Assessment of Soil Quality Index for Onion Cultivated Soils in a Semiarid Agricultural Ecosystem

Z. Demir*

Soil, Fertilizer and Water Resources Central Research Institute, Ankara, 06172 Turkey
*e-mail: zdemir06@yahoo.com
Received October 21, 2023; revised January 16, 2024; accepted February 12, 2024

Abstract—Soil quality (SQ) has been described as the ability of a particular type of soil to function, based on natural or managed ecosystem boundaries, to ensure animal and plant productivity, promote air and water quality, and contribute to the habitation and human's health. Aim of this study was to assessment SQ by using the integrated Soil Quality Index (SQI) model on onion cultivated soils in Polatlı district of Ankara province of the Continental Region of Turkey. The SQI was determined by giving weight with Analytic Hierarchy Process to scoring indicators with standard scoring functions. The soil samples were taken from 30 different onion cultivation areas. A total of 22 SQ parameters were included in the Soil Quality Index modeling, grouped into four classes. The parameters defined in the minimum data set are soil physical, chemical indicators, macro and micronutrient elements. 83% of the total samples in the study area were mostly medium quality soils, and 17% of the soil samples for onion cultivation were weak in terms of SQ. The soil organic matter (SOM) index had the highest weight (0.431), suggesting that SOM could be considered as the first restriction limiting the working potential of soils. It can be concluded that soil quality of the onion cultivation areas plays an important role for high onion production. It can be, therefore, suggested that the assessment of the soil quality of the onion cultivation field could play an important role in determining the high onion productivity in agricultural practices and sustainable soil management systems in arid as well as semi-arid regions.

Keywords: standard scoring functions, analytical hierarchy process, semi-arid region, *Allium cepa* L.

DOI: 10.1134/S1064229323603074

INTRODUCTION

Onion (*Allium cepa* L.) is of great economic importance; it belongs to the genus *Allium*, the only significant genus in the Alliaceae family [16]. Onion can be regarded as an important vegetable grown in the world, with the production of over 99.97 million tons in 5192651 ha area. China and India are known as the main producers of onion all over the world. Turkey also has the annual production of 2.2 million tons in 687130 da area of onions; this accounts for 2.2% of the world onion production [28]. During 2019, 669134 tons of onions in 138493 da area was produced in Ankara province, accounting for about 30% of the total onion produced in Turkey. Most bulb onion production in Ankara is in the Polatlı district. According to the 2019 data, Polatlı has approximately 402677 tons production of onions in 85000 da area [74]. The annual rainfall is 344 mm and the mean annual temperature in this area is 11.6°C in the Polatlı, with the dominance of a more terrestrial climate. The city has been developed on a rather rupped plateau with some kind of alluvial soil. When it comes to the most produced herbal products in Polatlı, wheat and barley for dry farming and beet and dried onion for irrigated farming come to the forefront.

Soil quality (SQ) has been described as the ability of a particular type of soil to function, based on natural, to ensure animal and plant productivity, promote air and water quality, and contribute to the habitation and human's health. Soil quality index (SQI) is applied in order to evaluate the possible effects of production of crops [3], different agricultural practices [83] and those practices related to litter management on soil [2], in addition to the possible effect of different soil management practices at the regional scale. It has been proposed that SQ assessment can serve as a tool to evaluate the soil sustainability and different practices related to crop management. A wide range of methods related to the assessment of SQ have been accordingly developed; these are such as soil test kits and health card, SQI methods and visual soil assessment. Nevertheless, the most widely-used method for evaluating the SQ is the calculation of the SQI; this is known as a quantitative method requiring the identification of the minimum soil attributes as SQ parameters, scoring and integration of all these parameters in order to obtain SQI [37]. The methods which have been used to identify a set of SQ parameters from a large number of soils attributes, called the minimum dataset (MDS), include experts' opinion (EO) and

Principal component analysis (PCA). PCA is known as the most common method applied for the identification of MDS, serving as a kind of quantitative and objective method [77]. Experts' opinion is equally suitable and effective; however, it sometimes overweighs the results which are determined by applying the principal component analysis approach. The EO method is also preferred for selecting MDS, as the effects of some factors are not easily demonstrated according to the numeric equations. Furthermore, the Principal component analysis method can easily lead to errors of inference in the case of samples with a small size. The EO method also makes it possible to work with samples that have a small size. Following the identification of MDS, the normalization of these indicators is done; then they are integrated by preferably applying a weighted additive method. The variance which is explained by each parameter during Principal component analysis is considered as the weight of that parameter. In regard to EO based on the minimum dataset selection, the weighing scheme which is based on experts' opinion could be more pragmatic in practice. Despite this, the experts' opinion method requires the system's expert knowledge; further directly assigning weights may involve disciplinary biases. Analytical Hierarchical Process (AHP) to check these biasness has been suggested to generate weight for each parameter in the minimum dataset. Analytical Hierarchical Process constitutes each indicator's weights in the minimum dataset based on the experts' pair-wise comparisons of the parameters [30, 40]. As well, AHP can control the consistency in the evaluations made by the decision maker, thereby lowering the bias that may be involved in the decision-making process. AHP can be suitable for both small and large samples, with parameters representing both a qualitative and quantitative nature. The development of a SQI should be according to three steps: [1] parameters selection, [2] assignment of score to the selected parameters and (3) the parameters integration in an index. The soil quality index calculation begins with the SQ indicators definitions; these are those processes and attributes of the soil which have sensitivity to the varies that are caused by both anthropogenic and natural factors. More specifically, SQ parameters are those soil attributes which can vary due to the changes occurring in the soil conditions [51]. Such soil attributes are the SOM content, BD, soil depth, respiration rate, EC, soil pH, and so on. The SQ evaluation was carried out by making use of the SQ indices in the general approach; this includes scoring functions for each of the above-mentioned soil attributes [4]. The concept of "scoring function" has been applied in soil quality indexes in order to explore the interconnection existing between soil processes, soil attributes, social perspectives and systems of management [85]. A soil quality index can vary 0 to 1 according to the scoring function analysis; such values can be subject to easy interpretation to reveal soil attributes under some spe-cific situations. The processes involve determination of some criteria and conditions a helpful for the evaluation; these are like establishing ranges for parameter values appropriate for some specific soils and identifying the relative weight that should be given to each parameter (43). A large number of the previous SQ evaluations have been done using the surface soil attributes [6, 16, 20, 21, 23, 24, 31, 32]. Aim of this study was to assessment SQ by using the integrated SQI model on onion cultivated soils in Polatlı district of Ankara province of the Continental Region of Turkey. Assessment of soil quality is essential for quantifying sustainability of onion production in this area.

MATERIALS AND METHODS

Study area. Polatlı is a district located in the Province of Ankara, the Central Anatolia region of Turkey. The district has been developed on a slightly rupped plateau with some alluvial soil. According to FAO/WRB classification system, the reference soil group here is Calcisol [82].

