Identification of Regional Soil Quality Factors and Indicators: An Alluvial Plain From Central Anatolia

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Abstract

Sustainable agriculture largely depends on soil quality (SQ). The evaluation of agricultural soil quality is essential for economic success and environmental stability in rapidly developing regions. A wide variety of methods are currently used to evaluate soil quality using vastly different indicators.

This study was conducted in one of the most important irrigated agriculture areas of Konya in central Anatolia, Turkey, to analyze the soil quality indicators of Çumra County in combination with an indicator selection method, the minimum data set (MDS). A total of 38 soil parameters were used to select the most suitable indicators with the MDS method. We therefore determined a minimum data set with principle component analysis (PCA) to assess soil quality in the study area and soil quality was evaluated on the basis of a scoring function.

Among other soil properties, physical properties, such as field capacity (FC_{33}), bulk density (Pb), aggregate stability (AS) and permanent wilting point (WP); chemical properties, such as electrical conductivity (EC), Mn, total nitrogen (TN), available phosphorus (AP), pH and NO_3-N; and biological properties, such as urease enzyme activity (UA), root health value (RHV), organic carbon (OC), respiration (R) and potentially mineralized nitrogen (PMN) were chosen as an MDS to assess soil quality in the area. According the results this properties were found as the most sensitive indicators of soil quality and they can be used as indicators for evaluating and monitoring soil quality at a regional scale.

Keywords: soil quality, Çumra plain, indicators, minımum data set

1. Introduction

Soil is an important non-renewable natural resource on which humanity and all flora and fauna are dependent. The ever increasing growth of the human population has brought about a global food safety problem, and it has become an urgent necessity to obtain greater efficiency per unit area. In developing countries, the intense use of land on the grounds of progress through fast economic development has brought about serious limitations on the sustainable use of soils and created a major problem in soil quality. Furthermore, the negative effects of land degradation from various causes on agricultural productivity and the indirect effects on environmental and food safety and quality of life have also become global problems. Increasing the amount of agricultural lands may seem to be a solution to fulfill the food demand. On the other hand, the amount of agricultural land is already at a maximum level in most countries. Thus, for both the resolution of this problem and the sustainable use of soils, it is much more important to focus on improving the soil quality rather than increasing the amount of arable land (Rasheed *et al.*, 1996; Yemefack *et al.*, 2006).

Soil quality is defined as the capacity of the soil to sustain biological productivity and preserve the environmental quality and health of plants and animals within the boundaries of the ecosystem (Doran and Parkin, 1994). Karlen *et al.* (1997) defined soil quality as the soil's ability to support sustainable plant and animal production, improve human and environmental health, enhance the quality of water and air as the function of the properties of each soil type, and they regarded it as the manifestation of the natural and dynamic properties of soils.

The efficient and sustainable usage of soils, which are among our most important natural resources, can be achieved by defining their properties through proper methods, determining the restrictions that affect their productivity and the properties that affect sustainability. Assessing and monitoring soil quality can provide effective tools for determining the properties of degraded soil (Bindraban *et al.*, 2000), revealing sustainable land practices for land managers (McGrath and Zhang, 2003; Karlen *et al.*, 2011) and defining the elements needed for plant nutrition (Yu-Dong *et al.*, 2013). Thus, soil quality has received great attention in the last 15 years. In recent years the number of studies assessing soil quality in different management and product systems has increased worldwide, and several methods and scoring models have been developed for the determination of soil quality.

In the past, soil quality was accepted as the natural capacity of soil that provides the main plant nutrients. However, it is currently regarded as an immaterial property of soils due to its dependency on land usage and soil management practices, ecosystem and environmental interactions, socio-economic and political priorities and several other external factors (Doran and Jones, 1996). So, it is not possible to use a single soil property to digitize soil quality. On the other hand, the combined assessment of several parameters formed by the combination of certain soil properties provides important indicators for monitoring and assessing soil quality.

In general, soil quality parameters are defined as the processes and properties of soil that are sensitive to the changes in soil functions (Doran and Jones, 1996; Aparicio and Costa, 2007). It is very important to establish simple, sensitive and practical methods for the assessment of soil quality and to select indicators accordingly. The quality parameters to be selected must correlate well with the natural processes in the ecosystem. They must also respond to significant external change in a measurable way, be related to the measurable soil functions (natural or human-based), be integrated with the physical, chemical and biological properties and processes of soil, provide the basic inputs needed for estimating soil properties or functions that are difficult to measured directly, be relatively practical to use in field conditions, and they must be components of the current data bases (Doran and Parkin, 1994; Doran *et al.*, 1996; Chen, 1998; Dumanski and Pieri, 2000; Herrick and Jones, 2002; Aparicio and Costa, 2007).

The following properties are reported to be suitable for use as soil quality factors and indicators when studies on soil quality are evaluated:

Physical properties: texture, bulk density, water retention, aeration, compression, hydraulic properties, aggregation state, consistence properties, and surface crusting (Larson and Pierce, 1991; Arshad and Coen, 1992; Doran and Parkin, 1994; Kay[1] *et al.*, 1996; Burger and Kelting, 1998; Powers *et al.*, 1998); Chemical properties: pH, salt content, total organic carbon, total nitrogen, organic nitrogen, soluble carbon, mineral nitrogen, total phosphorus, extractable ammonium, nitrate, phosphor, potassium, calcium, magnesium, microelements, contaminants, cation change capacity (Doran and Parkin, 1994; Larson and Pierce, 1994; Reganold and Palmer, 1995; Harris *et al.*, 1996); Biological properties: microbial carbon, microbial nitrogen, soil respiration, biological activity, enzyme activities, root development, germination and growth (Turco *et al.*, 1992; Doran and Parkin, 1994; Fauci and Dick, 1994; Gregorich *et al.*, 1994; Linden *et al.*, 1994; Blair *et al.*, 1995; Dick *et al.*, 1996; Harris *et al.*, 1996; Rice *et al.*, 1996); Genetic properties: soil color, type of structure, the thickness and depth of the impermeable layer that is genetically formed, the thickness of horizon A and depth of the clay accumulation horizon (Doran and Parkin, 1994; Brejda *et al.*, 2000a; Brejda *et al.*, 2000b; Qi *et al.*, 2009).

