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RESEARCH PAPER

Soil quality index as affected by long-time continuous cultivation in a Mediterranean sub-humid region

Fatemeh Kafei[1] · Salar Rezapour[2] · Mohammad Reza Dalalian[3] · Elnaz Sabbaghtazeh[3] · Omid Rafieyan[4]

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Abstract

Evaluating the Soil Quality Index (SQI affected by continuous and long-term cultivation operations to identify the threat of soil destruction and its controlling is a severe challenge. The current study has investigated the effects of cultivation operations on SQI in a wide area (37,524 ha), and with various types of soil (three soil orders including Inceptisols, Mollisols, and Vertisols) and the record of several decades of wheat cultivation. After determining the total data set (TDS) and minimum data set (MDS), the SQI was calculated using Integrated Quality Index (IQI) and Nemoro Quality Index (NQI) models. The results showed that most soil indicators (e.g., electrical conductivity, sodium adsorption ratio, organic carbon, and bulk density) were negatively affected by long-term cultivation operations. Compared to the control soils, the values of IQI-T, NQI-T, IQI-M, and NQI-M had been decreased ranging from 17 to 24%, 20 to 27%, 17 to 22%, and 21 to 26%, respectively, in the cultivated soils. The most significant decrease in the average SQI value was observed in the Vertisols (24% decrease), followed by Inceptisols (21% decrease) and Mollisols (19.5% decrease). The regression equations indicated that IQI-T, NQI-T, IQI-M, and NQI-M models could explain 59%, 39%, 53%, and 35% and 57%, 37%, 51%, and 33% of changes in the biological and grain yields of wheat, respectively. The current study provides a quantitative method for evaluating the soil quality at the soil type-scale and creatively analyzes the effects of long-term and continuous cultivation operations on the soil quality and product performance.

Keywords Soil Quality Index · Agricultural soil · Soil order · Organic carbon · Soil bulk density

1 Introduction

Soil has various roles and duties in agroecosystem e.g., the ability of its production, carbon and water storage, cycling of nutrients, and filtering of water (Brady and Weil 2016). Therefore, depending on the aims when using the soil, its quality can be great importance. During the last few decades, several definitions have been provided for soil quality, which most of them have focused on the soil's ability to perform the activities (Doran and Parkin 1996). For example, Karlen et al. (1998) and de Paul Obade and Lal (2016) defined soil quality as the soil's permanent ability for performing its role as a living biological system in the ecosystem under different applications, so that it can maintain its biological fertility, while having the ability to improve water and air quality, and ensure the health of humans, animals, and plants. From the agricultural view, soil quality is its ability to produce or soil fertility. Due to the vulnerability of the agricultural soils to environmental changes and human activities, attention to

✉ Salar Rezapour
S.Rezapour@urmia.ac.ir; S_Rezapour2000@yahoo.com

✉ Mohammad Reza Dalalian
mdalalian@iaut.ac.ir

Fatemeh Kafei
f.kafei.2000@gmail.com

Elnaz Sabbaghtazeh
elnazsabbagh@iaut.ac.ir; elnaz_sabbagh@yahoo.com

Omid Rafieyan
o_rafieyan@iaut.ac.ir; o_rafieyan@yahoo.ca

[1] Department of Soil Science, Tabriz Branch, Islamic Azad University, Tabriz, Iran

[2] Soil Science Department, Urmia University, PO Box 165, Urmia 57134, Islamic Republic of Iran

[3] Department of Soil Science, Tabriz Branch, Islamic Azad University, Tabriz, Iran

[4] Department of Environmental Sciences, Tabriz Branch, Islamic Azad University, Tabriz, Iran

soil quality has a high strategic and economic importance in many countries (Wander et al. 2002; Sun et al. 2022).

Due to the vulnerability of agricultural soils from biological, environmental, and human health perspectives, providing a suitable method for measuring soil quality of cropland is essential to achieve sustainable management and predicting the risks of damage to the soil (Armenise et al. 2013; Qi et al. 2009). However, due to heterogeneity and the variety of soil changes and their consequences, selecting a suitable method for measuring soil quality still provides an immense challenge. Among various methods currently used to measure soil quality, SQI has the most significant number of applications due to its flexibility, quantitative nature, and suitability for various soils (Biswas et al. 2017), as well as its ability to combine different physical, chemical and biological characteristics of the soil. Further examples of successful use of this approach for measuring soil quality are available worldwide. Some of the most important examples included investigating the effects of deforestation (Shao et al. 2020), irrigation with wastewater (Jahnay and Rezapour 2020), soil erosion (Santos-Francés et al. 2019), land use (Choudhury and Mandal 2021), soil's nutrients (Zhang et al. 2021), morphological properties of soil (Vasu et al. 2021), and soil desertification and degradation (Kaya et al. 2022) on SQI. However, the impact of long-term and continuous cultivation of cereals on SQI have not been investigated.

Cereals (e.g., wheat) are a group of plants that produce the primary food source for the majority of the people of the world as well as are being used for feeding animals, birds, and industrial applications (Grote et al. 2021). Nodaway, more than 70% of the total 1 billion Hectares of the soil under cultivation around the world are used for the cultivation of cereals and approximately half of the needed food of humans, especially in Asia, are directly satisfied using cereals (Grote et al. 2021). This indicates the critical role of cereals, mainly wheat, in food security around the world. Therefore, protecting and maintaining the quality of soils under cereal cultivation around the world is undoubtedly essential for protecting and preserving the ecosystem and achieving sustainable management of these soils.

Previous studies have investigated the relationship between each soil characteristic (physical, chemical and biological characteristics), and the cultivation of cereals. However, there is very little information regarding the soil quality index, which provides an integrated view of different soil qualities with yield components of wheat, especially for soils in the Mediterranean climate, which covers a vast area of Asia and Europe.

The main aims of the current study were 1. Evaluating SQI for soils under constant and long-term wheat cultivation using credible models; 2. Comparing the changes in SQI for different soils under continuous and long-term wheat cultivation, and adjacent uncultivated soils, and 3. Evaluating the relationship between SQI and yield components of wheat.

2 Materials and methods

2.1 Field description of the study area

This study was conducted in the Piranshahr region (36° 30′–36° 50′ North, 45° 05′–45° 25′ East), located at Western Azerbaijan Province of Iran (Fig. 1). The total area of this region is 37524 ha and includes Piranshahr, Jaldiyan, and Pasveh areas. The altitude of the area ranged from 1300 to 1650 m above sea level. The examined soils are developed mainly on alluvial deposits with the plateau and alluvial fan landforms (a slope 3–12%) along with slight to medium erosion. The average annual temperature and rainfall of the region was 10.5 °C and 500–600 mm, respectively, resulted in a sub-humid Mediterranean type climate (Rezapour 2014). Its minimum and maximum temperature is 8.5 °C and 31.8 °C recorded in January and August, respectively. The soils of the region have high cultivation potential and have been under comprehensive cultivation operation (especially wheat) for more than six decades. Annually, a significant amount of chemical and organic fertilizers (an average of 90 kg of urea fertilizer and 50 kg of triple phosphate fertilizers per hectare) are used to maintain the agricultural yield.