The district covers an area of 3789 km², with the mean elevation being 850 m. Polatlı is located at the high Anatolian plateau heart, which is known as a large steppe with grass cover. It is far from the coast, with a steppes-like climate. It is generally cold in this area during winter, while the summers are usually dusty and dry. On the other hand, the most humid times are in spring. Polatlı is also known as a productive agricultural district in Turkey; it is famous for its cereal production, particularly wheat and barley. Many agricultural activities are pursued in the present research area, Polatlı can also be regarded as one the largest grain stores in Turkey. Onion, melon and sugar beet are grown there as well. The average annual temperature and precipitation are, respectively, 12.1°C and 380 mm [22]. According to the Newhall simulation model which has been developed for the soil climate regime, moisture regimes and soil temperature in this area are mesic and weak aridic, respectively [76]. The study area is coordinated at 31.93958–32.52978 East and 39.03760–39.83512 North. In addition, the elevation in the research area is between 670 m and 1070 m from the sea level. Locations of the samples taken from 30 onion fields are given in Fig. 1. Onion planting was carried out on 2 March 2022. Mean evapotranspiration (ETc) of onion was 55 mm in April, 125 mm in May, 162 mm in June, 193 mm in June and 151 mm in August. Total seasonal mean ETc is 693 mm. Onion cultivation in Polatlı district of Ankara province is the region with the highest production in our country. Polatlı district, where soil sampling was carried out, has a slope between 2 and 5%, where slope values are accepted as ideal for agricultural lands. Therefore, it can be considered that these areas where soil quality indicators were studied reflect the real fertile soils. Alluvial soils rich in minerals and nutrients are very favourable for agriculture. There was
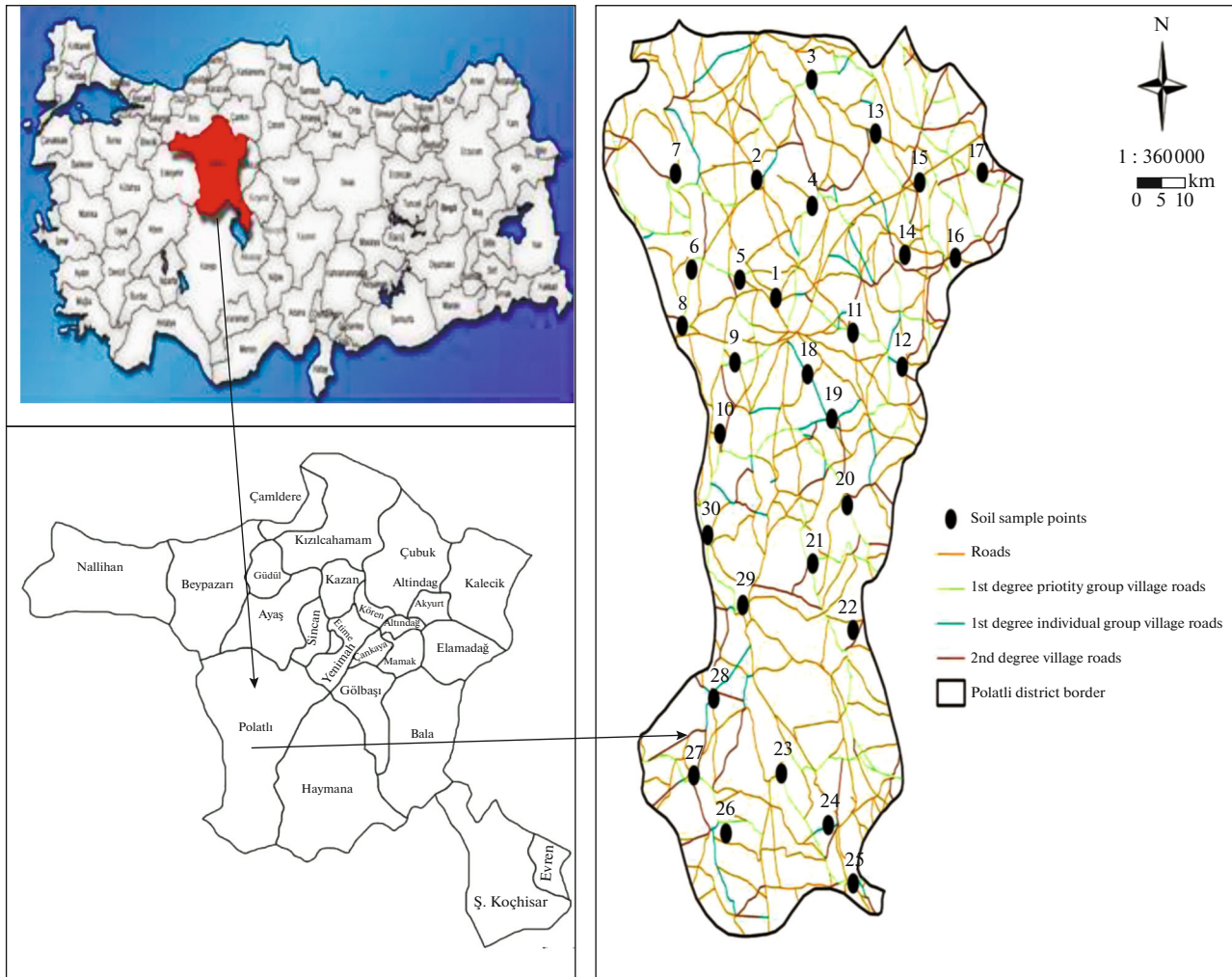
Fig. 1. Location of the study area.

no significant relationship between soil quality index and slope (−0.210). In this study, the soil quality of the samples taken from 670 and 1070 m above sea level were evaluated as class III and IV land. In these conditions, the soil quality indicator reflects the actual fertile soil and current situation of the studied areas together with the given climate data.

Sampling and soil analysis. In the present study, surface soil samples (0−20 cm depth) of 30 different onion fields were taken from onion-cultivaed soils in Ankara province, in the Continental Region of Turkey. A total of 90 soil samples were taken from three different points, representing each field where onion is grown intensively in Polatlı district of Ankara province, and analyzed separately. Mineral fertilization was applied along with planting on 2 March 2022. In Ankara province of the continental region of Turkey, 12 kg/da nitrogen fertilization and 6 kg/da phosphorus fertilization were applied in onion fields. Potassium fertilization was not applied because potassium con-

tent (100−150 kg/da) was sufficient in all onion fields. The soil samples were obtained in the fall following harvest (14 October 2022) and prior to the next cropping season to guard against the effect of recent fertilization during the crop growing season. Organic fertilization was not applied in these onion cultivation areas. The recording of the location of each sampling point was done by applying a handheld GPS tool. Field data were obtained in 2022 for agricultural fields under onion cultivation. The samples sieving was done using a 2 mm sieve; they were prepared for structural stability by passing through the use of some 4 mm sieve, as well as for analyses of the soil properties. Hydrometer method was then used to get particle size distribution [10]. Specifications related to the field capacity (FC), permanent wilting point (PWP) and available water content (AWC) were considered by applying the disturbed samples. After the saturation of the samples by applying tap water for a period of 24 h, the FC soil moisture content was identified by equilibrating the soil water for a period of 24 h at 33 kPa on

some kind of ceramic plate; PWP was measured through the equilibration of the moisture for a period of 96 h at 1500 kPa [35]. Calculation of AWC was then done as the difference between FC and PWP. Determination of the bulk density (BD) was done according to those undisturbed samples taken by applying a 100 cm^3 volume steel cylinder [9]. Aggregate stability (AS) was identified with the aid of a wet sieving apparatus, which had already been characterized [39]. Saturated hydraulic conductivity (K_{sat}) [75] was determined by applying a constant head permeameter and using:

$$K_{sat} = \frac{Q}{At}\left(\frac{S}{S+H}\right), \qquad (1)$$

where K_{sat}—saturated hydraulic conductivity (cm h^{-1}), Q—outflow from the soil column (cm^3), A—cross-sectional area of the soil column (cm^2), t—time (h), S—length of the soil column (cm), H—water head over the soil column (cm).

Structural stability index (SSI) (44) was calculated by using:

$$SSI = \sum b - \sum a, \qquad (2)$$

where SSI—Soil Stability Index, b—clay fraction (%), a—silt + clay fraction (%).

Electrical conductivity (EC) and soil reaction (pH) of the soil saturation paste extract were determined. Scheibler calcimeter was then used to determine the $CaCO_3$; also, the ammonia acetate extraction method was used to identify the exchangeable cations (Mg, Ca, K, Na). DTPA—extraction method was then used to determine the soil micro nutrients with the aid of a spectrophotomer (36). Extraction of the samples was done with 0.5 M $NaHCO_3$ to identify the available phosphorus (P) [56]. Soil organic matter (SOM) was identified using the Modified Walkley-Black method [8]. Measurment of the total N was done by applying the Kjeldahl method [13].

Soil quality indexes and scoring. Soil quality was assessed by choosing a set of soil attributes which could be regarded as the soil quality parameters. Soil functions have sensitivity to soil quality parameters [5]; therefore, measurement of the parameters should be easy [26]. In this study, land utilization type is onion production. Regarding the assessment of the SQ, the selection of the parameters was done according to the management aims, associated soil processes and other site-specific factors. Further, each parameter and process relative weights in crop productivity were considered in the SQ assessment. Totally, twenty-two SQ indicators were considered in the soil quality index (SQI) modeling by classifying them in four classes; these included physical parameters (BD, Ksat, AWC, SSI, AS, sand, silt and clay contents), chemical parameters (pH, EC, SOM and lime content), macronutrient contents (available P, total N, exchangeable Ca, K and Mg), and micronutrient contents. SQI was classified (20) in the range 0.00−1.00, according to the

soil requirements of onion. Soil quality index (SQI) classes are defined according to index values as follows. Class-I: Index value <0.00, Description: none; Class-II: Index value 0.00−0.19, Description: poor; Class-III: Index value 0.20−0.39, Description: weak; Class-IV: Index value 0.40−0.59, Description: Moderate; Class-V: Index value 0.60−0.79, Description: Strong/ Suitable; Class-VI: Index value 0.80−1.00, Description: Excellent/ The most suitable. As shown, classification was based on a scale of 1 to 6, with the values I, II, III, IV, V and VI presenting very poor quality, poor quality, weak quality, moderate quality, strong/suitable quality and excellent/ the most suitable quality, respectively [54]. Then the scoring and weighting of all parameters were done; after that, estimation of soil quality indices for each soil sample was done by applying the following equation [25]:

$$SQI_O = \sum_{i=1}^{n}(W_i X_i), \qquad (3)$$

where SQI_O—soil quality index of onion, W_i—weighting of indicator i, X_i—score of indicator i as obtained by standard scoring function (SSF), n— number of parameters.

In this study, a standard scoring function (SSF) owing to the variation occurring in the parameter units was applied for the normalization of the soil quality indicators by assigning scores which ranged from 0 to 1 [45]. Two types of parameters were separated based on their functional impact on the SQ; accordingly, the best soil functionality was accompanied by low, high or intermediate values.