To digitize and reveal out soil quality, it is necessary to determine and score the measurable soil quality parameters. Selection of the indicators to be used is very important for the determination of soil quality. Several properties affect the soil quality in varying degrees. Many of the above-mentioned physical, chemical and biological parameters are reported to be suitable for use as indicators. On the other hand, the concurrent use of all these properties as quality indicators is both impractical and contrary to the main principles of quality assessment parameters. Doran *et al.* (1996) advised that the number of indicators used to determine soil quality should be as few as possible. In general, the greater the number of indicators, the more comprehensively the soil quality can be determined. However, when a high correlation exists among the indicators, significant effects may emerge as a problem. ~~Carrying out too many soil analyses is also laborious.~~ Therefore, neglecting some indicators should be considered. On the other hand, if the indicators to be neglected are not well selected, non-realistic losses in soil quality may emerge. Therefore, these authors recommended several approaches. They recommended some soil quality indicator sets for the assessment of soil quality based on the total data set (TDS) (Doran and Parkin, 1994; Larson and Pierce, 1994; Karlen *et al.*, 1997). On the other hand, some studies proposed that instead of using all the properties, certain parameters such as the presence or absence of a correlation among the parameters and the measurement practicality could be considered. The MDS formed by representative indicators selected by various methods such as multiple-variant regression analysis (Doran and Parkin, 1994; Li and Lindstrom, 2001), principal components analysis, factor analysis (Brejda *et al.*, 2000b; Shukla *et al.*, 2004) and cluster analysis (Einax and Soldt, 1999) could be used for the determination of soil quality (Andrews *et al.*, 2002; Govaerts *et al.*, 2006; Rezaei *et al.*, 2006). Other authors stated that just as in the Delphi data set (DDS) (Zhang *et al.*, 2004), soil quality could be determined by using the indicators that are selected according to expert views (Herrick and Jones, 2002).

The effective and productive use of soils for many years can be achieved by protecting or improving soil properties. This can be accomplished through approaches that consider the physical, chemical and biological properties of soils and solutions based on these factors. In the Middle Eastern Anatolia region in Turkey, sufficient data are lacking about the general soil quality and the parameters that could be used to determine the soil quality. The Çumra Plain is one of the most fluvial plains in Turkey. In this study, we aimed to select the parameters that could be used to establish regional quality indexes and to determine the variables that affect soil quality.

2. MATERİALS AND METHODS

2.1. Site description

The study area (Çumra Plain) is a part of the Great Konya Basin in Konya Province, Turkey, is located in the Central Anatolian Plateau (N 37.5° - 37.8° latitude and E 32.5°- 33.3° longitude). The alluvial plains and fans comprise the sediments of several rivers debouching into the southern part of the basin. The alluvial fans or inland deltas consist of sediments ranging from coarse sand to a heavy clay texture. The climate is semi-arid with mild summers and very cold winters. The Konya meteorological station's long-term records show a mean annual precipitation of 296.8 mm, which mostly falls during winter and spring. The total evaporation is 996.6 mm, the mean annual temperature is 10.8°C, and the mean annual soil temperature at 50 cm is 13.1°C (MGM, 2014). The soil moisture and temperature regimes are xeric and mesic, respectively (Staff, 1999).

Detailed soil investigation reports and maps (1:15,000) were used to determine the research area (De Meester, 1970; Meester, 1970, 1971). Physiographically, the study area was a homogenous alluvial plain. When determining the study area on this detailed soil map that was prepared at series and phase levels, we considered the prevalence of the soil series. Accordingly, the ***Alibey series,*** which covered the largest area in the region, was selected as the study area. This series consists of deep loamy-textured soils formed on the main alluvial fan of the May River. It covers an area of approximately 4000 ha, which represents 6% of the Çumra Plain where irrigated farming is carried out, and is approximately 1023 m above sea level.

2.2 Soil Sampling and Analysis

The map of the series, including the coordinate information, was created to determine the points where soil samples would be taken. Samplings and measurements were carried out on

108 parcels of land on which wheat and sugar beet were grown in the years 2013-2014 and the necessary parameters were defined.

Degraded samples were taken from different points in each parcel at depths of 0-20 and 20-40 cm and mixed samples were formed for each depth. Mixed samples taken from the surface to depths of 0-20 cm depth were divided into three subsamples, each of which weighed 1 kg (Karlen *et al.*, 2003; Gugino *et al.*, 2009). One of these subsamples was dried ~~in the laboratory,~~ sieved ~~through a 2 mm sieve~~ and used for chemical and physical analyses. The second was kept in the cooler for biological analysis. The third subsample ~~was carried to the laboratory in proper containers to~~ be used for the determination of aggregate stability. ~~This subsample was not ground or sieved and was air dried.~~