2.2 Soil sampling

During field operations, based on a semi-detailed study, a total of 40 profiles were dug, evaluated, sampled, and analyzed. The soils were classified (Keys to Soil Taxonomy 2014) in three orders of Mollisols, Inceptisols, and Vertisol with a total area of 21,184, 8877.1, and 7462.9 ha, respectively. For each soil order, one profile was selected and analyzed as the control soil from adjacent rangelands (uncultivated soil). The features of the control soil include the type of materials, physiographic characteristics, slope, slope direction, and drainage were similar to the profile of the cultivated soils. Therefore, any difference between the cultivated soils and the adjacent uncultivated soils can only be due to cultivation activities and human management.

2.3 Laboratory analyses

Soil samples were air-dried and prepared to analyze the various physicochemical properties including particle

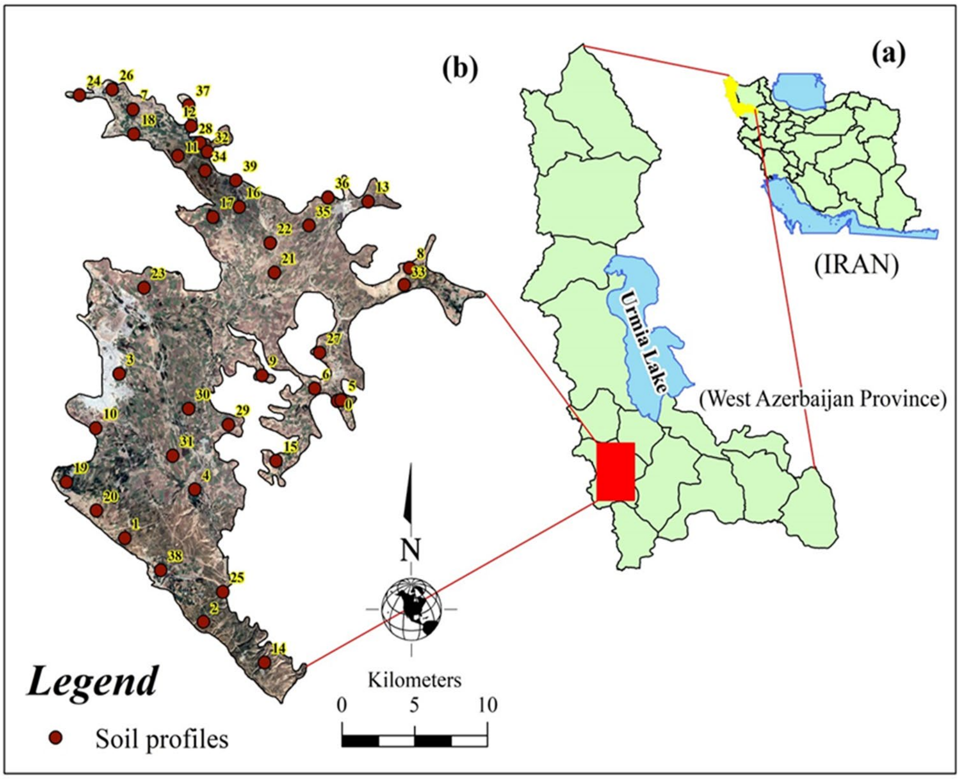

Fig. 1 Location of soil profile sites in the study region

size distribution, pH, electrical conductivity EC, organic carbon (OC), cation exchange capacity (CEC), calcium carbonate equivalent (CCE) and active carbonate calcium (ACC), total nitrogen, available P and K, soluble and exchangeable cations, available water (AW), porosity, and bulk density (BD) using standard methods (Sparks et al. 1996). Sodium absorption ratio (SAR) and exchangeable sodium percentage (ESP) were calculated using Eqs. 1 and 2, respectively (Sparks et al. 1996).

$$\mathrm{SAR} = \frac{\mathrm{Na}^{+}}{\sqrt{\frac{1}{2}(\mathrm{Ca}^{2+} + \mathrm{Mg}^{2+})}} \tag{1}$$

$$\mathrm{ESP} = \frac{\mathrm{Na}}{\mathrm{CEC}} \times 100 \tag{2}$$

2.4 Soil degradation indices

Soil Degradation Index (SDI) was calculated using the following equation:

$$\mathrm{SDI} = \frac{P_{\mathrm{c}} - P_{\mathrm{f}}}{P_{\mathrm{f}}} \times 100$$

where, P_{c} is the value of each characteristic for cultivation soils and P_{f} is the same property for adjacent uncultivated soils. This equation is used for soil characteristics that are negatively affected by cultivation activities. A negative SDI value ($< 0\%$) indicates soil degradation, with larger negative values indicating higher levels of degradation (Zhao et al. 2014).

2.5 Selected indicators and soil quality indices

A total of 18 soil characteristics which were sensitive to human management and cultivation activities (Biswas et al. 2017; Mamehpour et al. 2021) were selected as total data set (TDS). These characteristics included clay, silt, sand, pH, EC, OC, CEC, CCE, ACC, total N, available P and K, SAR, ESP, porosity, BD, and soil depth. To select the minimum data set (MDS) of the characteristics affecting soil quality, all soil parameters were investigated using the principal component analysis (PCA) method, and principal components (PC) were selected. By selecting the MDS, the number of soil characteristics decreases, and only effective and key variables remain. During PCA calculations, PCs with factor loadings of less than 1 are PCs that are not statistically significant and are therefore eliminated from the analysis. In PCs with eigenvalues higher than 1, the PC with the highest eigenvalue is selected and eigenvalues with 10% difference from the first principal component (PC1) are selected as the minimum number of components affecting soil quality. To prevent repetition, if two PCs have a correlation coefficient of higher than 0.6 with each other, the PC with the higher eigenvalues is selected. In contrast, for coefficient correlation of less than 0.6, both PCs are selected (Andrews and Carroll 2001). Since the measured characteristics have different units and scales, making their addition and multiplication impossible, all data are converted into dimensionless criteria using the standard scoring functions. Three criteria are specified in soil quality according to their functions, which include “the lower, the better", "the upper, the better", and the optimum range (Karlen et al. 1998; Andrews et al 2003). The more-is-better function is used for soil characteristics where higher values indicate higher soil quality (such as OC). In comparison, the less-is-better function is used for variables where higher values decrease the soil quality (such as BD), and optimum level function is used for soil characteristics where values higher or lower than the optimum value result in the depredation of soil quality (such as soil pH). The equations for these functions are as follows:

Function 1: standard scoring function for upper limit (more-is-better):

$$f(x) = \left\{0.9 * \frac{x - L}{U - L} + 0.1\right\},$$

$$L \leq x \leq U$$

$$x \leq L$$

$$x \geq U$$

Function 2: standard scoring function for lower limit (less-is-better):

$$f(x) = \left\{1 - 0.9 * \frac{x - L}{u - L}\right\},$$

$$x \geq L$$

$$L \leq x \leq U$$

$$x \geq U$$

Function 1: standard scoring function for optimum limit (optimum level):

$$f(x) = \begin{cases} 0.9 * \frac{x-L1}{L2-L1} + 0.1 \\ 0.9 * \frac{x-U1}{U2-U1} - 1 \end{cases}$$

$$L1 \leq x \leq L2$$

$$L2 \leq x \leq U1$$

$$L1 \leq x \leq U2$$

In these equations, x is the measured value for each characteristic, $f(x)$ is the scoring of the factors between 0.1 and 1, L is the minimum threshold, and U is the maximum threshold.