The parameters were then rated; a "Less is better" function was assigned to EC, $CaCO_3$, pH, exchangeable Na, BD, Ksat, silt and sand contents for water holding capacity, low quality and degradation of soils; second, a "More is better" function was applied to the AWC, AS, SSI, clay content, SOM, total N and macro-and micronutrient contents for the roles they played in soil fertility as high concentrations could contribute to good soil functionality for onion production. In the literature, the use of the "midpoint is optimum" curve is preferred when scoring pH [4]. The most desirable pH limits for plant growth in determining the SQ in terms of productivity are between 6.0 and 7.0 [50]. The fact that the pH values obtained in the study were greater than 7 caused this indicator to be scored with "less is better". Standard scoring function equations developed for the indicators can be seen in Table 1.

Analytic hierarchy process (AHP) can help decision makers to develop a model of a complex problem with the aim at the top level, while criteria, sub-criteria and alternatives are located at other levels in the drop-down manner. The AHP general framework used in the present research can be seen in Fig. 2. Totally, 22 SQ indicators were grouped in four sub-criteria; these included physical and chemical properties and,

Table 1. SSF and indicators for quantitative soil attributes

Indicators	FT	L	U	Standard Scoring Function Equation
Sand, %	LB	6.14	61.55	
Silt, %	LB	21.09	46.27	
EC, dS m^{-1}	LB	0.35	1.98	
BD, g cm^{-3}	LB	0.91	1.38	$f(x) = \begin{cases} 0.1 & x \leq L \\ 1 - 0.9\dfrac{x-L}{U-L} + 0.1 & L \leq x \leq U \\ 1 & x \geq U \end{cases}$
Ksat, cm h^{-1}	LB	0.37	8.16	
Exc.Na, cmol$_c$ kg^{-1}	LB	0.26	2.61	
pH (sat. ext.)	LB	7.58	8.18	
CaCO$_3$, %	LB	5.00	38.46	
Clay, %	MB	15.71	61.27	
AWC, %	MB	7.15	18.62	
AS, %	MB	10.24	80.82	
SSI, %	MB	14.94	77.16	
SOM, %	MB	0.73	2.39	
Total N, %	MB	0.01	0.14	$f(x) = \begin{cases} 0.1 & x \leq L \\ 0.9\dfrac{x-L}{U-L} + 0.1 & L \leq x \leq U \\ 1 & x \geq U \end{cases}$
Exc.Ca, cmol$_c$ kg^{-1}	MB	17.98	37.78	
Exc.Mg, cmol$_c$ kg^{-1}	MB	0.09	13.01	
Exc. K, cmol$_c$ kg^{-1}	MB	0.25	1.66	
Av.P, mg kg^{-1}	MB	1.25	64.46	
Av.Fe mg kg^{-1}	MB	0.61	5.48	
Av.Mn mg kg^{-1}	MB	0.57	16.98	
Av.Zn mg kg^{-1}	MB	0.04	2.05	
Av.Cu mg kg^{-1}	MB	0.29	1.75	

Function type = FT, more is better = MB, low is better = LB, standard scoring function in two equations = SSF, indicators monitoring value = x, score of indicators ranging from 0.1 to 1 = $f(x)$, upper and lower threshold values = U and L, respectively

macro- and micronutrients; so, all matrices in the hierarchies A, B and C were logically constructed [63].

Analytic hierarchy process (AHP) and matrix construction. AHP which is known as a flexible method assigning weight to various factors in a hierarchical structure is basically a method for the identification of the factors significance by employing pair-wise comparisons. Analytic hierarchy process has useful applications in decision making in a wide range of areas according to several factor comparisons [58, 84]. The majority of classical multi-attribute modeling techniques are on the basis of the assumption of utility functions [38]. Despite this, analytic hierarchy process is founded on the assumption that a factor quantification without comparison of it in a pair can not lead to a better picture. So, the measurement of the relevant dominance of one property in comparison to another can be done based on a pair-wise comparison of preferences, in a systematic manner, on each level of a number of factors hierarchically organized [41]. The predominance of a particular farming or modeling the factors shapping up the land use change is a difficult

issue since diverse factors play different roles at different scales in a specific location. A large number of such factors are intertwined; thus, there may be a high degree of relation between them [29, 73]. Therefore, AHP can be applied for comparison purposes, thus exploring diverse farming practices as the important influential factors. The present study, thus, employed AHP to assess soil quality by applying the integrated SQI model on onion-cultivated soils in Polatlı district of Ankara province of the Continental Region of Turkey.

Three steps were identified in the AHP [60, 62]. First, preparation of a comparison matrix was done using a set of pair-wise comparisons, on the basis of the AHP preference scale (Table 2). Significance of one criterion, relative to another one, in the pair was determined qualitatively by considering a range between 1 and 9, based on the preference scale of AHP. According to this scale, 1 represents the equal significance, while 9 reflects that one factor is absolutely more significant than other. Further, the reciprocals of 1 to 9 show that one has less significance than the other. The degree of of significance between the two criteria in the matrix
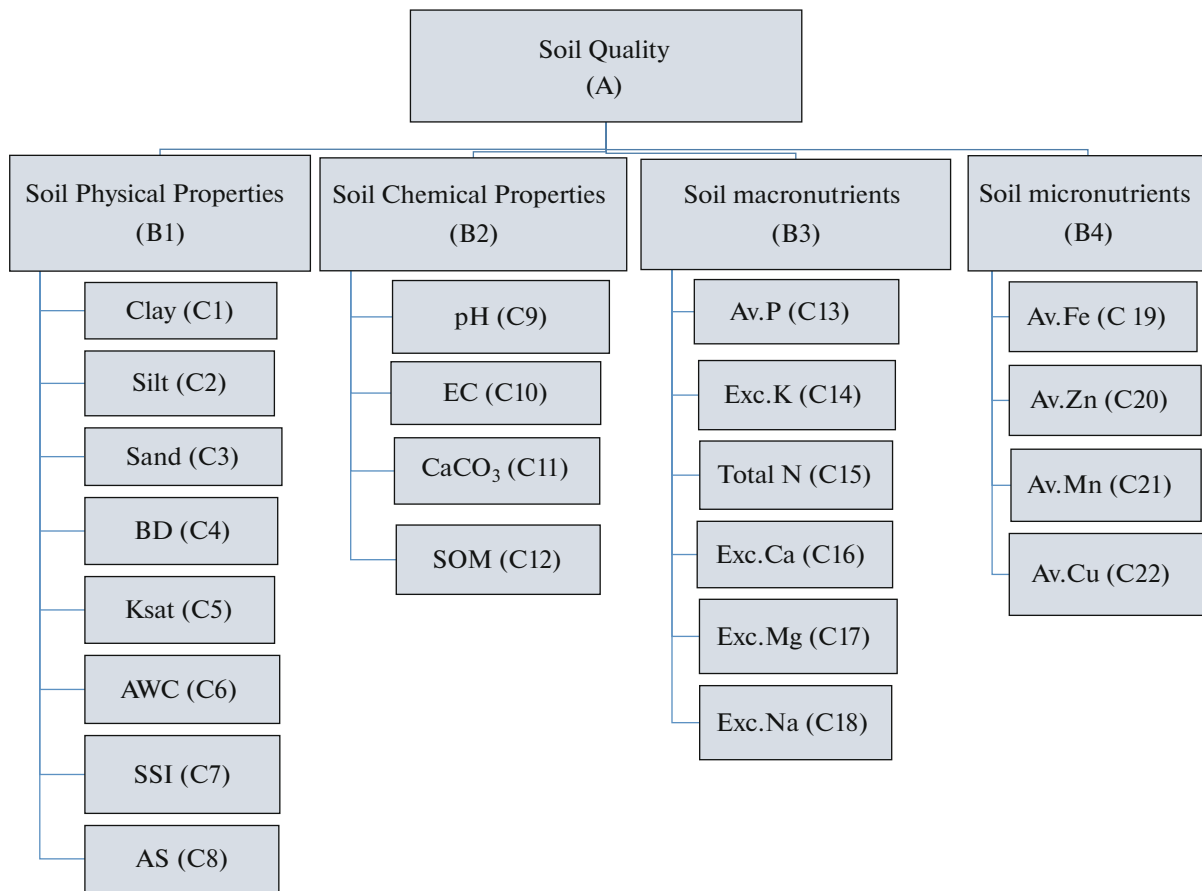
Fig. 2. Hierarchy for the parameters' weight assignments. Available water content—AWC, Structural stability index—SSI, Bulk density—BD, Saturated hydraulic conductivity—Ksat, Aggregate stability—AS, Soil reaction—pH, Electrical conductivity—EC, Lime content—CaCO₃, Available phosphorus—Av.P, Soil organic matter—SOM, Exchangeable calcium—Exc.Ca, Exchangeable potassium—Exc.K, Exchangeable magnesium—Exc.Mg, Available zinc—Av.Zn, Available iron—Av.Fe, Available manganese—Av.Mn, Available copper—Av.Cu.

was filled based on the EO. Second, the calculation of the weights was done based on the pair-wise comparison matrix by applying an eigenvalue and eigenvector calculation. The eigenvector which corresponds to the largest principal eigenvector leads to providing the relative priorities of each of the indicators. The sum of the components of the eigenvector leads to unity. Therefore, a vector of weights was determined, representing the relative significance of diverse indicators obtained from the paired comparisons matrix. In the analytic hierarchy process matrix, the cells along the diagonal were given the value of 1; the row factor, incomparison to the same column factor, received a unit value. The cell which represented two different factors in the row and column with an equal contribution or influence gets a unit value as well. Despite this, the user should be aware that this choice itself is a statement of the relative value. Third, to keep the judgment matrix consistency, it was tested. The AHP approach is based on the assumption that each of the factors assessed is independent. It, therefore, allows some small inconsistency in the judgment as human responses are not always necessarily consistent. Practically, 100% consistency can not be achieved; however, the method can be applied when some degree of interdependence is considered. An consistency index (CI) [61], which is known as the consistency ratio (CR) in AHP is used in order to show the probability that the matrix judgment could be generated in a random manner.

$$CR = CI/RI, \qquad (4)$$

where RI (Random Index)—mean of the resulting consistency index which depends on the order of the matrix, CI—consistency index,

$$CI = (\lambda_{max} - n)/(n - 1), \qquad (5)$$

where λ_{max}—principal eigenvalue of the matrix; it can be easily estimated from the matrix; n—the matrix order (size of matrix).