To determine the texture of the samples, the Bouyoucos hydrometer (Gee and Bauder, 1986) was used and the oven-dried weight of the non-degraded soil samples was divided into sample's density to obtain the bulk density (*Pb*) (Blake and Hartge, 1986). The pycnometer method (Blake and Hartge, 1986) was used to find the particle density (*Pk*) and bulk density and particle density were used to find porosity (*P*) (Danielson *et al.*, 1986). To find field capacity (*Fc*), a pressure plate was used to obtain the percentage of humidity remaining in the soil as weight at pressures of 10 kPa (FC_{10}) and 33 kPa (FC_{33}) (Klute, 1986). To find the permanent wilting percentage (*PWP*), a pressure plate was used to obtain the percentage of humidity left in the soil as weight at 1500 kPa pressure (Klute, 1986), and to obtain the available water (*AW*), the wilting point was deducted from the field capacities (FC_{10} and FC_{33}). Aggregate stability (*AS*) was determined once the degraded samples taken from the field at 0-20 cm depth were oven dried at 40 °C (for 5 minutes they were kept under a total rain of 12.5 mm coming from a simulator with a precipitation intensity of 150 mm hour^{-1}) (Gugino *et al.*, 2009). Penetration resistance was measured using Eijkelkamp's penetrologger, which is pushed under the soil by hand. Upper-layer penetration resistance (PR_{0-20}) was measured by taking the averages of the penetration resistance values at 0-20 cm depth, and lower-layer penetration resistance (PR_{20-40}) was measured by taking the averages of the penetration resistance values at 20-40 cm depth. The pH among the chemical properties was measured using a glass electrode digital display pH meter in a 1:1 soil-pure water mixture. Electrical conductivity (EC) was measured using an electrical conductivity device in a 1:1 soil and pure water mixture (Kacar, 2009). Total nitrogen was measured using a LECO CN-2000 device with the Dumas dry combustion method (Wright and Bailey, 2001). Ammonium nitrogen ($NH_4^+ - N$) and nitrate nitrogen ($NO_3^- - N$) were measured using the Kjeldahl device through H_2SO_4 titration in the solution obtained as a result of distillation first with MgO and then with Devardo alloy (Keeney and Nelson, 1982). Available phosphorus (AP) was determined by the Olsen method (Olsen *et al.*, 1982). The solution was extracted using extractable Ca, Mg, Na and K, 1 N ammonium acetate solution and available Fe, Cu, Mn and Zn were determined with atomic absorption spectrophotometry through DTPA extraction (Kacar, 2009). Organic matter was determined by using a LECO CN-2000 device with Dumas dry combustion (Wright and Bailey, 2001). Active carbon was displayed at 550 nm on the spectrophotometer in samples with a shaken solution of 0.02 M potassium permanganate ($KMnO_4$) (Blair *et al.*, 1995; Gugino *et al.*, 2009). Potential mineralizable nitrogen (PMN) was measured by H_2SO_4 titration in the distilled solution together with MgO in a Kjeldahl device in extracts obtained from normal and incubated samples and the difference was obtained (Gugino *et al.*, 2009). Roots of germinated bean plants were removed from the soil at the end of the blooming period to determine the root health value (RHV) (Gugino *et al.*, 2009). The following activities were determined: urease enzyme activity (UA) (Hoffmann and Teicher, 1961), catalyzing enzyme activity (CA) (Beck, 1971), dehydrogenase enzyme activity (DA) (Thalmann, 1968), and soil respiration (R) (Isermeyer, 1952). Moreover, mycorrhizal fungi (MSN) were isolated and counted using 30×–40× enlarged microscopic images of the fungi in samples prepared by washing through 38 µm sieves (Gerdemann and Nicolson, 1963).

2.3 Indicators Selection

Selection of the indicators to be used for the determination of soil quality is very important. Though it would be proper to assess all soil properties within the framework of soil quality, this is not practical. This is because several parameters are concerned with the assessment of soil quality, and assessing each of these would require both time and significant costs. Thus, it is necessary to select among the indicators to be used. The important thing here is that the parameters to be used as indicators should reflect the soil primarily in a simple and accurate way (Andrews *et al*., 2004). Various methods were used to assess soil quality and other environmental data, such as multiple-variable regression analysis (Doran and Parkin, 1994; Li and Lindstrom, 2001), principal components and factor analysis (Brejda *et al.*, 2000b; Shukla *et al.*, 2004), discriminant analysis (Brejda *et al.*, 2000a) and cluster analysis (Einax and Soldt, 1999).

In this study, we used principal components analysis among others to assess and monitor soil quality. For this purpose, the total data set was divided into three groups first to create the minimum data set from the total of 38 data sets obtained in the study. Physical properties were included in the first group, chemical properties in the second and biological properties in the third group. In the first stage, the Kaiser-Meyer-Olkin (KMO) and Bartlett test was conducted to verify whether the data included in each group were in conformity with the principal components analysis (Tatlidil, 2002). All properties had values above 0.5 and passed the KMO and Bartlett test (Table 1). In the second stage, principal components analysis (PCA) was conducted for each of four data groups to create the minimum data set and correlation matrixes of the data sets were established (Minitab, 1995). To determine the parameters that may take part in the minimum data set, minimum data set recommendations were prepared for each series by considering the component loads determined through PCA, correlation load totals, inter-data correlations and analysis methods.

3. RESULTS AND DISCUSSION

3.1. Indicator Selection and Creating the Minimum Data Set

The values concerning the physical, chemical and biological properties obtained at the end of the study are given in Table 2. The KMO and Bartlett tests were conducted to check whether the data sets that were created based on these properties were in conformity with the principal components analysis. The KMO and Bartlett test results are given in Table 1. The following percentages were obtained at the end of the KMO test: 63.4% for the physical properties (0.634>0.5), 66.7% for the chemical properties (0.0667>0.50), 62.9% (0.62.9>0.50) for the biological properties. The Bartlett test results were significant for all the data sets (significance level=0.000<0.05). These results showed that the physical, chemical and biological properties were in conformity with the principal components analysis and showed a high correlation among the variables (Karagöz and Kösterelioğlu, 2015). When selecting the number of principal components, it is necessary to make selections such that the minimum number of principal components can explain 2/3 (67%) of the total variance. This percentage can be increased up to 95%. On the other hand, as it is necessary to work with many principal components to increase the percentage after 67%, this ratio is kept limited and the number of principal components which meets 67% level is generally used. In the principal components test, we used the number of principal components (PC) whose was eigenvalue > 1 and which explained 2/3 of the total variance. This is because one of the most commonly accepted rules is to select the number of principal components that meets the number of R matrix or S matrix eigenvalues that are greater than 1 (Tatlidil, 2002). Therefore, the eigenvalues of the matrixes were found, and the same number of principal components was selected as the number of eigenvalues with values greater than 1. For selecting the principal component properties to be used to create the minimum data set as quality indicators, we accepted as candidates for the minimum data set those properties whose principal component value had the highest percentage in the components cluster for explaining the variance. Properties such as the principal component loads, correlation load totals, inter-data correlations, and analysis methods were considered when determining the minimum data sets. When deciding which ones to choose among the properties that are highly correlated, we considered issues such as whether the property would be practical and inexpensive and whether a relationship existed between that property and the other properties.