Further, the Integrated Quality Index (IQI) and Nemoro Quality Index (NQI) were calculated.Using the following equations (Doran and Parkin 1996; Qi et al. 2009):

$$\mathrm{IQI}w = \sum_{i=1}^{n} w_i N_i$$

in which W_i is the weight value, N_i is the score of each criterion, and n is the total number of criteria. The ratio of the communality value of each criteria to the sum of the communality values was considered as a weight of each soil criteria.

$$\mathrm{NQI} = \sqrt{\frac{p_{\mathrm{ave}}^2 + p_{\mathrm{min}}^2}{2}} \times \frac{n-1}{n}$$

In which P_{ave} and P_{min} are the average and minimum scores of the selected criteria.

2.6 Validation of soil quality indices

To validate the SQI, sensitivity index (SI) and correlation analysis between SQI models as well as between SQI models with wheat yield components were determined, and the best possible SQI model for the studied area was introduced. The sensitivity index was calculated as the ratio of the maximum SQI of each model to its minimum (Masto et al., 2008). Due to being more sensitive to environmental conditions and anthropogenic impacts, higher ratios of SI are preferable.

Using the SPSS 19 software package (SPSS INC., Chicago, USA), all statistical analyses were carried out. Mean comparison was performed with the independent-test (in case of two means), i.e. each soil order under cultivation was compared with control soil order.

3 Results and discussions

3.1 General qualitative characteristics of soils

Table 1 shows some of the statistical data related to the main characteristics of the studied soils. The range of particle size distribution was from 26.8 to 52.78% for clay, 10–63.2% for silt, and 13.4–50.75% for sand. These data indicated a significant change in the soil texture ranging from sandy loam to clay. Changes in the soil BD was in the range of 1.33–1.57 with the mean value of 1.42 gcm^{-3} indicated a medium class

Table 1 Some statistical characteristics of the cultivated soils

Soil variable	Unit	Max	Min	Mean	SD	CV (%)
Clay	%	52.77	26.0	37.54	7.24	19.29
Silt	%	63.2	10.04	29.66	11.36	38.29
Sand	%	50.75	13.4	32.22	12.51	38.84
pH		8.04	6.56	7.32	0.33	4.57
EC	dS m^{-1}	1.38	0.24	0.566	0.21	37.52
CCE	%	26.89	0.893	11.66	6.66	57.14
ACC	%	12.52	0.647	6.02	2.95	49.02
OC	%	1.59	0.518	0.863	0.21	23.85
CEC	cmol kg^{-1}	37.78	15.64	24.57	6.28	25.58
Total N	%	0.282	0.077	0.145	0.04	24.72
Available P	mg kg^{-1}	9.49	3.96	6.96	1.33	19.1
Available K	mg kg^{-1}	198.54	113.8	165.31	16.83	10.18
SAR		5.57	1.57	2.63	0.82	31.18
ESP	%	4.46	0.562	1.77	0.95	53.49
BD	g cm^{-3}	1.57	1.33	1.41	0.04	2.5
Porosity	%	50.5	41	43.3	0.015	3.41
AW	%	22.47	10.97	14.91	2.44	16.38

EC electrical conductivity, *CCE* calcium carbonate equivalent, *ACC* active calcium carbonate, *OC* organic carbon, *CEC* cation exchange capacity, *SAR* sodium adsorption ratio, *ESP* exchangeable sodium percentage, *BD* bulk density, *AW* available water

($1.3 < BD < 1.6$ gcm^{-3}) for bulk density in the majority of the soil samples, which is a typical class for agricultural soils with different texture classes (Hazelton and Marphy 2016; Brady and Weil 2016). The averages of pH and CCE values of the soils were 7.32 (a range of 6.56–8.04) and 11.66% (a range of 0.9–26.88%), respectively, which demonstrates that the investigated soils are mostly alkaline and calcareous. The content of soil EC with the CV of 37.5% was in the range of 0.24–1.4 dS m^{-1}, which indicates all the studied soils have low salinity. Furthermore, the mean values for SAR and ESP were 2.63 and 1.77%, respectively, which shows a lack of sodium-related problems in the soils. The mean value of 0.86, 0.145%, and 24.6 cmol kg^{-1} was observed for OC, total nitrogen and CEC of the soils, respectively, indicating a week class for OC ($0.6 < OC < 1\%$) and total N ($0.05 < N < 0.15\%$), and a medium- class for CEC ($12 < CEC < 25$ cmol kg^{-1}) (Hazelton and Marphy 2016; Wang et al. 2022). The available K of the soil had the mean value of 165.31 mg kg^{-1}, which was very high category (> 160 mg kg^{-1}; Havlin et al. 2005). In comparison, available P of the soil with the mean value of 6.96 mg/kg was weak to medium (a range of 4–7 mg kg^{-1}) (Havlin et al. 2005). Furthermore, the average values of 14.91 and 43.3% for AW and porosity were found. The majority of soil characteristics had a coefficient of variations higher than 35%, which indicates a wide range of changes in soil characteristics in the studied area (Wilding and Dress 1983) due to human management and cultivation activities (Table 1).

Soil degradation index (SDI) was calculated based on the characteristics that were sensitive to agricultural operations (e.g., clay, pH, EC, OC, CEC, total N, available P, available K, SAR, ESP, AW, BD, and porosity). The mean value of SDI the Vertisols (− 26.35) was lower (more negative) than Inceptisols (− 20.72) and Mollisols (− 17.96), indicating that long-term cultivation operations had more destructive effects on Vertisols than the other soil orders (Fig. 2). The SDI values of OC, EC, total, available P and K, SAR, ESP were lower than their mean value in each three soil orders, implying those soil indicators were exposed to the most degradation by agricultural operations. Previous studies also reported the adverse effects of natural resource changes (such as forest and pasture) to cropland on soil quality degradation using SDI, e.g., Zhao et al. (2014) and Raeisi and Beheshti (2022).

3.2 Soil Quality Index

3.2.1 Total data set

Considering the 18 soil characteristics, SQI was calculated using the IQI-TDS (IQI-T) and NQI-TDS (NQI-T) models. Among 18 soil characteristics, CCE and clay had the highest weights, and soil porosity had the lowest weight, with the weight of other features being placed in the middle (Table 2).

For the cultivated soils, IQI-T and NQI-T were in the range of 0.41–0.58 and 0.28–0.39 with a mean value of 0.5 and 0.33, respectively. These data for the uncultivated