RI used in measured consistency ratio and which varies functionally with size of matrix in the AHP [57]: (n: 1, RI: 0.00); (n: 2, RI: 0.00); (n: 3, RI: 0.58); (n: 4, RI: 0.90); (n: 5, RI: 1.12); (n: 6, RI: 1.24); (n: 7, RI: 1.32); (n: 8, RI: 1.41); (n: 9, RI: 1.45); (n: 10, RI: 1.49);

Table 2. The Pairwise comparisons scales used for the preferences in the AHP (57)

Intensity of importance	Explanation	Definition
1	Two factors contribute equally	Equal importance
3	Experience and judgment slightly favor	Weak importance of one over another
5	Experience and judgment strongly favor	Essential or strong importance
7	A factor is strongly favored and its	Demonstrated importance
9	The evidence favoring one factor over	Absolute importance
2, 4, 6, 8	When compromise is needed	
Reciprocals of above nonzero	If factor i has one of the above nonzero numbers assigned to it when compared with factor j, then j has the reciprocal value when compared with i	

(n: 11, RI: 1.51); (n: 12, RI: 1.48); (n: 13, RI: 1.56); (n: 14, RI: 1.57); (n: 15, RI: 1.59).

When the matrix has full coherence, consistency index = 0. The larger the consistency index, the worse coherence the matrix may have. When the consistency ratio is less than 0.10, the matrix can have reasonable consistency. However, the matrix should be modified. When the consistency ratio is satisfactory, the calculated weight results can be accepted. In this study, the findings obtained for all RIs for single and overall hierarchies were less than 0.1. The homogeneity of the parameters within each group, a smaller number of factors in the group and a better understanding of the decision problem may improve the CI [79].

RESULTS

Descriptive statistics related to the soil properties of the onion-cultivated soils in Ankara province of the Continental Region of Turkey can be seen in Table 3. Descriptive statistics of the soil parameters and onion soil quality index (SQIo) values were computed using SPSS 19.0, SPSS Inc., 2011. The CV was ranked to determine the nutrient variability according to the procedure developed, where CV ≤ 25% is the low variation, CV >25 ≤ 50% is the moderate variation and CV >50% represents the high variation (8). The sand content of the samples varied from 6.14 to 61.55%, with the mean being 31.54%; that of silt content was from 21.09 to 46.27%, with the mean being 30.94%, while the clay content ranged from 15.71 to 61.27%, with the mean being 37.52%.

In this study, BD values of the areas varied from 0.91 to 1.38 g cm^{-3}, with the mean being 1.20 g cm^{-3}. An ideal BD to root growth based on the loams and sandy loams soils should be lower than 1.40 g cm^{-3}. The mean values of the available water content and saturated hydraulic conductivity value were 11.66% and 3.90 cm h^{-1}, respectively. The soil pH of the areas varied from 7.58 to 8.18. The mean pH value was 7.80, which was slightly alkaline based on the rating provided by (69). In this study, the EC of the soils ranged from 0.35 to 1.98 dS m^{-1} with a mean of 0.85 dS m^{-1}.

The mean values which were related to the SOM and CaCO$_3$ content (%) were recorded to be 1.70 and 17.0, respectively. On the other hand, the soils total N varied from 0.01 to 0.14%, with the mean being 0.07%. In this study, the available P ranged from 1.25 to 64.46 mg kg^{-1}, with the mean being 10.37 mg kg^{-1}. Meanwhile, the available P of 25 soil samples in this study were found to be lower than 15 mg kg^{-1}; further, the 3 samples available P ranged from 15 to 22.5 mg kg^{-1}. The variability of CaCO$_3$ is high with 59.4% of CV. The mean CaCO$_3$ is medium (17.0%). The mean of micronutrients (available Fe, Mn, and Zn) were inadequate for onion production in the soils of the experimental site.

In the present study, twenty-two soil properties were identified as the parameters for the functioning capacity of soils. The selection of these 22 main indicators for SQIo was based on a broad review of the related literature. The soil quality index values calculated for the onion cultivation areas were 0.30 and 0.58, with the mean being 0.46. In this research, the necessary weightings of the indicators given to the SQIo were estimated using the analytic hierarchy process, as can be seen in Table 4. The assessment of the obtained results showed that mostly moderate quality soils were dominant with 83% of the total soil samples in the area studied (Class IV), whereas 17% of the soil samples were found to be weak in regard to soil quality for onion cultivation (Class III) (Table 5). In other words, 25 onion cultivation areas were determined as moderate quality soils (Class IV), while 5 (soil sample Nos: 2, 5, 11, 20 and 21) were observed to be weak (Class III) for onion cultivation in regard to the soil quality.

DISCUSSION

In this study, available P showed the very high variation (more than 100%). The CV for the SQIo was low. According to [70], soil texture in the areas were classified as clay (C) in 12, clay loam (CL) in 12, loam (L) in 2, sandy loam (SL) in 1, silty clay loam (SiCL) in 1, silty clay (SiC) in 1 and sandy clay loam (SCL) in 1. Onions can be grown in diverse soil types; however,

Table 3. Descriptive statistics of soil quality variables

	Min	Max	Mean	SD	Variance	Skewness	Kurtosis	CV, %
Clay, %	15.71	61.27	37.52	10.24	104.85	0.22	−0.18	27.3
Silt, %	21.09	46.27	30.94	6.30	39.66	0.63	0.49	20.4
Sand, %	6.14	61.55	31.54	11.91	141.84	−0.10	0.78	37.8
AWC, %	7.15	18.62	11.66	3.14	9.88	0.59	−0.67	27.0
BD, g cm^{-3}	0.91	1.38	1.20	0.12	0.02	−0.52	−0.17	10.2
AS, %	10.24	80.82	41.78	19.73	389.08	0.42	−0.85	47.2
Ksat, cm h^{-1}	0.37	8.16	3.90	2.10	4.40	0.28	−0.91	53.8
SSI, %	14.94	77.16	39.04	13.92	193.72	0.77	0.51	35.7
pH (sat. ext.)	7.58	8.18	7.80	0.17	0.03	0.92	0.23	2.1
EC (sat. ext.), dS m^{-1}	0.35	1.98	0.85	0.49	0.24	1.28	0.39	57.6
CaCO$_3$, %	5.00	38.46	17.00	10.09	101.82	0.78	−0.42	59.4
SOM, %	0.73	2.39	1.70	0.42	0.18	−0.20	−0.55	24.6
Total N, %	0.01	0.14	0.07	0.04	0.02	−0.01	−0.96	51.2
Av.P, mg kg^{-1}	1.25	64.46	10.37	12.03	144.64	3.46	14.42	116.0
Exc.K, cmol$_c$ kg^{-1}	0.25	1.66	0.92	0.41	0.17	0.26	−0.89	44.8
Exc.Ca, cmol$_c$ kg^{-1}	17.98	37.78	23.99	4.60	21.18	1.32	1.81	19.2
Exc.Mg, cmol$_c$ kg^{-1}	0.09	13.01	4.96	3.25	10.57	0.86	0.38	65.6
Exc.Na, cmol$_c$ kg^{-1}	0.26	2.61	0.79	0.53	0.276	1.97	4.48	67.1
Av.Cu, mg kg^{-1}	0.29	1.75	0.69	0.31	0.09	1.54	3.68	44.2
Av.Fe, mg kg^{-1}	0.61	5.48	1.80	1.10	1.21	1.97	4.32	61.2
Av.Mn, mg kg^{-1}	0.57	16.98	6.24	5.66	32.01	0.66	−1.17	90.6
Av.Zn, mg kg^{-1}	0.04	2.05	0.59	0.53	0.28	1.52	1.51	89.8
SQIo	0.30	0.58	0.46	0.06	0.01	−0.38	0.22	13.8

Onion soil quality index—SQIo, Maximum—Max.; Minimum—Min., sample number—n, Standard deviation—SD, Coefficient of Variation—CV.

excessively dense clay soils can have interference with root growth, whereas sandy soils need very frequent irrigation. As onions are shallow rooted, they can grow well on a friable soil having good moisture retention. Seedbed condition is critical, especially if the growth of crops occurs from seed. A fine, consolidated seed zone is needed to achieve the maximum germination and good establishment [57, 78]. The BD values of the onion groves areas in the present research were lower than 1.40 g cm^{-3}. The growth of onions should ocur on friable soils containing considerable SOM, with good water-infiltration rates, as well as good water holding capacity. Meanwhile, growth may be impedded when the available soil moisture is not high enough; however, onions also have sensitivity to water logging [64].