Eigenvalues, variance explanation ratios and total variances of the physical properties of soils at the end of principal component analysis are given in Figure 1. A correlation matrix of the physical properties selected through the principal component analysis is given in Table 3. According to that, the first PC explained 43.7%, the second PC 20.2%, the third PC 8.9% and the fourth PC 7.90% of the variance. As the four PCs explained 80.8% of the total variance and had an eigenvalue ≥1.1113, these four PCs were selected. The principal components results of the physical properties are given in Figure 3. The properties that contributed most to the first principal component were Sand (-0.381), Clay (0.294), FC_{10} (0.354), FC_{33} (0.379) and Silt (0.294); the properties contributing most to the second principal component were Pb (-0.457) and P (0.457); those contributing most to the third principal component were PWP (-0.564), AWC_{10} (0.359) and AWC_{33} (0.523); and the properties contributing most to the fourth principal component were PR_{0-20} (-0.481) and PR_{20-40} (-0.662). From the order of PCs achieved by assessing the physical properties of soils, Sand, Clay, FC_{10}, FC_{33}, Silt, Pb, P, PWP_{1500}, AWC_{10}, AWC_{33}, PR_{0-20} and PR_{20-40} were qualified for selection as candidates for the minimum data set. However, as it is necessary to use the fewest data in determining soil quality, we needed to select minimum data sets by considering the component data loads, correlation load totals, inter-data correlations, analysis methods and applicability.

According to these criteria, the correlation load totals of the candidate data in PC1, Sand, Clay, FC_{10}, FC_{33} and Silt, were 4.352, 3.153, 3.897, 4.099 and 4.209, respectively. It is not possible to change the values of Sand and Clay in practice and they have no sensitivity against the periodic climate and land management changes. Therefore, these two properties were eliminated from the minimum data set. Among the other three properties, FC_{33} was the first physical soil property selected for inclusion in the minimum data set, as it had the highest correlation load (4.209), was extensively used and showed correlation with 11 of the physical properties of soil (Table 6). Furthermore, as the high values of FC_{33} would mean a greater accumulation of water in the soils, it will be a quality indicator, particularly for dry and semi-dry regions to show that plants are less affected from water stress. This will also be valid for the other regions considering the cost-effective and sustainable use of water. The candidate PB and P data for PC2 had inner total correlation loads of 1.994. Because of a high negative correlation between these two candidate properties (R^2 = -0.994; p<0.01, Table 9) and P was measured from Pb, Pb was selected as the second physical property of soil for inclusion in the minimum data set. The total inner correlation loads of the candidate properties of PC3, PWP, AWC_{10} and AWC_{33}, were 1.200, 1.981 and 1.861, respectively. As PWP had the lowest total correlation load among these three properties and a high positive correlation existed between AWC_{10} and AWC_{33} (R^2 = 0.821; p<0.0; Table 9), AWC_{10} was included in the minimum data set for PC3. As the candidate data of PC4, $PR_{0\text{-}20}$ and $PR_{20\text{-}40}$ indicated the compression at different depths in the soil, both parameters were included in the minimum data set.

In conclusion, FC_{33}, Pb, AWC_{10}, $PR_{0\text{-}20}$ and $PR_{20\text{-}40}$ among the physical soil quality parameters were included in the minimum data set, and among these selected properties Pb, AWC_{10}, $PR_{0\text{-}20}$ and $PR_{20\text{-}40}$ are present in common soil quality assessment systems, such as the CSHA or

SMAF (Karlen *et al.*, 1997; Gugino *et al.*, 2009). These selected physical properties are used in the CSHA and SMAF and they were also reported by many researchers as the quality indicators for parameters such as FC_{33} that are not included in the CSHA (Erkossa *et al.*, 2007; Rashidi *et al.*, 2010; Yang *et al.*, 2010; Moncada *et al.*, 2014; Sánchez-Navarro *et al.*, 2015).

At the end of the principal component analysis, the eigenvalues of the chemical properties of soils, variance explanation ratios and total ratios are given in Figure 2, and the correlation matrix of the selected chemical properties is given in Table 4. According to this, the first PC explained 29%, the second PC 19.4%, the third PC 10.7% and the fourth PC 8.7% of the variance. As these four PCs explained 67.8% of the total variance and had an eigenvalue ≥1.3042, they were selected. The principal components results of the chemical properties are given in Figure 2. The properties that contributed most to the first principal component were EC (0.447), Lime (0.335) and Mg (0.375); the properties contributing most to the second principal component were Ca (-0.484), Na (-0.342), K (-0.431), Cu (-0.359) and Mn (-0.417); the properties contributing most to the third principal component were TN (-0.475), AP (-0.401) and Zn (-0.411); and the properties that contributed most to the fourth principal component were pH (-0.359) and NO_3-N (0.381).

From the order of the PCs obtained from assessing the chemical properties of soils, EC, Lime, Mg, Ca, Na, K, Cu, Mn, TN, AP, Zn, pH and NO_3-N qualified as candidates for the minimum data set. However, as it is necessary to use the fewest data in determining the soil quality, minimum data sets were selected. The total inner correlation loads of the candidate properties of PC1, EC, Lime and Mg, were 1.585, 1.839 and 1.962, respectively. Although the total EC correlation load was lower than the other two properties, as the PC load was higher, the region was located in a dry to semi-dry climate zone and significant salification problems existed in certain areas, it was included in the minimum set together with Lime. However, as Mg was highly correlated with EC (R^2=0,623; p<0,01) and $Lime_{0-20}$ (R^2=0,608; p<0,01) (Table 6) and the Mg scopes of the soils subject to the study were above the sufficiency level in all samples, it was not included in the minimum data set.

The total inner correlation loads of the candidate properties of PC2, Ca, Na, K, Cu and Mn, were 3.019, 2.280, 2.891 and 2.131, respectively. As Ca had the highest total correlation load among these five properties and Mn remained below the level of sufficiency in certain samples (<14.0 mg Mn kg^{-1} (FAO, 1990)), it was included in the minimum data set. However, as the Cu and K contents of the soils were above the level of sufficiency in all samples (>0.2 mg Cu kg^{-1} (Follett, 1969); >110 mg K kg^{-1} (FAO, 1990)) and Na was not a nutrient element, it was not included in the minimum data set. The total inner correlation loads of the candidate properties of PC3, TN, AP and Zn, were 1.244, 1.543 and 1.443, respectively. No significant correlation existed among these three properties, Zn remained below the sufficiency level (>0.7 mg Zn kg^{-1} presence (FAO, 1990)), P was an important macro nutrient element and TN remained below the sufficiency level in most of the soils studied (<0.09% N); thus, they were included in the minimum data sets for TN, AP and Zn. The total inner correlation load of the candidate properties of pH and NO_3-N was 1.425. Soil pH directly affects the usefulness of the nutrient elements. NO_3-N was lacking in our soils, and when it is excessive, it might cause environmental health problems, it was therefore included in the minimum data set. Similarly, pH, AP, Mn and Zn in CSHA and SMAF were also accepted as soil quality parameters (Andrews *et al.*, 2004; Gugino *et al.*, 2009).). In conclusion, EC, Lime**,** Mg, Ca, Mn, TN, AP, Zn, pH and NO_3-N among the chemical soil quality parameters were selected as the variables that could be included in minimum data set. Most of these selected properties are also used as quality criteria in the CSHA and SMAF. Several other researchers reported that Lime**,** Ca, TN and NO_3-N that are not used in these assessment systems could be used as quality indicators