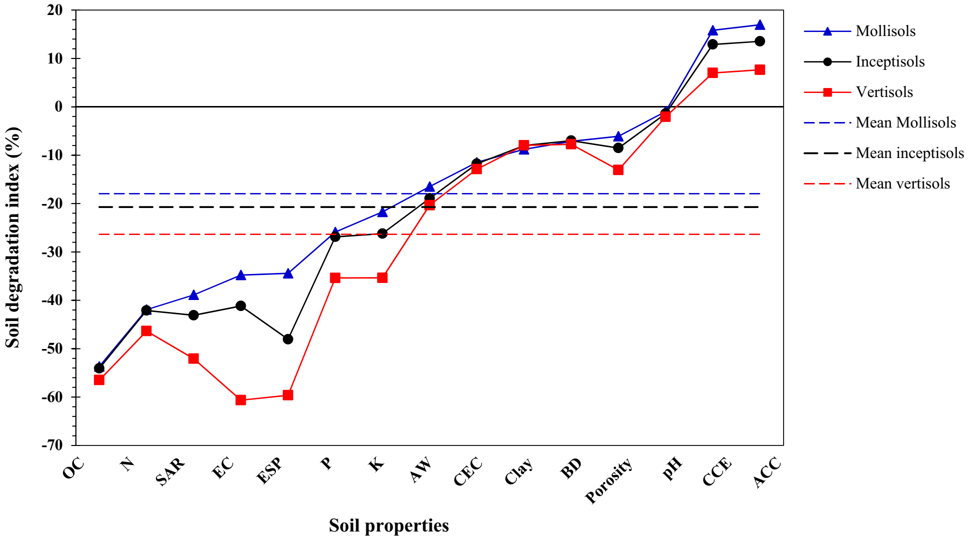

Fig. 2 Soil degradation of soil properties for different soil types

soils were from 0.56 to 0.71 with a mean of 0.66 for the IQI-T model and 0.42–0.51 with mean value of 0.4 for the NQI-T model. Comparing these results indicates that cultivation operations have resulted in a significant decrease in soil quality indices in the ranges of 17–21.3% for IQI-T and 20–27% for NQI-T (Fig. 3). Similar findings have been reported by Ji et al. (2020), Mamehpour et al. (2021), Raiesi and Beheshti (2022), and Li et al. (2022), which reported that human activities such as cultivation operations and floor irrigation, using the combination of chemical and organic compounds, and land use change could negatively affect soil quality indices. In the considerable area of the cultivated soils (Fig. 4), the SQI for both models showed a high grade II ($0.49 < \text{IQI-T} < 0.53$ and $0.32 < \text{NQI-T} < 0.34$) (Fig. 4) (Table 3). However, grade I or very high grade ($\text{IQI-T} > 0.53$ and $\text{NQI-T} > 0.34$) was observed in most adjacent uncultivated soils using both models. This indicates that cultivation operations have resulted in a drop in the SQI grade of significant area of soils by one grade compared to their adjacent uncultivated soils. The soils of grade I have very suitable and unlimited conditions for the growth of most agricultural products. In contrast, the soils of grade II offer suitable conditions with some limitations for plant growth (Qi et al. 2009).

Table 2 The communality and weight values of each soil attribute for TDS and MDS

Soil variable	TDS		MDS	
	Weight	Communality	Weight	Communality
Clay	0.067	0.903	0.222	0.55
Sand	0.065	0.875	–	–
Silt	0.055	0.742	0.101	0.609
pH	0.032	0.424	–	–
EC	0.039	0.526	–	–
CCE	0.069	0.928	0.11	0.636
ACE	0.07	0.943	–	–
OC	0.064	0.864	0.43	0.525
CEC	0.05	0.672	–	–
N	0.059	0.797	–	–
Available P	0.065	0.869	–	–
Available K	0.065	0.870	–	–
SAR	0.062	0.832	0.141	0.282
ESP	0.063	0.847	–	–
BD	0.064	0.862	–	–
Porosity	0.018	0.251	–	–
AW	0.053	0.713	–	–
Soil depth	0.038	0.509	–	–

3.2.2 Minimum data set (MDS)

To determine the MDS and key factors affecting soil quality index, PCA was carried out on the TDS. The PCA method is a common and accepted approach for determining MDS and widely used in previous studies (e.g., Andrews et al. 2004; Govaerts et al. 2006; Karlen et al. 2008; Mamehpour et al. 2021). The MDS data set has been introduced to reduce the number of indicators used in assessing SQI, resulted in reduce the process of laboratory analysis and cost (Karlen et al. 1998; Andrews et al. 2004). Table 4 shows the PCA data for all of the characteristics investigated in the current study. As can be seen, a total of 5 PCs with eigenvalue > 1, ranging from 1.33 to 5.73, explain 74.59 of total data variances. In PC1, which explains 31.74 of total data variance, the most significant weights belonged to OC, TN, AK, AP, and BD. In PC2, which described 16.56% of the total variances, the main factors included clay and sand fractions. In PC3, PC4, and PC5, which explained 10.55%, 8.11%, and 7.51% of the variances, respectively, SAR and ESP (for

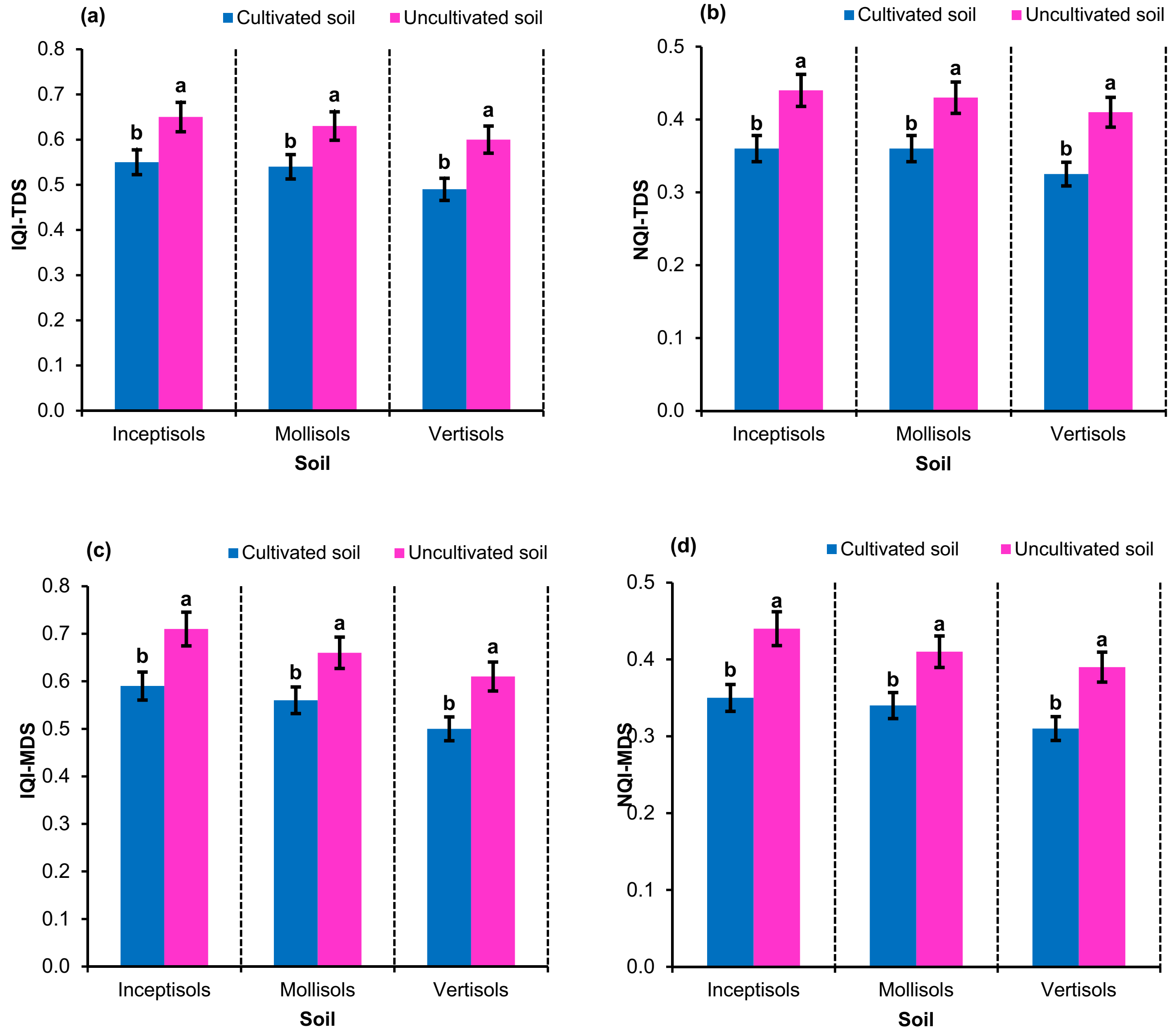

Fig. 3 The comparison of the mean values of IQI-TDS (**a**), NQI-TDS (**b**), IQI-MDS (**c**), and NQI-MDS (**d**) between cultivated and uncultivated soils in different soil types. Different letters indicate significant differences in SQI model for each soil type at $P<0.05$ confidence interval