The optimum pH for onion cultivation ranged from 6 to 8 [55]. Thus, the mean soil pH contributed to the production of onion. Soil reaction situation in Turkey can be regarded as a neutral or alkaline one which could be characterized in Central Anatolia [52]. Onions have sensitivity or moderate sensitivity to salinity, mostly at germination and emergence stages; when the establishment of plants occurs, they can tolerate salinity higher levels. Onion can be regarded as one of the crops which are highly sensitive to salinity, thus affecting plant growth and productivity, particularly when seedlings emerge; yield decrease starts over 1.4 dS m^{-1} EC, reaching 50% at 4.1 dS m^{-1}. The mean organic matters and the mean total nitrogen of the soil were low based on the rating proposed by [47]. This showed that the soil was weak in terms of supplying organic matter for the soil biota; also, it could be considered as a source of mineralized nitrogen for the mineral nitrogen uptake by crops [34]. Therefore, nitrogen should be applied for the production of onion. N is the main plant nutrient needed in remarkably large amounts. It is an significant component of proteins, vitamins and enzymes in plants [49]. Onion needs high levels of nitrogen, phosphorus and potassium to get the maximum bulbs yield, as compared to other vegetable crops, since the plants have a shallow, sparsely branched root system, leading to considerable waste nutrients in soil after

Table 4. Weights with AHP of soil quality indicators

Hierarchy A					
Hierarchy C	Hierarchy B				Combined weight $\sum B_i \times C_i$
	B1	B2	B3	B4	
	0.387	0.275	0.198	0.140	
Clay, %	0.262				0.101
Silt, %	0.042				0.016
Sand, %	0.040				0.015
BD, g cm^{-3}	0.045				0.018
Ksat, cm h^{-1}	0.148				0.057
AWC, %	0.276				0.107
SSI, %	0.076				0.030
AS, %	0.111				0.043
pH (sat. ext.)		0.178			0.049
CaCO$_3$, %		0.273			0.075
EC (sat. ext.), dS m^{-1}		0.117			0.032
SOM, %		0.431			0.119
Av.P, mg kg^{-1}			0.262		0.052
Total N, %			0.419		0.083
Exc.K, cmol$_c$ kg^{-1}			0.163		0.032
Exc.Ca, cmol$_c$ kg^{-1}			0.076		0.015
Exc.Mg, cmol$_c$ kg^{-1}			0.060		0.012
Exc.Na, cmol$_c$ kg^{-1}			0.020		0.004
Av.Fe, mg kg^{-1}				0.400	0.056
Av.Zn, mg kg^{-1}				0.361	0.050
Av.Mn, mg kg^{-1}				0.180	0.025
Av.Cu, mg kg^{-1}				0.059	0.008
Total	1	1	1	1	1

Saturated hydraulic conductivity—Ksat, Bulk density—BD, Available water content—AWC, 745 Structural stability index—SSI, Aggregate stability—AS, Soil organic matter—SOM, Soil reaction—746 pH, Electrical conductivity—EC, Available phosphorus—Av.P, Available potassium—Av.K, Exchangeable calcium—Exc.Ca, Exchangeable magnesium—Exc.Mg, Available iron— Av.Fe, Available zinc—Av.Zn, Available manganese—Av.Mn, Available copper—Av.Cu.

harvest. Despite this, the plant nutrients uptake is dependent on several factors including cultivar, soil fertility, crop environment and fertilization methods [29]. The available P contents related to 2 soil samples were only found to be suitable for onion growth. The experimental site soil was low in terms of the mean available P based on [60]. Phosphorus is regarded an important nutrient contributing to the plant nutrition. Despite this, it has a relatively low availability in soils; this could be attributed to the low solubility of the P which contained soil constituents, as well as its high retention onto soil colloids. P deficiencies in onions can decrease leaf and root growth, as well as reducing the bulb yield and size; they can also lead to delaying maturation [1, 14]. This, therefore, evidences that using an external source of phosphorus in the soil of the experimental site can be important for growing onions. In addition, the tolerance ranges related to other soil indicators are as follows: exchangeable Ca, Mg and K, 5.8–6.7 cmol$_c$ kg^{-1}, 2.1–2.7 cmol kg^{-1} and 0.39–0.50 cmol$_c$ kg^{-1}, respectively [42]. The soils of the experimental site were adequate exchangeable K, Ca and Mg contents for onion production. K is one of the three major nutrients needed by plants, with the others being N and P. Onion fertility is one of the important things influential on onion productivity all over the world. Onion has a particularly shallow branched root system; most roots are in the top 30 cm of soil [33, 72]. This root system can lead to the roots low density in

Table 5. Locations of onion cultivated areas in Ankara province of the Continental Region of Turkey, land use—onion

Sample no	Coordinates		Elevation, m	Soil quality		Onion yield, t/da	Sample no	Coordinates		Elevation, m	Soil quality		Onion yield, t/da
	North'	East		index	class			North	East		index	class	
1	39.61871	32.12378	990	0.43	IV	3.95	16	39.65833	32.45335	920	0.38	III	3.85
2	39.73591	32.08867	870	0.38	III	3.87	17	39.76005	32.52978	1010	0.49	IV	4.30
3	39.83512	32.18963	890	0.48	IV	4.22	18	39.54286	32.18178	910	0.48	IV	4.25
4	39.71001	32.19030	950	0.41	IV	3.90	19	39.49882	32.22650	860	0.49	IV	4,32
5	39.63664	32.05735	760	0.30	III	3.80	20	39.41308	32.25487	890	0.43	IV	3.90
6	39.64678	31.96916	680	0.44	IV	4.05	21	39.35522	32.19156	870	0.37	III	3.84
7	39.74215	31.93958	670	0.50	IV	4.40	22	39.28815	32.28475	910	0.43	IV	3.92
8	39.59094	31.95147	690	0.45	IV	4.15	23	39.14672	32.13402	930	0.56	IV	4.70
9	39.55475	32.04859	820	0.51	IV	4.45	24	39.09556	32.22016	940	0.43	IV	3.94
10	39.48405	32.02098	700	0.52	IV	4.52	25	39.03760	32.26583	930	0.48	IV	4.23
11	39.58400	32.26527	1020	0.37	III	3.82	26	39.08733	32.03229	840	0.57	IV	4.76
12	39.55049	32.35584	1070	0.48	IV	4.20	27	39.14475	31.97323	800	0.49	IV	4.32
13	39.78167	32.30684	790	0.44	IV	4.07	28	39.22101	32.00967	750	0.53	IV	4.55
14	39.66131	32.36066	860	0.50	IV	4.42	29	39.31407	32.06321	750	0.45	IV	4.16
15	39.73327	32.38775	750	0.58	IV	4.80	30	39.38379	31.99441	710	0.51	IV	4.47

onion. It also means onion needs more fertilizer for the production of the crop [13]. The sparse shallow rooting of onions can have noteworthy consequences for the management of nutrients which are relatively immobile. The onions unbranched root system is less effective in comparison to most crop plants in terms of the extraction of the immobile nutrients. So, onions can have more susceptibility in comparison to the vast majority of other crops to these nutrients deficiencies. Onions are heavy feeders needing more fertilizer in comparison to the majority of vegetable crops. This depends on the soil type and its productivity status. While the available Fe content of 2 soils were more than 4.5 mg kg^{-1} [46], the others were lower than this value; so, they could be classified as Fe deficient for onion growth. According to the rating of [29], the available Cu content in this study for all onion groves areas was more than 0.2 mg kg^{-1}, which was adequate for onion production. Meanwhile, the available Mn content belonging to 16 soil samples was less than 4 mg kg^{-1}; 10 of them were between 4—14 mg kg^{-1} and 4 others were higher than 14 mg kg^{-1}; meanwhile, the available Zn content related to 6 soil samples was recorded to be less than 0.2 mg kg^{-1}; 17 of these were between 0.2—0.7 mg kg^{-1} and 7 others were higher than 0.7 mg kg^{-1} [66]. Soils could be, therefore, assumed to be marginal at 0.8 to 1.0 mg kg^{-1} DTPA exc. Zn [11]. Onions have sensitivity to zinc deficiency. Zn deficiency correction can be done by soil Zn applications. Treatment of compost or manure to other crops, in rotation with onions, might lead to the reduction or elimination of the deficiencies related to Zn and other micronutrients in onions. Zinc is known as one of the most significant micro-nutrients; it is necessary for cell divi-