(Mojiri *et al.*, 2011; Baridón and Casas, 2014; Liu *et al.*, 2014; Viana *et al.*, 2014; Zdruli *et al.*, 2014; Benintende *et al.*, 2015; Sánchez-Navarro *et al.*, 2015; Shirani *et al.*, 2015).

From the principal component analysis, the eigenvalues for the biological properties of soils, variance explanation ratios and total ratios are given in Figure 3 and the correlation matrix for the selected physical properties is given in Table 5. The first PC explained 34%, the second PC 23.2% and the third PC 15.3% of the variance. As the three PCs explained 72.5% of the total variance and had an eigenvalue ≥1.3738, these three PCs were selected. The properties that contributed most to the first principal component were the amounts of UA (0.486), DA (-0.412) and MSN (0.461); properties that contributed most to the second principal component were OC (-0.410), AC (0.411) and R (-0.426); properties that contributed most to the third principal component were PMN (0.584), RHV (-0.506) and CA (-0.380), and these became candidates for minimum data set. The total inner correlation loads of the candidate properties of PC1, the levels of UA, DA and MSN, were 2.248, 2.044 and 2.184, respectively. As urease had the highest total correlation load among these properties, UA was included in the minimum data set for PC1. Although dehydrogenase was the second property with the highest correlation total, due to the presence of significant correlations both between DA and UA and between DA and AC and the difficulty of determining the amount of MSN, the latter two properties were not included in the minimum data set. The properties that contributed the most to PC2 were OC, AC and R. The correlation load totals of these were 1.680, 1.043 and 1.671, respectively. Among these properties, R and OC, which had the highest principal component coefficient, were included in the minimum set for PC2. Only PMN, RHV and CA were selected as candidates for the PC3 data set. The correlation load totals of PMN, RHV and CA were 1.269, 1.685 and 1.526, respectively. They were included in the minimum data set, as the highest correlation load total was in the RHV. According to the results obtained, OC and R were accepted as soil quality parameters in the CSHA, and OC and R were accepted as soil quality parameters in the SMAF (Andrews *et al.*, 2004; Gugino *et al.*, 2009; Moebius-Clune *et al.*, 2011). Though urease activity among these selected properties is not listed in the CSHA or SMAF, many other researchers reported that these could be used as quality indicators (Saviozzi *et al.*, 2001; Masto *et al.*, 2007; Baridón and Casas, 2014; Benintende *et al.*, 2015).

4. CONCLUSIONS

This paper discusses the parameters that could be used to monitor the soil quality in the Konya Çumra region, one of the most important agricultural lands in Turkey.

The study also revealed the physical, chemical and biological parameters that could be used to assess the soil quality in the study area and in other areas. The MDS was created for the selection of indicators using the principal component analysis for this purpose. FC_{33}, Pb, AW_{10}, PR_{0-20} and PR_{20-40}, among the physical properties; EC, Mg, lime, Ca, Mn, TN, AP, Zn, pH and NO_3-N among the chemical properties; and UA, OC, R and root health among the biological properties were selected as indicators that could be used in the assessment of soil quality. Score functions for the properties that exist in the CSHA and SMAF among these parameters can be used in scoring. On the other hand, other parameters such as FC_{33}, lime, Ca, TN, NO_3-N and urease were also found to be suitable for use in assessing soil quality. Consequently, scoring functions of these properties must be developed. In this study, the MDS method and principal components analysis were found to be appropriate statistical methods to select the quality indicators.

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Table 1. Physical, Chemical and Biological Data Sets Belonging to the KMO and Barlett Sphericity Test

	Physical Properties	Chemical Properties	Biological Properties
Kaiser-Meyer-Olkin Measure of Sampling Adequacy	0.634	0.667	0.629
Bartlett's Test of Sphericity Approx. Chi-Square	3967.603	977.069	453.937
Sphericity	91	105	36
Significance level	0.000	0.000	0.000

Table 2. Physical, Chemical and Biological Properties of Soil at Sampling Sites.

Parameters	Variable		Mean	%CV	Min.	Max.
Physical Properties	Sand	%	40.32	27.55	17.10	61.88
	Silt	%	25.17	24.03	11.60	40.00
	Clay	%	34.52	21.76	18.05	53.53
	Pb	g cm^{-3}	1.35	8.80	1.10	1.63
	Pk	g cm^{-3}	2.64	0.99	2.54	2.71
	P	%	48.85	9.22	38.38	58.00
	FC_{10}	g g^{-1}	0.32	16.55	0.22	0.46
	FC_{33}	g g^{-1}	0.24	17.17	0.17	0.38
	PWP	g g^{-1}	0.14	21.92	0.10	0.25
	AWC_{10}	g g^{-1}	0.18	21.61	0.09	0.29
	AWC_{33}	g g^{-1}	0.10	27.36	0.04	0.20
	AS	%	17.84	56.07	4.83	52.32
	PR_{0-20}	PSI	208.08	37.70	83.00	415
	PR_{20-40}	PSI	314.82	31.32	147.00	689
Chemical Properties	pH	-	8.03	1.98	7.34	8.29
	EC	-	523.50	48.08	243.00	1748
	Lime	%	8.97	20.33	6.47	16.48
	TN	%	0.08	35.65	0.03	0.16
	NH_4-N	mg kg^{-1}	17.13	30.56	7.00	44.89
	NO_3-N	mg kg^{-1}	25.07	83.61	3.46	129.88
	AP	mg kg^{-1}	12.97	50.80	3.36	37.79
	Ca	mg kg^{-1}	5089	28.82	2622	8160
	Mg	mg kg^{-1}	818.90	53.54	220	1925
	Na	mg kg^{-1}	82.36	38.41	25.00	203
	K	mg kg^{-1}	577.50	33.95	307	1356
	Fe	mg kg^{-1}	7.52	33.53	3.65	14.38
	Cu	mg kg^{-1}	1.29	29.61	0.45	2.06
	Mn	mg kg^{-1}	15.82	38.81	5.45	25.97
	Zn	mg kg^{-1}	1.10	43.10	0.26	3.77
Biological Properties	OC	%	0.71	31.90	0.29	1.43
	AC	mg kg^{-1}	486.70	49.25	96	996
	PMN	µg $g^{-1}w^{-1}$	9.59	50.37	0.51	20.26
	RHV	-	3.90	40.29	1.00	8.00
	R	mg $100g^{-1}$ $24h^{-1}$	25.56	23.42	11.37	39.27
	CA	mgO_2 $5g^{-1}$	6.56	41.33	1.87	16.20
	UA	µgN g^{-1}	189.20	90.49	17.80	581
	DA	µgTPF g^{-1}	2.29	69.26	0.12	5.87
	MSN	number $10g^{-1}$	60.90	78.16	5.83	259