PC3), CCE and ACC (for PC4), and silt fraction (for PC5) were significant. Considering the correlation coefficients (Fig. 5) between soil factors presented in Table 5 and their weights, five factors, including OC (PC1), clay (PC2), SAR (PC3), CCE (PC4), and silt content (PC5) were selected as MDS. These results indicate a drop from 18 soil variables associated with the TDS to five in the MDS which can result in a decrease of more than 70% in the cost and time of soil analysis using MDS.

Among the variables included in the MDS, OC has the most significant weight and contribution (43%) in the IQI determined by MDS (IQI-M), followed by clay 22.1%), SAR (14%), CCE (10.96%), and silt (10.1%). OC, clay, and SAR have a combined contribution of 80% in IQI- M, which have been widely reported as effective and sensitive factors for the development of SQI (Tian et al. 2020; Karaca et al. 2021; Zhang et al. 2021; Roy et al. 2022). These three factors have a crucial impact on the combination of soil physicochemical and biological properties, soil fertility- productivity, and yield components of crop (Brady and Weil 2016). For example, OC plays an essential role in the cycling and storage of soil nutritional elements and the development of soil structure as well as acts as the main source of food for soil heterotrophic microorganisms (Brady and Weil 2016). Likewise, SAR is subject to the degradation of soil physical properties (e.g.,

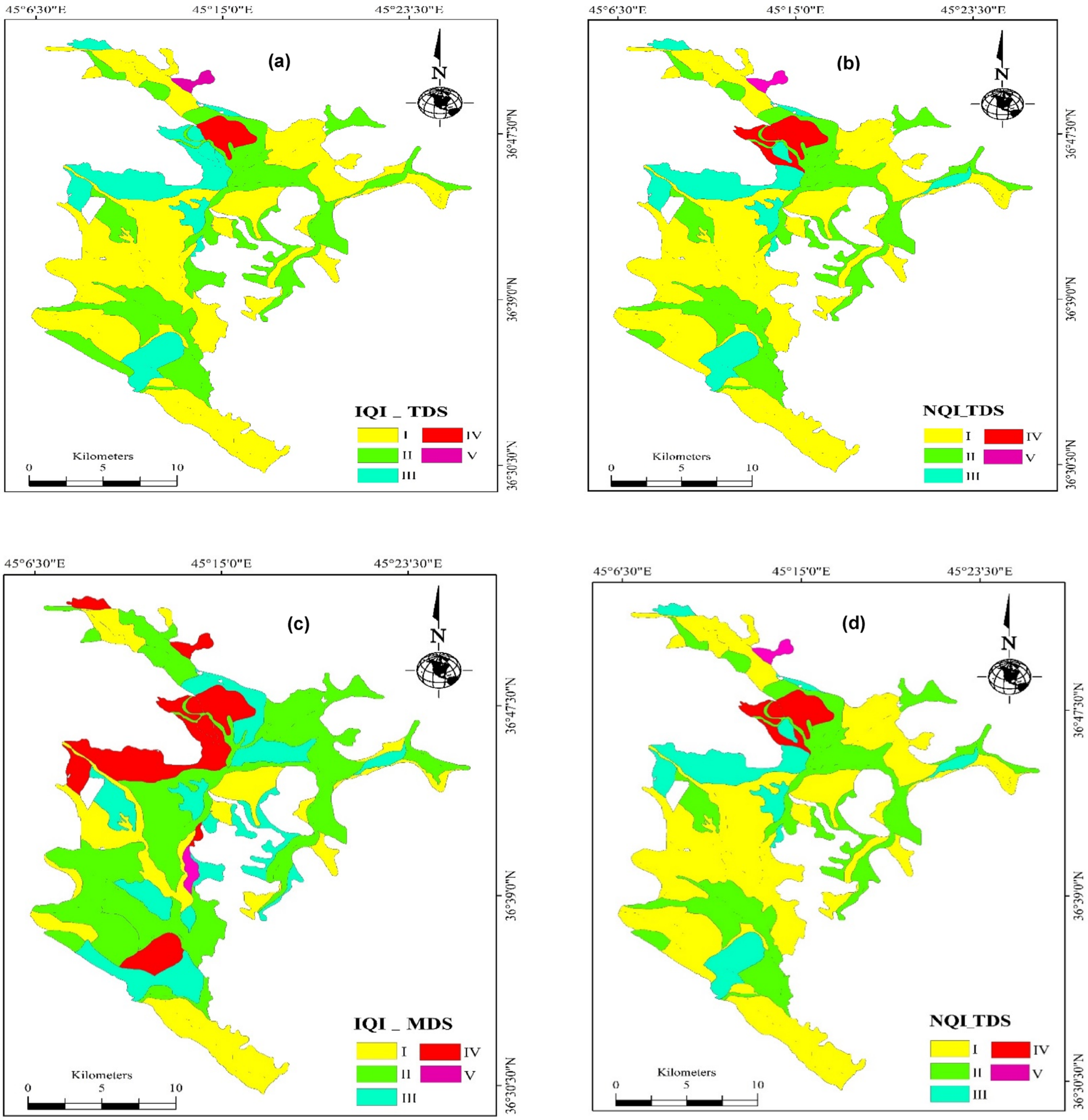

Fig. 4 Soil quality grades distribution for different SQI models in the study region

degradation of soil structure and restricted soil water–air circulation and permeability) and has an adverse effect on soil microbial population as well as root growth and, therefore, reduces the growth and performance of crop yield (Yeilagi et al. 2021; Mamehpour et al. 2021). The IQI is calculated using the following equation based on the MDS and weights for each factor:

$$\text{IQI-M} = (0.43)\ \text{OC} + (0.222)\ \text{clay} + (0.141)\ \text{SAR} + (0.11)\ \text{CCE} + (0.101)\ \text{silt}$$

Given the cultivated soils, the IQI-M values were in the range of 0.39–0.66 with a mean value of 0.55, while NQI-M values were in the range of 0.25–0.41 with the mean value of 0.33. These values for the adjacent uncultivated soils were 0.6–0.75 with a mean of 0.68 for IQI-M and 0.38–0.49 with a mean of 0.42 for NQI-M. For both cultivated and

Table 3 Categorization of soil quality grades using different methods

SQI methods	SQI grade				
	I (very high)	II (high)	III (moderate)	IV (low)	V (very low)
IQI-T	≥ 0.53	0.49–0.53	0.45–0.49	0.41–0.45	≤ 0.41
NQI-T	> 0.34	0.32–0.34	0.30–0.32	0.28–0.30	< 0.28
IQI-M	> 0.58	0.52–0.58	0.46–0.52	0.40–0.46	< 0.40
NQI-M	> 0.34	0.31–0.34	0.28–0.31	0.25–0.28	< 0.25

uncultivated soils, the most significant IQI-M and NQI-M values were observed in the Inceptisols, followed by Mollisols and Vertisol. This is similar to the behavior observed for IQI-T and NQI-T. These results indicate the importance of the effect of soil type on the SQI. Furthermore, Inceptisols and Mollisols often had the quality grade of II to I, while the majority of Vertisols showed grade III to II, which is similar to the data found by Stevenson et al. (2015) and Mamehpour et al. (2021). Such data are almost comparable to those recorded for IQI-T and NQI-T. As a result, most the cultivated soils of the region had a quality grade of II–I regarding all SQI models and provides suitable conditions for the growth and development of agricultural crops mainly cereals.