sion, carbohydrate and nitrogen metabolism, as well as water relation in the plant growth [10]. In this regard, zinc can considerably enhance the bulbs dry weight [53]. Consequently, the soil quality index values calculated for the onion cultivation areas were in the range of 0.30 to 0.58, with the mean being 0.46. There were positive significant correlations between the soil quality index values and onion yield (0.953**). Many soil quality indicators (SQI) are generally used and adapted to evaluate the variation of SQ in the medium and long term. One mechanism widely used to verify the viability of the indicator is its correlation with the soil function being studied, in this case, agricultural production (yield) [17]. Cherkashina et al. [16] stated that the parameters analysed should be selected in accordance with the correlation coefficient characterizing the relationship of soils with the crop yield in each particular area, in order to increase the reliability of the assessment results. Monsalve et al. [48] evaluated five different soil quality indicator methods: soil management assessment framework (SQ_{SMAF}), simple additive indicator (SQ_{SA}), weighted additive indicator (SQ_W), an indicator using principal component analysis (SQ_{PCA}), and an indicator using partial least squares regression (SQ_{PLSR}). Two aggregation techniques were also evaluated: weighted additive (A) and geometric or multiplicative (P). They found that SQ_{SA}, $SQ_W(A)$, $SQ_W(P)$, $SQ_{PCA}(A)$, and $SQ_{PCA}(P)$ indicators efficiently detected quality changes in response to the treatments applied to the soil. They found that no SQI was significantly correlated with yield in all experiments. Azizsoltani et al. [7] found that while most authors evaluate soil quality by analyzing and describing individual properties, others

consider the importance of using a soil quality indicator (index or function) to relate it to crop production and management practices.

Assessment of the SQ is a three-step process consisting of determining the parameters for the minimum data set (MDS), scoring the parameters selected or indicators' interpretation, and integrating the individual parameter scores into the SQI. First of all, a multi-level hierarchical structure of objectives, alternatives and criteria was made [4]. The comparison matrix was established according to the EO. These soil properties have been considered the most crucial for onion cultivation. MDS were selected according to the analysis of different soil properties, considering the EO; the values were then normalized using linear scoring. A linear scoring method was then applied to score each of the attribute values. A weighted additive method was also applied to estimate the soil quality index for all soil properties. The weights were obtained by applying the analytic hierarchy process method for the weighted summation of the minimum data set scores into a SQ index. The data determined for the parameters were transformed into some unitless values which ranged from 0 to 1 by applying linear scoring curves. Following transformation by using a linear scoring method, the scores estimated for each observation were multiplied by the weighted factor determined from the AHP findings. The weights of the parameters revealed the potential contribution rate of the parameters in the SQ assessment [4]. The highest value (0.387) was obtained for the hierarchy B1, whereas the lowest one (0.140) was recorded for the hierarchy B4. The highest values for the parameters in each of the hierarchies B1, B2, B3 and B4 were calculated for AWC (0.276), OM (0.431), total N (0.419) and available Fe (0.400), respectively. The variation in SQ between territories and geographical regions is a result of differences in some of the main soil forming factors such as topography, parent material, climate, vegetation cover and anthropogenic factors such as land use practices in each region [12].

In hierarchy B1, the available water capacity (AWC) obtained the highest value; this was followed by the clay content. AWC is the amount of water a soil can store to be used by plants. Many soil properties affect the moisture storage and hence, the AWC of the soil. The soil texture is often considered as the most decisive factor for AWC; this, in turn, affects water availability for the onion plant's growth. Soil texture has a great impact on the crops yield and the soil hydraulic properties [65]. Texture influences water holding capacity; it also has a direct effect on the nutrient availability and retention [67]. Onions have more susceptibility to nutrient deficiencies in comparison to the vast majority of crop plants; this is attributed to their shallow and un-branched root system; therefore, they are required, often responding well to the fertilizers addition. All sampled soils can support plant growth by applying some amendments [13]. In the

B2 hierarchy, the highest weight values were found for the soil organic matter (0. 431) and lime content (0.273). Organic matter could be, therefore, regarded as the most commonly used parameter of SQ for various types of soils around the world, particularly for the semi-arid and arid regions (59). The organic matter indicator received the highest weightage by the researchers due to the contribution to the ability of soils to form stable aggregates, adsorb and release nutrients and water on its surface which sustain and support the plant's growth and biodiversity in soils [11]. On the other hand, the indicator of lime contents can be under the effect of soil and onion crop management practices. The macronutrient contents of the soil, in the hierarchy B3, the indicators of total N (0.419), the available P (0.262) and exchangeable K (0.163) were given the highest weight values. Total N (51.2) and available P (116.0%) showed very high variation. The variability of the exchangeable K was moderate with 44.8% of CV. Lack of enough knowledge of variation in nutrient elements and soil chemical properties in all parts of the region and the uniform use of the fertilizers can all lead to some soils with more or less fertilizer, as compared to what is really needed [71]. As well, the soils natural fertility could change in relation to the type of the main material. In the B4 hierarchy, with the lowest weight value, the micronutrient contents were insufficiently available Fe, Zn and Mn contents in all study areas, except available Cu. The available Fe value had the highest weight (0.400), while the available Cu value had the lowest (0.339) in the SQI, where the indicators were weighted. [27] also reported that the enhanced levels of lime could reduce P, Zn, Cu, Mn and Fe uptake, while it could raise the Ca and Mg uptake in rice, wheat, common, bean and maize. Generally, soils in the area studied should support micronutrients (Fe, Zn and Mn) on the onion plant's growth. Consequently, the weights were added up to a sum of 1.0, as the linear weighted combination calculation was required. The analytical hierarchy process could be regarded as an extension of the AHP approach, combining the factor weights which are obtained by AHP with the values of each of the influential indicators. According to this procedure, the values which were obtained by each indicator were multiplied in the factor weight.

Very high quality soil was not detected in the experimental site. Restricting soil factors for onion cultivation in the areas included the low organic matter, macronutrients (N and P), micronutrients (Fe, Zn and Zn), high $CaCO_3$ and clay contents. The OM indicator in onion cultivation area had the highest weightage (0.431) with the AHP technique, thus suggesting that organic matter may be the primary constraint limiting the functioning potential of soils in the onion production. Since organic matter is the key element of soil fertility, it fulfills an important role in sustaining productivity. OM could have a large impact on some nutrient elements availability; these include K, P and

Mn, owing to increasing the water capacity of the soil, particularly in arid as well as semi-arid regions. Moreover, the moderate or loamy textural classes could be important for onion cultivation [68].

CONCLUSIONS

Onion (*Allium cepa* L.) based cropping systems are inevitable in the Turkey's cropping system to meet the growing demand for food. In this study, the soil quality of 30 different (0−20 cm soil depth) onion cultivation area located in Ankara province of the Continental Region of Turkey, were assessed according to soil quality indicators. The weightages of each parameter were calculated using the AHP. AHP could serve as a powerful tool for ranking soils according to multiple indicators, particularly in the case of samples with a small size. Specified SQI ranks help decision makers to define the effective management plan for each crop system by considering its suitability. Totally, twenty-two soil quality parameters were included in the onion soil quality index (SQIo) modeling by grouping them in four classes. The parameters identified in the minimum dataset (MDS) were soil physical indicators (sand, silt, clay, BD, Ksat, AWC, SSI, AS), chemical indicators (pH, EC, SOM, CaCO₃), macronutrients (total nitrogen, av.P, exc. K, Ca, Mg and Na), and micronutrients (available Fe, Zn, Mn and Cu). To calculate SQIo, experts' opinions were considered to select MDS and identify their weights. The present study developed and compared SQIo for onion cultivation soils. To guard against biases in the direct assigningment of weights, the AHP method was deployed. 25 onion cultivation areas were determined as moderate quality soils (Class IV), where as 5 others (soil sample Nos: 2, 5, 11, 16 and 21) were deemed as weak (Class III) for onion cultivation in regard to soil quality. Restricting soil factors for onion cultivation in the areas included low organic matter, macronutrients (N and P), micronutrients (Fe, Zn and Mn), high CaCO₃ and clay contents. The soil organic matter indicator in the onion cultivation area had the highest weightage (0.431) with the AHP technique, thus suggesting that soil organic matter may be considered the primary constraint limiting the functioning potential of the soils in the onion production. It can be, therefore, suggested that the assessment of the soil quality of the onion cultivation field could play an important role in determining the high onion productivity in agricultural practices and sustainable soil management systems in arid as well as semi-arid regions.

ETHICS APPROVAL AND CONSENT TO PARTICIPATE

This work does not contain any studies involving human and animal subjects.

CONFLICT OF INTEREST

The author of this work declares that he has no conflicts of interest.

REFERENCES

1. K. M. Al-Rohily, A. M. Ghoneim, A. S. Modaihsh, and M.O. Mahjoub, "Phosphorus availability in calcareous soil amended with chemical phosphorus fertilizer, cattle manure and sludge manure," Int. J. Soil Sci. **8**, 17−24 (2013).

2. S. S. Andrews and C. R. Carroll, "Designing a soil quality assessment tool for sustainable agroecosystem management," Ecol. Appl. **11**, 1573−1585 (2001).

