	14.36	-0.51	-0.46
FC (%)	32.86	21.10	44.53	3.60	10.96	-0.14	0.35
PWP (%)	15.48	6.95	23.92	3.22	20.81	0.09	-0.25
PAWC (%)	17.37	5.09	28.44	4.57	26.34	0.00	-0.38
ASI (%)	48.58	39.45	57.06	3.20	6.60	-0.42	0.00
$CaCO_3$ (%)	1.32	0.22	4.87	0.71	53.69	1.98	5.38
OM (%)	4.21	2.48	6.23	0.80	19.04	0.11	-0.57
pH	6.45	3.59	8.04	0.51	7.88	0.40	-0.29
EC (µS cm^{-1})	296.44	102.70	1352.95	113.56	38.31	2.43	18.36
CEC (cMol kg^{-1})	19.64	14.24	25.89	1.82	9.26	0.36	0.37
*K (mg kg^{-1})	80.97	16.35	187.00	36.38	44.93	0.51	-0.39
*Ca (mg kg^{-1})	189.19	6.63	533.09	94.02	49.69	0.07	-0.18
*Mg (mg kg^{-1})	47.95	9.04	222.89	23.88	49.81	2.55	13.15
P_{av} (mg kg^{-1})	0.20	0.12	0.84	0.06	29.74	4.19	34.99
**Fe (mg kg^{-1})	26.11	2.80	74.22	15.19	58.19	0.72	-0.18
**Cu (mg kg^{-1})	1.14	0.27	3.10	0.49	42.80	0.73	0.60
**Mn (mg kg^{-1})	13.68	1.88	117.22	12.24	89.47	4.43	28.34
**Zn (mg kg^{-1})	11.09	0.82	25.93	4.72	42.55	0.54	0.38

BD: Bulk density, PR: Penetration resistance, FC: Field capacity, PWP: Permanent wilting point, PAWC: Plant available water content, ASI: Aggregate stability index, EC: Electrical conductivity, CEC: Cation exchange capacity, SD: Standard deviation, CV: Coefficient of variation

* Exchangeable.

** DTPA-extracted.

Appendix C

Results of factor analysis for 0-10, 10-20 and 0-20 cm soil depth on Kurşunlu and Ilgaz site

Factor analysis of soil properties at 10-20 cm depth on the Kurşunlu site

	Components									
Variables	1	2	3	4	5	6	7	8	9	10
BD										0.88
PR	**0.82**									
PAWC					0.59					
ASI				0.78						
$CaCO_3$			-0.68							
OM			0.750							
pH									0.91	
EC										
CEC				0.49						
*K	-0.66									
*Ca							-0.41			
*Mg					0.83					
P_{av}							0.89			
**Fe		0.73								
**Cu		**0.82**								
**Mn						0.89				
**Zn								0.91		
Variance%	9.49	8.15	8.08	7.39	6.83	6.70	6.55	6.35	6.30	6.17
VC%	9.49	17.64	25.72	25.72	39.94	46.64	53.19	59.53	65.83	72.00

BD: Bulk density, PR: Penetration resistance, FC: Field capacity, PWP: Permanent wilting point, PAWC: Plant available water content, ASI: Aggregate stability index, EC: Electrical conductivity, CEC: Cation exchange capacity.
* Exchangeable.
** DTPA-extracted.

Factor analysis of soil properties at 10-20 cm depth on the Kurşunlu site

Variables	Components							
	1	2	3	4	5	6	7	8
BD	0.968							
PR	0.959							
PAWC						0.780		
ASI								0.906
$CaCO_3$						-0.661		
OM		-0.509						
pH							0.789	
EC				0.664				
CEC		0.502						
*K				0.756				
*Ca								
*Mg		0.737						
P_{av}				0.600				
**Fe			0.796					
**Cu			0.750					
**Mn			-0.473					
**Zn		0.793						
Variance%	12.887	10.519	9.803	9.235	8.558	7.498	6.889	6.474
VC%	12.887	23.406	33.209	42.444	51.003	58.500	65.389	71.863

BD: Bulk density, PR: Penetration resistance, FC: Field capacity, PWP: Permanent wilting point, PAWC: Plant available water content, ASI: Aggregate stability index, EC: Electrical conductivity, CEC: Cation exchange capacity.
* Exchangeable.
** DTPA-extracted.