Table 4 Results of principal component analysis (PCA) of soil quality properties

PCA	PC1	PC2	PC3	PC4	PC5
Eigen value	5.73	2.98	1.9	1.46	1.35
Of variance	31.84	16.56	10.55	8.11	7.51
Cumulative variance (%)	31.84	48.41	58.97	67.1	74.59
Clay	− 0.069	**0.893**	− 0.122	0.138	0.216
Sand	− 0.028	− 0.906	− 0.044	− 0.177	0.144
Silt	0.244	0.161	0.309	0.080	**− 0.745**
pH	− 0.346	0.076	− 0.219	0.256	− 0.415
EC	0.212	0.030	0.456	0.221	0.472
CCE	− 0.191	0.078	− 0.005	**0.941**	− 0.025
ACC	− 0.144	0.111	− 0.125	0.946	0.014
OC	**0.919**	0.071	0.040	− 0.097	− 0.049
CEC	0.196	0.736	− 0.254	− 0.103	− 0.129
Total N	0.879	− 0.012	0.058	− 0.128	− 0.059
Available P	0.888	0.037	0.222	− 0.131	0.111
Available K	0.901	0.124	0.114	− 0.147	0.089
SAR	0.133	− 0.084	**0.891**	− 0.037	0.111
ESP	0.147	− 0.167	0.874	− 0.121	− 0.137
BD	− 0.902	− 0.130	− 0.134	− 0.074	− 0.087
Prosity	0.321	0.057	− 0.342	0.104	0.129
AW	0.441	0.392	0.076	0.108	0.590
Soil depth	− 0.704	0.059	0.084	0.013	− 0.046

Bold-underlined soil variables correspond to the indicators included in the MDS for soil quality investigation

Compared to the adjacent uncultivated soils, a 17–22% decrease in IQI-M and a 21–26% decrease in NQI-M was observed in the agricultural soils, resulting in a decrease in the SQI grade from grade I to grade II in most of the study soils. The most significant decrease in SQI as a result of cultivation operations (24% decrease) was observed in Vertisols, followed by Inceptisols (21% decrease) and Mollisols (19.5% decrease). Vertisols are the soils with unique characteristics (e.g., high expansion and shrinkage potential), make up 2.4% of all the soils worldwide, and found in more than 80 countries (Boul et al. 2011). These soils, when wet, sticky and plastic and, in contrast, are very hard when dried. Such a trend makes it extremely problematic to perform any tillage, cultivation, or engineering operations. (Brady and Weil 2016). Therefore, the significant decrease in the quality of these soils as a result of long-term cultivation operations is not unexpected because Vertisols are susceptible to cultivation operations, and performing advanced and scientific soil management operations are vital to prevent their degradation. Kraemar et al. (2021) from Argentina, Wang et al. (2022) from China, and Garg et al. (2022) reported that Vertisols have a high sensitivity and problematic issues to cultivation operations for soybeans, wheat, corn, and rice.

3.3 The relationship between SQI and wheat performance indicators

Linear regression analysis (Fig. 6) showed that all SQI models have a positive and significant correlation with the yield components of wheat. Therefore, any of the models can monitor the wheat performance components despite having different coefficients of variations (R^2). Several studies (e.g., Tian et al. 2020; Mendes et al. 2021; Roy et al. 2022) have also found a significant correlation between the yield components of various agricultural products and SQI with different coefficients of variations. Regression equations showed that IQI-T, NQI-T, IQI-M, and NQI-M models could explain 59%, 39%, 53%, and 35% of variations in wheat biological yield and 57%, 37%, 51%, and 33% of variations in wheat grain yield, respectively (Fig. 6), showing that the IQI scenario present a more accurate evaluation of the yield