3. S. S. Andrews, D. L. Karlen, and J. P. Mitchell, "A comparison of soil quality indexing methods for vegetable production systems in Northern California," Agric. Ecosyst. Environ. **90**, 25−45 (2002).

4. S. S. Andrews, D. L. Karlen, and C. A. Cambardella, "The soil management assessment framework. a quantitative soil quality evaluation method," Soil Sci. Soc. Am. J. **68**, 1945−1962 (2004).

5. V. Aparicio and J. L Costa, "Soil quality indicators under continuous cropping systems in the Argentinean pampas," Soil Tillage Res. **96**, 155−165 (2007).

6. E. Armenise, M. A. Redmile-Gordon, A. M. Stellacci, A. Ciccarese, and P. Rubino, "Developing a soil quality index to compare soil fitness for agricultural use under different managements in the Mediterranean environment," Soil Tillage Res. **130**, 91−98 (2013).

7. E. Azizsoltani, N. Honarjoo, and S. Ayoubi, "How soil pore distribution could help in soil quality studies as an appropriate indicator," Eurasian Soil Sci. **52**, 654−660 (2019). https://doi.org/10.1134/S1064229319060036

8. A. O. Aweto, "Variability of upper slope soils developed under sandstones in South- western Nigeria," Geogr. J. **25**, 27−37 (2013).

9. C. A. Black, *Methods of Soil Analysis*, Part 1: *Physical and Mineralogical Methods including Statistics of Measurement and Sampling* (Agronomy Monograph 9.1, Am. Soc. Agron. Soil Sci. Soc. Am., Madison, 1965).

10. G. J. Bouyoucos, "A recalibration of the hydrometer method for making mechanical analysis of soils," Agron. J. **43** (9), 434−438 (1951).

11. N. C. Brady, *Nature and Properties of Soils*, 10th Ed. (Macmillan Publishing Co., New York, 1990)

12. J. J. Brejda, T. B. Moorman, D. L. Karlen, and T. H. Dao, "Identification of regional soil quality factors and indi-

cators I. Central and Southern High Plains," Soil Sci. Soc. Am. J. **64** (6), 2115−2124 (2000).

13. J. M. Bremner and C. S. Mulvaney, "Nitrogen total," in *Methods of Soil Analysis*, Part II: *Chemical and Microbiological Properties,* Ed. by A. L. Page, R. H. Miller, and D. R. Keeney (Madison, 1982), pp. 595−625

14. J. L. Brewster, *Onions and Other Vegetable Allium*, 1st Ed. (CAB, International, Wallingford, 1994), p. 236.

15. F. Candemir and C. Gülser, "Effects of different agricultural wastes on some soil quality indexes at clay and loamy sand fields," Commun. Soil Sci. Plant Anal. **42**, 13−28 (2008).

16. E. Cebeci and F. Hancı, "Soğan ıslahında kullanılan biyoteknolojik yöntemler," in *GAP VII. Tarım Kongresi. 28 Nisan-1 Mayıs 2015* (Şanlıurfa, 2015).

17. A. A. Cherkashina, V. A. Golubtsov, and E. V. Berezhnaya, "Application of methodology for soil quality assessment in intermontane depressions of the cis-Baikal region," Eurasian Soil Sci. **54**, 1732−1745 (2021). https://doi.org/10.1134/S106422932111003X

18. M. R. Cherubin, D. L. Karlen, A. L. C. Franco, C. E. P. Cerri, C. A. Tormena, and C. C. Cerri, "A soil management assessment framework (SMAF) evaluation of Brazilian sugarcane expansion on soil quality," Soil Sci. Soc. Am. J. **80**, 215−226 (2016). https://doi.org/10.2136/sssaj2015.09.0328

19. A. F. Da Silva, A. P. Barbosa, C. R. L. Zimback, P. M. B. Landim, and A. Soares, "Estimation of croplands using indicator kriging and fuzzy classification," Comput. Electron. Agric. **111**, 1−11 (2015).

20. Z. Demir and C. Gülser, "Effects of rice husk compost application on soil quality parameters in greenhouse conditions," Eurasian J. Soil Sci. **4** (3), 185−190 (2015).

21. O. Dengiz, "Soil quality index for paddy fields based on standard scoring functions and weight allocation method," Arch. Agron. Soil Sci. **66** (3), 301−315 (2020). https://doi.org/10.1080/03650340.2019.1610880

22. O. Dengiz, S. İç, F. Saygın, and A. İmamoğlu, "Assessment of soil quality index for tea cultivated soils in ortaçay micro catchment in Black Sea region," J. Agric. Sci. **26** (1), 42−53 (2020). https://doi.org/10.15832/ankutbd.468900

23. *DMI Turkish State Meteorological Service* (Ankara, 2020).

24. B. Doğan and C. Gülser, "Assessment of soil quality for vineyard fields. A case study in Menderes District of Izmir, Turkey," Eurasian J. Soil Sci. **8** (2), 176−183 (2019). https://doi.org/10.18393/ejss.551874

25. B. Doğan and C. Gülser, "Soil quality assessment for olive groves areas of Menderes District, Izmir-Turkey," Eurasian J. Soil Sci. **9** (4), 298−305 (2020). https://doi.org/10.18393/ejss.758380

26. J. W. Doran and B. T. Parkin, "Defining and assessing soil quality," in *Defining Soil Quality for a Sustainable Environment. Special Publication No. 35*, Ed. by J. W. Doran, D. C. Coleman, D. F. Bezdicek, and B. A. Stewart (Soil Sci. Soc. Am., Madison, 1994), pp. 3−21.

27. J. Dumanski and C. Pieri, "Land quality indicators. research plan," Agric. Ecosyst. Environ. **81**, 93−102 (2000).

28. N. K. Fageria, F. J. P. Zİmmermann, and V. C. Baligar, "Lime and phosphorus interactions on growth and nutrient uptake by upland rice, wheat, common bean, and corn in an oxisol," J. Plant Nutr. **18** (11), 2519−2532 (1995).

29. FAOSTAT, The Statistics Division of the Food and Agriculture Organization (FAO) (2019). http.//faostat.fao.org/site. Cited April 27, 2021.

30. R. H. Follet, PhD Dissertation (Colorado State Univ., 1969).

31. B. Govaerts, K. D. Sayre, and J. Deckers, "A minimum data set for soil quality assessment of wheat and maize cropping in the highlands of Mexico," Soil Tillage Res. **87** (2), 163−174 (2006). https://doi.org/10.1016/j.still.2005.03.005

32. C. A. Gülser, "Comparison of some physical and chemical soil quality indicators influenced by different crop species," Pak. J. Biol. Sci. **7**, 905−911 (2004).

33. C. Gülser, R. Kızılkaya, T. Aşkın, and İ. Ekberli, "Changes in soil quality by compost and hazelnut husk applications in a hazelnut orchard," Compost Sci. Util. **23** (3), 135−141 (2015).

34. H. L. Havlin, J. D. Beaton, S. L. Tisdale, and W. L. Nelson, *Soil Fertility and Fertilizers. An Introduction to Nutrient Management*, 7th Ed. (PHI Learning Private Limited, New Delhi, 2010).

35. P. Hazelton and B. Murphy, *Interpreting Soil Test Results*, 2nd Ed. (CSIRO Publisher, Australia, 2007).

36. D. Hillel, *Introduction to Soil Phyics*, (Academic Press Limited, London, 1982), pp. 14−28.

37. B. Kacar, *Chemical Analysis of Plant and Soil-III. Soil Analysis* (Ankara University Faculty of Agriculture, Ankara, 1994), No. 3.

38. K. Karthikeyan, N. Kumar, J. Prasad, and R. Srivastava, "Soil quality and its assessment. A review," J. Soil Water Conserv. **14** (2), 100−108 (2015).

39. T. Kauko, "Sign value, topophilia, and the locational component in property prices," Environ. Plann. **36**, 859−878 (2004).

40. W. D. Kemper and R. C. Rosenau, "Aggregate stability and size distribution," in *Methods of Soil Analysis*, Part I, Ed. by A. Klute (ASA, Madison, 1986), pp. 425−442.

41. N. Kumar, S. K. Singh, V. N. Mishra, G. P. Obi Reddy, and R. K. Bajpai, "Soil quality ranking of a small sample size using AHP," J. Soil Water Conserv. **16** (4), 339−346 (2017). https://doi.org/10.5958/2455-7145.2017.00050.9

42. S. Kumar, N. Parashar, and A. Haleem, "Analytical hierarchy process applied to vendor selection problem. Smallscale, medium scale and large scale industries," Bus. Intell. J. **2**, 355−362 (2009).

43. J. Lee and S. Lee, "Correlations between soil physicochemical properties and plant nutrient concentrations in bulb onion grown in paddy soil," Sci. Hortic. **179**, 158−162 (2014).

44. C. H. Lee, M. Y. Wu, V. B. Asio, and Z. S. Chen, "Using a soil quality index to assess the effects of applying swine manure compost on soil quality under a crop rotation system in Taiwan," Soil Sci. **171**, 210−222 (2006).