Factor analysis of soil properties at 0-20 cm depth on the Kurşunlu site

Variables	Components								
	1	2	3	4	5	6	7	8	9
BD	0.849								
PR	0.801								
PAWC							0.490	-0.405	
ASI					0.804				
$CaCO_3$				-0.768					
OM				0.666					
pH	0.425				0.609				
EC						0.511			
CEC		0.612							
*K		0.812							
*Ca		0.646							
*Mg							0.849		
P_{av}									0.890
**Fe			0.749						
**Cu			0.830						
**Mn						-0.850			
**Zn								0.886	
Variance%	10.408	10.121	8.300	8.200	7.841	7.272	6.989	6.836	6.519
VC%	10.408	20.528	28.828	37.028	44.869	52.141	59.130	65.966	72.485

BD: Bulk density, PR: Penetration resistance, FC: Field capacity, PWP: Permanent wilting point, PAWC: Plant available water content, ASI: Aggregate stability index, EC: Electrical conductivity, CEC: Cation exchange capacity.
* Exchangeable.
** DTPA-extracted.

Factor analysis of soil properties at 0-10 cm depth on the Ilgaz site

Variables	Components								
	1	2	3	4	5	6	7	8	9
BD				0.826					
PR	-0.723								
PAWC								0.886	
ASI						0.923			
$CaCO_3$				-0.594					
OM						0.443			
pH	0.785								
EC	0.698								
CEC									0.990
*K	-0.435	-0.424						0.416	
*Ca			-0.794						
*Mg			0.820						
P_{av}					0.810				
**Fe		0.556							
**Cu		0.855							
**Mn							0.900		
**Zn					0.479				
Variance%	13.09	9.14	7.98	7.55	7.23	6.82	6.59	6.33	5.98
VC%	13.09	12.24	30.22	37.77	45.00	55.83	58.42	64.76	70.74

BD: Bulk density, PR: Penetration resistance, FC: Field capacity, PWP: Permanent wilting point, PAWC: Plant available water content, ASI: Aggregate stability index, EC: Electrical conductivity, CEC: Cation exchange capacity.
* Exchangeable.
** DTPA-extracted.

Factor analysis of soil properties at 10-20 cm depth on the Ilgaz site

Variables	Components								
	1	2	3	4	5	6	7	8	9
BD							**0.939**		
PR		-0.656							
PAWC									**0.975**
ASI								**0.910**	
$CaCO_3$					**-0.782**				
OM				0.617					
pH	**-0.759**								
EC		**0.781**							
CEC	-0.618								
*K					0.651				
*Ca			**-0.822**						
*Mg			**0.810**						
P_{av}						**0.820**			
**Fe	**0.736**								
**Cu	**0.733**								
**Mn				**-0.791**					
**Zn	0.528					0.494			
Variance%	15.130	8.396	8.210	7.347	7.212	6.997	6.352	6.236	6.054
VC%	15.130	23.526	31.735	39.082	46.295	53.297	59.644	65.880	71.934

BD: Bulk density, PR: Penetration resistance, FC: Field capacity, PWP: Permanent wilting point, PAWC: Plant available water content, ASI: Aggregate stability index, EC: Electrical conductivity, CEC: Cation exchange capacity.
* Exchangeable.
** DTPA-extracted.

Factor analysis of soil properties at 0-20 cm depth on the Ilgaz site

Variables	Components								
	1	2	3	4	5	6	7	8	9
BD								**0.956**	
PR					**-0.781**				
PAWC							**0.937**		
ASI									**0.977**
$CaCO_3$		**0.645**							
OM				0.528					
pH	**-0.926**								
EC					0.701				
CEC	**-0.900**								
*K		**-0.690**							
*Ca			**0.829**						
*Mg			**-0.807**						
P_{av}				**0.715**					
**Fe	0.607								
**Cu		0.623							
**Mn						**0.892**			
**Zn				0.634					
Variance%	14.755	8.438	8.288	7.958	7.534	6.524	6.150	6.118	5.958
VC%	14.755	23.193	31.480	39.438	46.961	53.485	59.636	65.553	71.712

BD: Bulk density, PR: Penetration resistance, FC: Field capacity, PWP: Permanent wilting point, PAWC: Plant available water content, ASI: Aggregate stability index, EC: Electrical conductivity, CEC: Cation exchange capacity.
* Exchangeable.
** DTPA-extracted.