Pb, bulk density; Pk, particle density; P, porosity; FC_{10}, field capacity (10 kPa); FC_{33}, field capacity (33 kPa); PWP_{10}, permanent wilting percentage; AW_{10}, available water (10-1500 kPa); AW_{33}, available water (33-1500 kPa); AS, Aggregate stability; PR_{0-20}, penetration resistance (0-20 cm); PR_{20-40}, penetration resistance (20-40 cm); TN, total nitrogen; NH_4-N, Ammonium nitrogen; NO_3-N, nitrate nitrogen; YP; Available phosphorus; OC, organic carbon; AC, active carbon; PMN, Potential mineralizable nitrogen; RHV, root health value; R, respiration; UA urease enzyme activity; CA, catalyzing enzyme activity; DA, dehydrogenase enzyme activity, MSN, mycorrhizal fungi number.

Table 3. Principal components analysis of the matrix of correlation of the selected physical properties

PC1 variables	Sand	Silt	Clay	FC_{10}	FC_{33}
Sand	1	-0,770	-0,858	-0,843	-0,881
Silt	-0,770	1	0,334	0,485	0,564
Clay	-0,858	0,334	1	0,856	0,849
FC_{10}	-0,843	0,485	0,856	1	0,915
FC_{33}	-0,881	0,564	0,849	0,915	1
Total	4,352	3,153	3,897	4,099	**4,209**
PC2 variables	**Pb**	**P**			
Pb	1	-0,994			
P	-0,994	1			
Total	**1,994**	1,994			
PC3 variables	**PWP**	**$AW_{10-1500}$**	**$AW_{33-1500}$**		
PWP	1	0,160	0,040		
AWC_{10}	0,160	1	0,821		
AWC_{33}	0,040	0,821	1		
Total	1,200	**1,981**	1,861		
PC4 variables	**PR_{0-20}**	**PR_{20-40}**			
PR_{0-20}	1	0,788			
PR_{20-40}	0,788	1			
Total	**1,788**	**1,788**			

Table 4. Principal Components Analysis of the Matrix of Correlation of the Selected Chemical Properties

PC1 variables	EC	Lime	Mg		
EC	1	-0,231	-0,354		
Lime	-0,231	1	0,608		
Mg	-0,354	0,608	1		
Total	**1,585**	**1,839**	**1,962**		
PC2 variables	Ca	Na	K	Cu	Mn
Ca	1	0,308	0,539	0,756	0,416
Na	0,308	1	0,415	0,243	0,314
K	0,539	0,415	1	0,566	0,371
Cu	0,756	0,243	0,566	1	0,030
Mn	0,416	0,314	0,371	0,030	1
Total	**3,019**	2,280	2,891	2,595	**2,131**
PC3 variables	TN	AP	Zn		
TN	1	0,172	0,072		
AP	0,172	1	0,371		
Zn	0,072	0,371	1		
Total	**1,244**	**1,543**	**1,443**		
PC4 variables	pH	NO_3-N			
pH	1	-0,425			
NO_3-N	-0,425	1			
Total	**1,425**	**1,425**			

Table 5. Principal Components Analysis of the Matrix of Correlation of the Selected Physical Properties

PC1 variables	UA	DA	MSN
UA	1	-0,554	0,694
DA	-0,554	1	-0,490
MSN	0,694	-0,490	1
Total	**2,248**	2,044	2,184
PC2 variables	OC	AC	R
OC	1	-0,026	0,654
AC	-0,026	1	0,017
R	0,654	0,017	1
Total	**1,680**	**1,043**	**1,671**
PC3 variables	PMN	RHV	CA
PMN	1	-0,214	-0,055
RHV	-0,214	1	0,471
CA	-0,055	0,471	1
Total	1,269	**1,685**	1,526

Table 6. Correlation matrix of physical, chemical and biological properties of soils

		Sand	Silt	Clay	Pb	Pk	P	FC_{10}	FC_{33}	PWP	AWC_{10}	AWC_{33}	PR_{0-20}	PR_{20-40}
Physical Properties	**Silt**	-0,770**												
	Clay	-0,858**	0,334**											
	Pb	0,375**	-0,547**	-0,114										
	Pk	0,182na	-0,147	-0,151	0,062									
	P	-0,353**	0,532**	0,095	-0,994**	0,048								
	FC_{10}	-0,843**	0,485**	0,856**	-0,115	-0,148	0,096							
	FC_{33}	-0,881**	0,564**	0,849**	-0,295**	-0,146	0,277**	0,915**						
	PWP	-0,689**	0,374**	0,718**	-0,285**	-0,132	0,268**	0,704**	0,763**					
	AWC_{10}	-0,602**	0,361**	0,599**	0,073	-0,102	-0,087	0,808**	0,644**	0,160				
	AWC_{33}	-0,574**	0,446**	0,489**	-0,132	-0,071	0,123	0,612**	0,664**	0,040	0,821**			
	AS	-0,174	0,220*	0,080	-0,525**	-0,223*	0,499**	0,087	0,165	0,157	-0,004	0,087		
	PR_{0-20}	0,334**	-0,416**	-0,159	0,520**	0,089	-0,507**	[illegible]	-0,334**	-0,352**	0,022	-0,127	-0,313**	
	PR_{20-40}	0,328**	-0,350**	-0,204*	0,333**	0,116	-0,316**	-0,252	-0,349**	-0,296**	-0,114	-0,219**	-0,199**	0,788**