45. W. M. Leo, "A rapid method for estimating structural stability of soils," Soil Sci. **96**, 342−346 (1993).

46. M. A. Liebig, G. Varvel, and J. Doran, "A simple performance-based index for assessing multiple agroecosystem functions," J. Agron. **93** (2), 313−318 (2001).

47. W. L. Lindsay and W. A. Norvell, "Development of a DTPA soil test for zinc, iron, manganese, and copper," Soil Sci. Soc. Am. J. **42**, 421−428 (1978).

48. W. L. Lindsay and W. A. Norvell, "Development of a DTPA micronutrient soil test," Proc. Soil Sci. Soc. Am. **35**, 600−602 (1969).

49. O. I. Monsalve Camacho, J. S. Gutiérrez Díaz, C. R. Bojacá Aldana, et al. "Soil quality indicators with potential use at plot or experimental unit scale," Eurasian Soil Sci. **54** (1), S62−S75 (2021). https://doi.org/10.1134/S1064229321140027

50. H. Marschner, *Mineral Nutrition of Higher Plants* (Academic Press, London, 1995).

51. P. Marschner, D. Crowley, and Z. Rengel, "Rhizosphere interactions between microorganisms and plants govern iron and phosphorus acquisition along the root axis-model and research methods," Soil Biol. Biochem. **43**, 883−894 (2011).

52. R. Marzaioli, R. D'Ascoli, R. A. De Pascale, and F. A. Rutigliano, "Soil quality in a Mediterranean area of Southern Italy as related to different land use type," Appl. Soil Ecol. **44**, 205−212 (2010).

53. B. Mater, *Soil Geography* (İstanbul Çantay Kitapevi, İstanbul, 1998).

54. O. S. Meena and D. Singh, "Effect of sulfur and zinc application on onion yield and sulfur and zinc uptake in three soil orders," J. Indian Soc. Soil Sci. **46**, 636−640 (1998).

55. K. Nabiollahi, R. Taghizadeh-Mehrjardi, R. Kerry, and S. Moradian, "Assessment of soil quality indices for saltaffected agricultural land in Kurdistan Province, Iran," Ecol. Indic. **83**, 482−494 (2017).

56. O. Nikus and F. Mulugeta, *Onion Seed Production Techniques. A Manual for Extension Agents and Seed Producers* (FAO-CDMDP, Asella, 2010).

57. S. R. Olsen, C. V. Cole, F. S. Watanabe, and L. A. Dean, *Estimation of Available Phosphorus in Soils by Extraction with Sodium Bicarbonate* (United States Department of Agriculture. U.S. Government Printing Office, Washington D.C., 1954), Vol. 939, p.19.

58. M. D. Orzolek, G. L. Greaser, and J. K. Harper, *Agricultural Alternatives* (Snap Bean Production, University Park, PA, Penn State Cooperative Extension, 2000). http://agalternatives.aers.psu.edu/publications.cfm.

59. I. Palcic and B. Lalic, "Analytical hierarchical process as a tool for selecting and evaluating projects," Int. J. Simul. Modell. **8**, 16−26 (2009).

60. F. Raiesi and V. Kabiri, "Identification of soil quality indicators for assessing the effect of different tillage practices through a soil quality index in a semi-arid environment," Ecol. Indic. **71**, 198−207 (2016). https://doi.org/10.1016/j.ecolind.2016.06.061

61. R. Ramanathan, "A note on the use of the analytic hierarchy process for environmental impact assessment," J. Environ. Manage. **63**, 27−35 (2001).

62. T. L. Saaty, *The Analytic Hierarchy Process. Planning, Priority Setting and Resource Allocation* (McGraw-Hill, New York, 1980).

63. T. L. Saaty, "Decision-making with the AHP: why is the principal eigenvector necessary," Eur. J. Oper. Res. **145**, 85−91 (2003).

64. T. L. Saaty, "Relative measurement and its generalization in decision making. Why pairwise comparisons are central in mathematics for the measurement of intangible factors—The analytic hierarchy/network process," Rev. R. Acad. Cienc. Exactas, Fis. Nat. Ser A. Math. **102** (2), 251−318 (2008).

65. A. Savva and K. Frenken, *Irrigation Manual Module 3. Agronomic Aspects of Irrigated Crop Production* (Water Resources Development and Management Officers and FAO Sub-Regional Office for East and Southern Africa, Harare, 2002).

66. K. Saxton, W. J. Rawls, J. Romberger, and R. Papendick, "Estimating generalized soil-water characteristics from texture," Soil Sci. Soc. Am. J. **50** (4), 1031−1036 (1986).

67. M. Sillanpää, *Micronutrient Assessment at Country Level. An International Study. FAO Soils Bulletin 63* (Food and Agricultural Organization of the United Nations, Rome, 1990).

68. W. L. Silver, J. Neff, M. McGroddy, E. Veldkamp, M. Keller, and R. Cosme, "Effects of soil texture on belowground carbon and nutrient storage in a lowland Amazonian forest ecosystem," Ecosystems **3** (2), 193−209 (2000).

69. L. Sobhani and B. Sadat, "Effects of organic content in corn grain yield in dry land areas," Water Soil **13**, 51−59 (2010) [in Persian].

70. Soil Quality Institute Staff, *Soil Quality Test Kit Guide* (United States Department of Agriculture, Agricultural Research Service Natural Resources Conservation Service, Soil Quality Institute, USA 1999) https. //efotg. sc.egov.usda.gov/references/public/WI/Soil_Quality_Test_Kit_Guide.pdf. Cited November 9, 2019.

71. Soil Survey Division Staff, *Soil Survey Manual* (USDA Handb. 18. U.S. Government Printing Office, Washington, DC, 1993).

72. R. Sokouti and M. H. Mahdian, "Spatial variability of macronutrient for soil fertilization management: a case study on Urmia plain," Int. J. Soil Sci. **6**, 49−59 (2011).

73. D. M. Sullivan, B. D. Brown, C. Shock, D. A. Horneck, R. G. Stevens, G. Q. Pelter, and E. B.G. Feibert, *Nutrient Management for Onions in the Pacific Northwest* (Oregon State Univ., Washington State Univ., Univ. of Idaho, Pacific Northwest Ext. Publ. 546, 2001).

74. R. B. Thapa and Y. Murayama, "Drivers of urban growth in the Kathmandu Valley, Nepal: examining the efficacy of the analytical hierarchy process," Appl. Geogr. **30**, 70−83 (2010).

75. TURKSTAT, Turkish Statistical Institute, *Crop Production Statistics* (2019). http://www.tuik.gov.tr/bitkiselapp/bitkisel.zul. Cited April 27, 2021.

76. US Salinity Lab. Staff, *Diagnosis and Improvement of Saline and Alkali Soils. USDA Agricultural Handbook No. 60* (U. S. Government Printing Office, Washington, DC, 1954).

77. A. R. Van Wambeke, *The Newhall Simulation Model for Estimating Soil Moisture & Temperature Regimes* (Department of Crop and Soil Sciences, Cornell University, Ithaca, 2000).

78. D. Vasu, S. K. Singh, S. K. Ray, V. P. Duraisami, P. Tiwary, P. Chandran, A. M. Nimkar, and S. G. Anantwar, "Soil quality index (SQI) as a tool to evaluate crop productivity in semi-arid Deccan plateau, India," Geoderma **282**, 70−79 (2016).
https://doi.org/10.1016/j.geoderma.2016.07.010

79. R. Voss, M. Murray, K. Bradford, K. Mayberry, and I. Miller, *Onion Seed Production in California, UCANR Publications #8008* (UC Agriculture and Natural Resources Communication Services, Richmond, 2013).

80. M. M. Wander and G. A. Bollero, "Soil quality assessment of tillage impacts in Illinois," Soil Sci. Soc. Am. J. **63**, 961−971 (1999).

81. R. Whitaker, "Validation examples of the analytic hierarchy process and analytic network process," Math. Comput. Modell. **46**, 840−859 (2007).

82. B. J. Wienhold, S. S. Andrews, and D. L. Karlen, "Soil quality: a review of the science and experiences in the USA," Environ. Geochem. Health **26**, 89−95 (2004).

83. *World Reference Base on Soil Resources. International Soil Classification System for the Designation of Soils and the Creation of Symbols for Soil Maps. Reports on World Soil Resources No. 106* (FAO, Rome, 2015).
https://www.fao.org/3/i3794en/I3794en.pdf.

84. X. Ying, Z. Guang-Ming, C. Gui-Qiu, T. Lin, W. Ke-Lin, and H. Dao-You, "Combining AHP with GIS in synthetic evaluation of eco-environment quality—a case study of Hunan Province. China," Ecol. Modell. **209** (2−4), 97−109 (2007).

85. F. Yoldas, S. Ceylan, N. Mordogan, and B. C. Esetlili, "Effect of organic and inorganic fertilizers on yield and mineral content of onion (*Allium cepa* L.)," Afr. J. Biotechnol. **10**, 11488−11492 (2011).

86. S. Zang and X. Huang, "An aggregated multivariate regression land-use model and its application to land-use change processes in the Daqing region (Northeast China)," Ecol. Modell. **193**, 503−516 (2006).