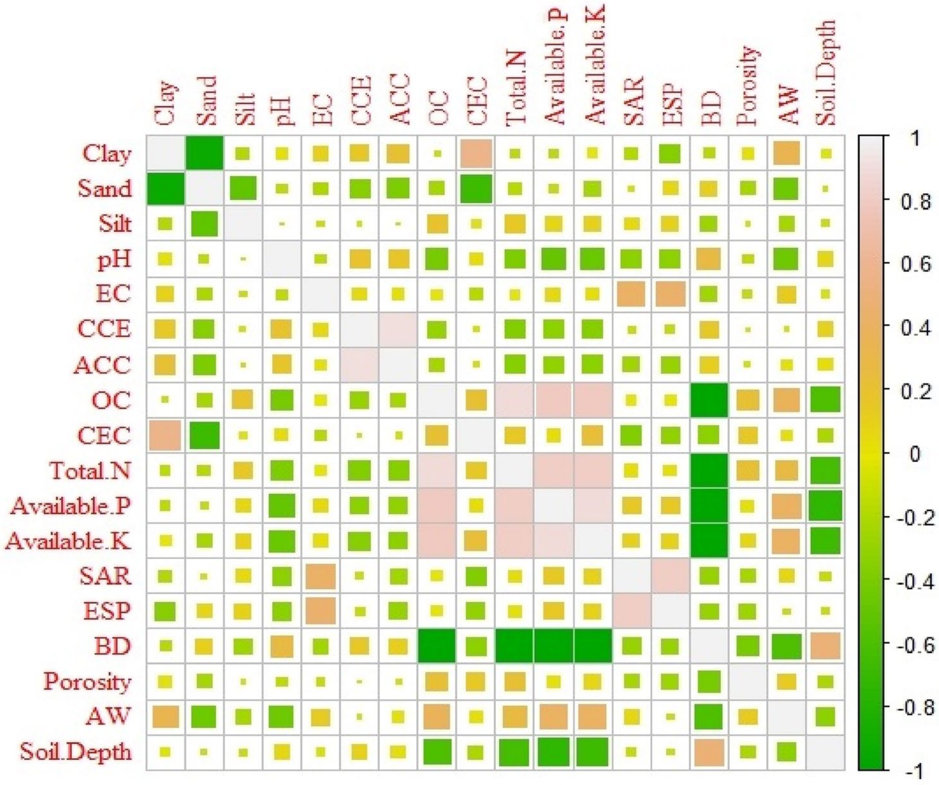

Fig. 5 Correlation matrix between the different soil variables

components of wheat than the NQI scenario. The difference between IQI and NQI models can be because of a combination of scoring and weights are used for soil properties in calculating the IQI model, while the NQI model is calculated based on the mean and values of minimum scores for soil properties (Vasu et al. 2016; Rezapour et al. 2021). Although the most significant correlation coefficient between SQI and the yield components of wheat was observed in the IQI-T model, we suggest the IQI-M model has better performance for assessing SQI compared to the other modes due to: (1) there was a positive and significant correlation between IQI-T and IQI-M models (Table 5), while the correlations between the other models were less significant and (2) the sensitivity index (SI) for the IQI-M model was the highest (1.73), followed by IQI-T (1.64), NQI-M (1.42), and NQI-T (1.39), indicating the higher sensitivity of the IQI model to soil management activities when compared to other models. The sensitivity index is a valuable and helpful tool that can be used to distinguish the differences between different models of soil quality assessment, as shown in previous studies (Yeilagi et al. 2021; Mamehpour et al. 2021). The studies conducted by Santos-Francés et al (2019) and Zhou et al (2020) on cropland in Spain and China, respectively, highlighted the performance of the IQI-MDS method for predicting SQI using the SI analysis. Furthermore, evaluating soil quality using the IQI-M model can result in a significant decrease in the number of soil factors measured in the lab for SQI determination, resulting in a considerable reduction in analysis time and cost. Therefore, the correlation coefficients between different SQI, SI, time and money savings, and regression coefficient between SQI and the yield components of wheat confirmed that IQI-M model was an effective tool and good criterion for evaluating changes in land use as well as the effect of different soil management systems on soil quality.

Table 5 Correlation coefficients between four SQI models

	IQI-T	IQI-M	NQI-T	NQI-M
IQI-T	1			
IQI-M	0.91**	1		
NQI-T	0.81**	0.71**	1	
NQI-M	0.72**	0.90**	0.68*	1

4 Conclusion

In the current study, the SQI of cropland with a cultivation history of more than six decades was investigated using four SQI models (IQI-T, IQI-M, NQI-T, and NQI-M). Among 18 soil variables, five variables including OC, clay, SAR, CCE, and silt were selected as MDS based on the ANOVA and PCA results. Compared to the uncultivated

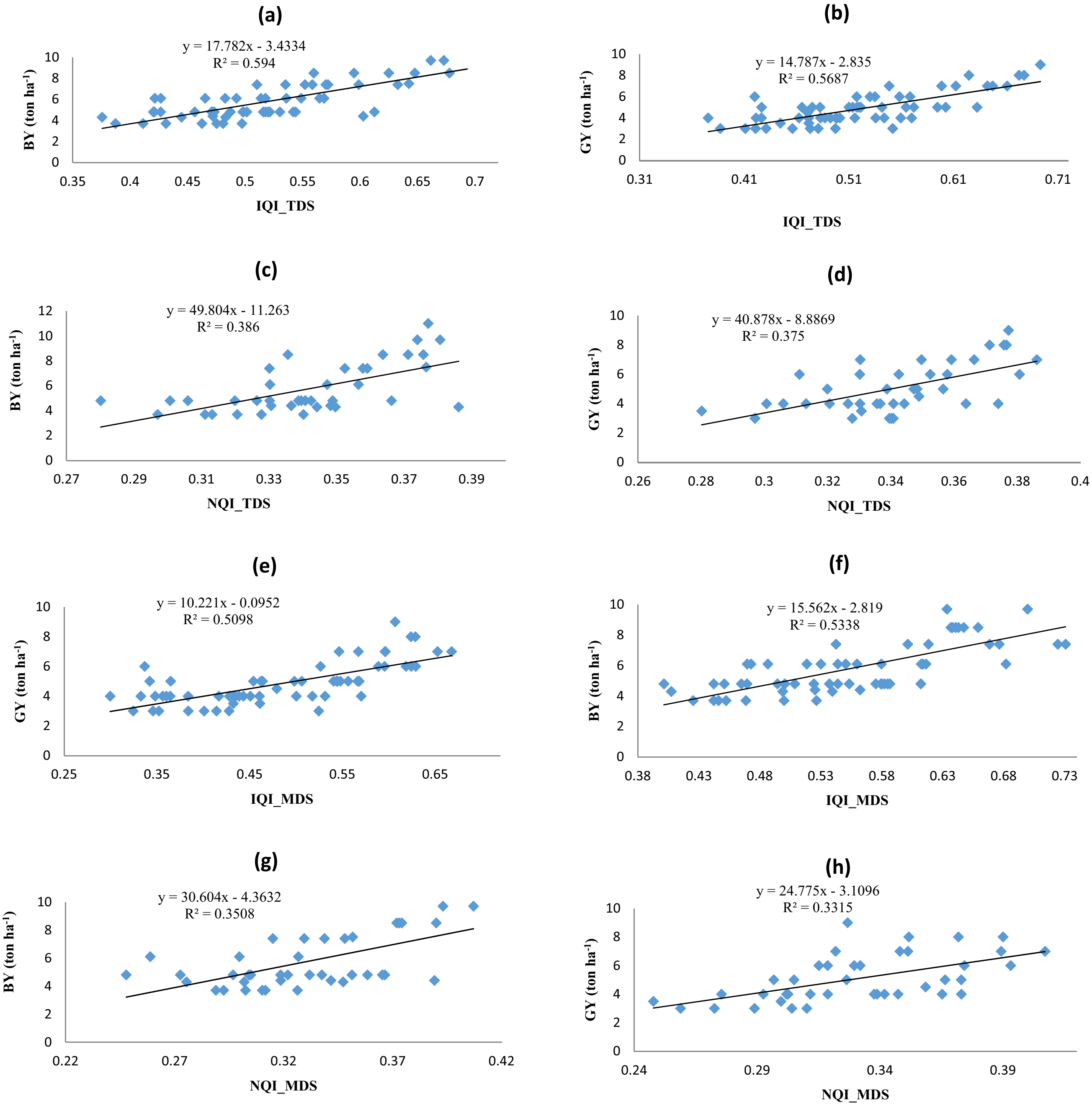

Fig. 6 The biological yield (BY) and grain yield (GY) of wheat versus different SQI models

soils, a 17% to 27% decrease in soil quality was observed in the cultivated soils. The most significant reduction in SQI was observed in Vertisols, indicating its high sensitivity to agricultural and management operations compared to other soil types. All SQI models used in the current study showed a significant correlation (with a correlation coefficient in the range of 0.33–0.59) with the yield components of wheat. Although the IQI-TDS was established as the most accurate model for soil quality assessment in the study region, IQI-M could be a good alternative as it adequately performed the TDS method; in addition to its reliability and economic feasibility. This soil quality model can help local smallholder farmers to be aware of the potential for low soil quality in future following current conventional farming systems and to consider suitable agricultural management operations for maintaining soil quality in highly intensive agroecosystems. Nevertheless, a potential limitation of this soil quality model is that it might be specific to the soil and location. Another potential limitation of this study is that the soil biological indicators were not considered and can be an interesting subject of study in the future. Hence, its application with additional studies in the other ecosystems and soil orders can be further recommended to provide a more accurate test. The SQI assessment would have important implications for resource management and can be of particular importance for soil owners and policy makers to assess the sustainability of management practices after long-term continuous cultivation.

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Data availability The datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request.

Declarations

Conflict of interest The authors declare that they have no competing interests.