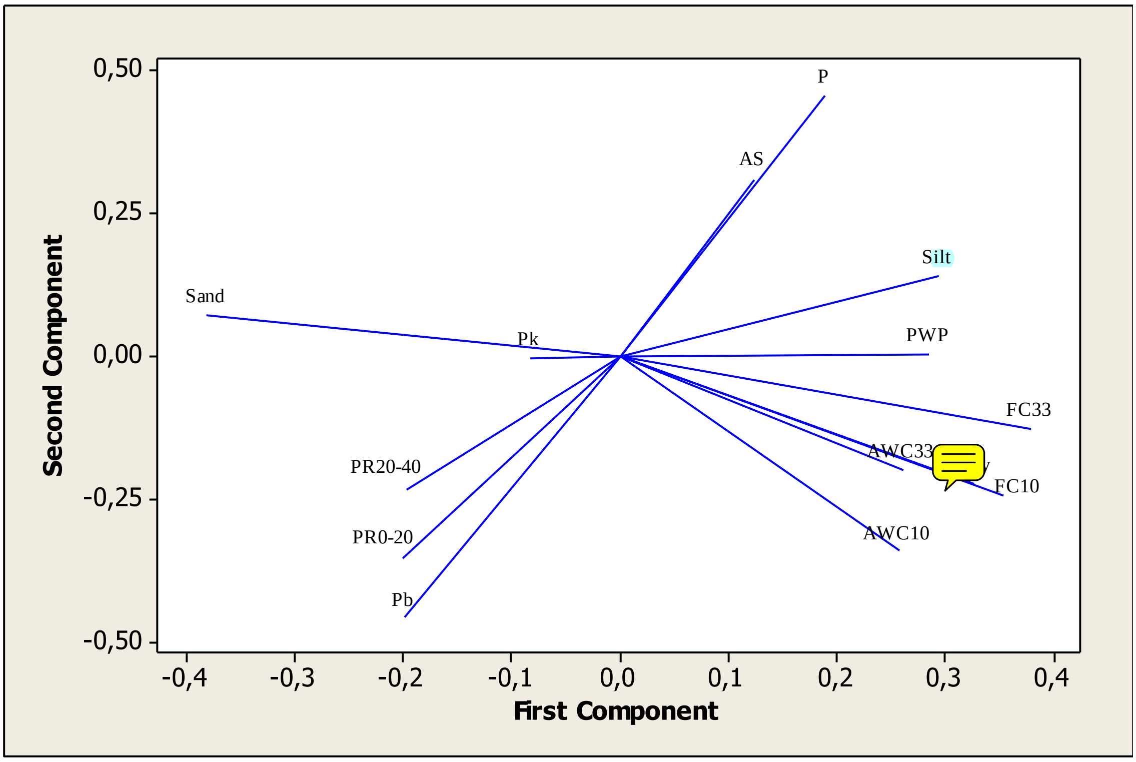
		pH	EC	Lime	TN	NH_4-N	NO_3-N	AP	Ca	Mg	Na	K	Fe	Cu	Mn
Chemical Properties	**EC**	-0,604**													
	Lime	-0,231*	0,531**												
	TN	0,020	-0,161	-0,226*											
	NH_4-N	-0,164	0,221*	0,195*	-0,036										
	NO_3-N	-0,425**	0,719**	0,371**	-0,141	0,240*									
	AP	-0,230*	0,522**	0,259**	0,172	0,058	0,257**								
	Ca	0,072	0,235*	0,115	0,002	0,083	0,279**	-0,120							
	Mg	-0,354**	0,623**	0,608**	-0,115	0,181	0,307**	0,518**	-0,208**						
	Na	0,064	0,030	-0,036	0,328**	-0,059	-0,081	0,117	0,308**	-0,042					
	K	0,077	0,229*	0,277**	0,206*	0,054	0,111	0,209*	0,539**	-0,010	0,415**				
	Fe	0,315**	-0,353**	-0,350**	0,168	0,118	-0,091	-0,066	0,258**	-0,418**	0,115	-0,077			
	Cu	-0,233*	0,576**	0,434**	-0,051	0,228*	0,444**	0,133	0,756**	0,306**	0,243*	0,566**	-0,041		
	Mn	0,207*	-0,348**	-0,428**	0,458**	-0,218*	-0,164	-0,273**	0,416**	-0,749**	0,314**	0,371**	0,296**	0,030	
	Zn	-0,374*	0,518**	0,004	0,072	-0,110	0,345**	0,371**	0,105	0,208*	0,061	0,134	-0,176	0,264**	0,029

		OC	AC	PMN	RHV	R	CA	UA	DA
Biological Properties	**AC**	-0,026							
	PMN	0,042	0,281**						
	RHV	-0,229	0,195	-0,214*					
	R	0,654**	0,017	0,085	-0,255**				
	CA	-0,098	0,007	-0,055	0,471**	-0,343**			
	UA	0,363**	0,401**	-0,020	0,166	0,526**	-0,190		
	DA	0,068	-0,821**	-0,338**	-0,180	-0,040	0,094	-0,554**	
	MSN	0,298**	0,337**	0,118	0,025	0,482**	-0,127	0,694**	-0,490**

* *P*<0,05.

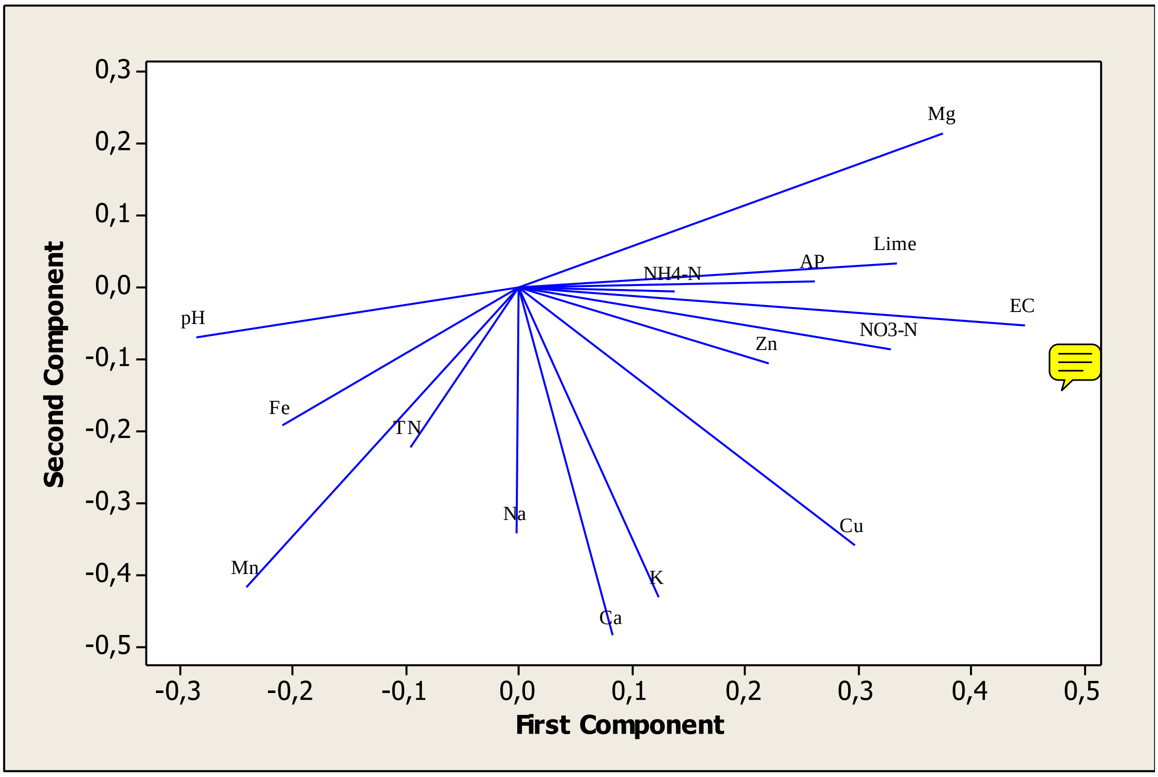
** *P*<0,01.

Figure 1. Loading plots for soil physical properties on the first two principle components.



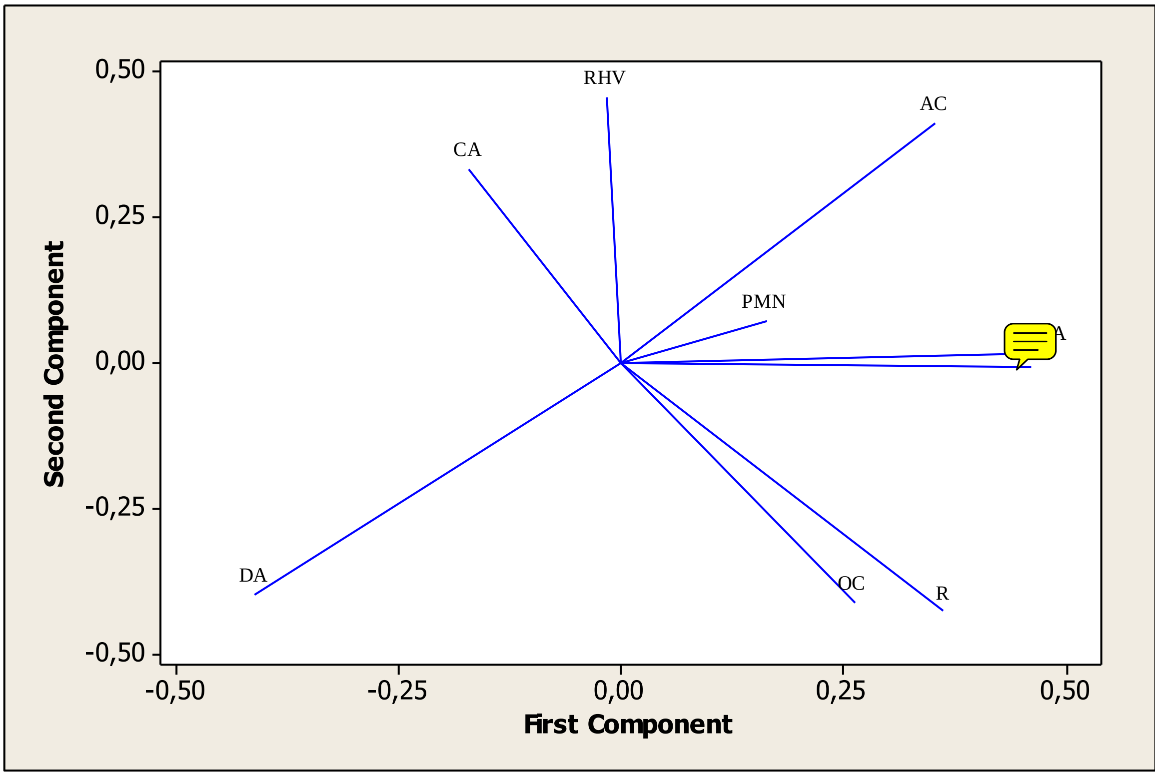
Pb, bulk density; Pk, particle density; P, porosity; FC10, field capacity (10 kPa); FC33, field capacity (33 kPa); PWP10, permanent wilting percentage; AW10, available water (10-1500 kPa); AW33, available water (33-1500 kPa); AS, Aggregate stability; PR0-20, penetration resistance (0-20 cm); PR20-40, penetration resistance (20-40 cm).

Figure 2. Loading plots for soil chemical properties on the first two principle components.



TN, total nitrogen; NH_4-N, Ammonium nitrogen; NO_3-N, nitrate nitrogen; AP; Available phosphorus.

Figure 3. Loading plots for soil biological properties on the first two principle components



OC, organic carbon; AC, active carbon; PMN, Potential mineralizable nitrogen; RHV, root health value; R, respiration; UA urease enzyme activity; CA, catalyzing enzyme activity; DA, dehydrogenase enzyme activity; MSN, mycorrhizal fungi number.