References

Andrews SS, Flora CB, Mitchell JP, Karlen DL (2003) Growers' perceptions and acceptance of soil quality indices. 114(3–4):187–213

Andrews SS, Karlen DL, Cambardella CA (2004) The soil management assessment framework: a quantitative soil quality evaluation method

Armenise E, Redmile-Gordon MA, Stellacci AM, Ciccarese A, Rubino P (2013) 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

Biswas S, Hazra GC, Purakayastha TJ, Saha N, Mitran T, Roy SS, Mandal B (2017) Establishment of critical limits of indicators and indices of soil quality in rice-rice cropping systems under different soil orders. Geoderma 292:34–48

Brady NC, Weil RR (2016) The nature and properties of soils. Pearson JM, Rezapour S (2020) Assessment of the quality indices of soils irrigated with treated wastewater in a calcareous semi-arid environment. Ecol Indic 109:105800

Buol SW, Southard RJ, Graham RC, McDaniel PA (2011) Soil genesis and classification. Wiley, New York

Choudhury BU, Mandal S (2021) Indexing soil properties through constructing minimum datasets for soil quality assessment of surface and profile soils of Intermontane valley (Barak, North East India). Ecol Ind 123:107369

de Paul Obade V, Lal R (2016) Towards a standard technique for soil quality assessment. Geoderma 265:96–102

Doran JW, Parkin TB (1996) Quantitative indicators of soil quality: a minimum data set. Soil Sci Soc Am 49:25–37

Govaerts B, Sayre KD, Deckers J (2006) 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

Havlin JL, Beaton JD, Tisdal SL, Nelson WL (2005) Soil fertility and fertilizers an introduction to nutrient management, 7th edn

Hazelton P, Murphy B (2016) Interpreting soil test results: what do all the numbers mean? CSIRO Publishing

Jahany M, Rezapour S (2020) Assessment of the quality indices of soils irrigated with treated wastewater in a calcareous semi-arid environment. Ecol Indic 109:105800

Ji L, Ni K, Wu Z, Zhang J, Yi X, Yang X, Ruan J (2020) Effect of organic substitution rates on soil quality and fungal community composition in a tea plantation with long-term fertilization. Biol Fertil Soils 1–14

Karaca S, Dengiz O, Turan İD, Özkan B, Dedeoğlu M, Gülser F, Ay A (2021) An assessment of pasture soils quality based on multi-indicator weighting approaches in semi-arid ecosystem. Ecol Indic 121:107001

Karlen DL, Gardner JC, Rosek MJ (1998) A soil quality framework for evaluating the impact of CRP. J Prod Agric 11(1):56–60

Karlen DL, Andrews SS, Wienhold BJ, Zobeck TM (2008) Soil quality assessment: past, present and future

Kaya NS, Özkan B, Dengiz O, Turan İD (2022) Digital mapping and spatial variability of soil quality ındex for desertification in the Akarçay Basin under the semi-arid terrestrial ecosystem using neutrosophic fuzzy-AHP approach. Nat Hazards 1–32

Li S, Wang C, Cai M, Yang F, Liu Y, Chen J, Chen X (2022) Facile fabrication of TaON/Bi_2MoO_6 core–shell S-scheme heterojunction nanofibers for boosting visible-light catalytic levofloxacin degradation and Cr (VI) reduction. Chem Eng J 428:131158

Mamehpour N, Rezapour S, Ghaemian N (2021) Quantitative assessment of soil quality indices for urban croplands in a calcareous. Geoderma 382:114781

Mendes IC, Sousa DMG, Dantas OD, Lopes AAC, Junior FBR, Oliveira MI, Chaer GM (2021) Soil quality and grain yield: a win–win combination in clayey tropical oxisols. Geoderma 388:114880

Qi Y, Darilek JL, Huang B, Zhao Y, Sun W, Gu Z (2009) Evaluating soil quality indices in an agricultural region of Jiangsu Province. China Geoderma 149(3–4):325–334

Raiesi F, Beheshti A (2022) Evaluating forest soil quality after deforestation and loss of ecosystem services using network analysis and factor analysis techniques. CATENA 208:105778

Rezapour S (2014) Response of some soil attributes to different land use types in calcareous soils with Mediterranean type climate in north-west of Iran. Environ Earth Sci 71(5):2199–2210

Rezapour S, Nouri A, Jalil HM, Hawkins SA, Lukas SB (2021) Influence of treated wastewater irrigation on soil nutritional-chemical attributes using Soil Quality Index. Sustainability 13(4):1952

Roy D, Datta A, Jat HS, Choudhary M, Sharma PC, Singh PK, Jat ML (2022) Impact of long term conservation agriculture on soil quality under cereal based systems of North West India. Geoderma 405:115391

Santos-Francés F, Martínez-Graña A, Ávila-Zarza C, Criado M, Sánchez Y (2019) Comparison of methods for evaluating soil quality of semiarid ecosystem and evaluation of the effects of physico-chemical properties and factor soil erodibility (Northern Plateau, Spain). Geoderma 354:113872

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

Sparks DL, Helmke PA, Page AL (1996) Methods of soil analysis: chemical methods (no. 631.417/S736 V.3)

Stevenson BA, McNeill S, Hewitt AE (2015) Characterising soil quality clusters in relation to land use and soil order in New Zealand: an application of the phenoform concept. Geoderma 239:135–142

Sun J, Zhao X, Fang Y, Gao F, Wu C, Xia J (2022) Effects of water and salt for groundwater-soil systems on root growth and architecture of Tamarix chinensis in the Yellow River Delta, China. J For Res 1–12

Tian K, Zhang B, Zhang H, Huang B, Darilek JL, Zhao Y, Yang J (2020) Evaluation of soil quality in major grain-producing region of the North China Plain: integrating minimum data set and established critical limits. Ecol Indic 117:106613

Vasu D, Singh SK, Ray SK, Duraisami VP, Tiwary P, Chandran P, Anantwar SG (2016) Soil quality index (SQI) as a tool to evaluate crop productivity in semi-arid Deccan plateau, India. Geoderma 282:70–79

Vasu D, Tiwari G, Sahoo S, Dash B, Jangir A, Sharma RP, Naitam R, Tiwary P, Karthikeyan K, Chandran P (2021) A minimum data set of soil morphological properties for quantifying soil quality in coastal agroecosystems. CATENA 198:105042

Wander MM, Walter GL, Nissen TM, Bollero GA, Andrews SS, Cavanaugh-Grant DA (2002) Soil quality: science and process. Agron J 94(1):23–32

Wang J, Delang CO, Hou G, Gao L, Yang X, Lu X (2022) Carbon sequestration in biomass and soil following reforestation: a case study of the Yangtze River Basin. J For Res 1–28

Wilding LP, Dress LR (1983) Application of geostatistics to spatial studies of soil. Advances in agronomy. Trangmar BB, Yost RS, Uehara G (eds), vol 38

Yeilagi S, Rezapour S, Asadzadeh F (2021) Degradation of soil quality by the waste leachate in a Mediterranean semi-arid ecosystem. Sci Rep 11(1):1–12

Zhang Y, Chen Z, Wang X, Huang B (2021) Comprehensive assessments of soil fertility and environmental quality in plastic greenhouse production systems. Geoderma 385:114899

Zhao HL, Li J, Liu RT, Zhou RL, Qu H, Pan CC (2014) Effects of desertification on temporal and spatial distribution of soil macro-arthropods in Horqin sandy grassland, Inner Mongolia. Geoderma 223:62–67

Zhou M, Xiao Y, Li Y, Zhang X, Wang G, Jin J, Ding G, Liu X (2020). Soil quality index evaluation model in responses to six-year fertilization practices in Mollisols. Arch Agron Soil Sci 1–15