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Soil Quality Assessments in Some Iranian Saffron Fields

A. Ranjbar[1], H. Emami[1*], R. Khorassani[1], and A. R. Karimi Karouyeh[1]

ABSTRACT

Little information is available about Soil Quality (SQ) in Iran, especially in saffron [*Crocus sativus* (L.) *Iridaceae*] fields. The objectives of this research were to: (i) Establish a Minimum Data Set (MDS) for quantifying soil quality in saffron fields; (ii) Evaluate soil quality status using two indices of Integrated Quality Index (IQI) and Nemoro Quality Index (NQI), and (iii) Investigate the relationship between soil quality and the economics of saffron production. Thirty soil samples were collected from the Ghayen area of South Khorasan, Iran, and analyzed for soil physical and chemical properties. Principal Component Analysis (PCA) was used to identify a Minimum Data Set (MDS) consisting of sand, Relative Field Capacity (RFC), zinc, *SAR*, Ca, $CaCO_3$, Fe and Bulk Density (BD). Soil Quality was evaluated using the *IQI* and the *NQI* for both the Total Data Set (TDS), and *MDS*. Four SQ indices i.e., IQI_{TDS}, IQI_{MDS}, NQI_{TDS}, and NQI_{MDS} were used to evaluate soil quality in saffron fields in the study area. A significant correlation ($P< 0.05$) was shown between the IQI_{TDS} ($r= 0.44$), NQI_{TDS} ($r= 0.41$) and economic yield of saffron. Correlation analysis indicated that the IQI_{TDS} performed better compared to the NQI_{TDS} for evaluating the soil quality. Use of the *TDS* with the *IQI* index was the most effective approach for evaluating SQ in saffron fields.

Keywords: Economic yield, Integrated quality index, Minimum data set, Nemoro quality index.

INTRODUCTION

One of the most useful parameters for guiding sustainable land use management and achieving maximum yield in developing countries is soil quality (Mc Grath and Zhang, 2003). During the last decades, there is growing awareness that in addition to producing food and fiber, maintenance of environmental quality is also an important soil function (Glanz, 1995). As Bhardwaj *et al.* (2011) reported, an ideal evaluation of soil quality should involve three components i.e., physical, chemical, and biological properties and/or processes. Results of several research studies have shown that when soil quality indicators are within the "ideal" or "optimum" range, crop production is maximized. In addition, soil and environmental degradation are minimized (Reynolds *et al.*, 2009; Dexter, 2004). Within the framework of agricultural production, high soil quality should maintain high productivity without significantly degrading the soil or environment (Govaerts *et al.*, 2006; Griffiths *et al.*, 2010). Few of researchers have related soil quality with crop yields (Hanse *et al.*, 2011; Van Eekeren *et al.*, 2010).

Understanding and assessing soil quality have been identified as two important goals for modern soil science, which can play an important role in maintaining or improving soil quality and crop production (Wang and Gong, 1998). To evaluate soil quality properly, its indicators should be selected according to the soil functions (Nortcliff, 2002). In order to identify and determine an *MDS*, factor analysis is commonly used because of its ability to group related soil properties into a small set of independent factors and to reduce the original data set (Yao *et al.*, 2013). A *MDS* set with suitable indicators not only reduces the need

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[1] Department of Soil Science, Faculty of Agriculture, Ferdowsi University of Mashhad, Islamic Republic of Iran.
[*] Corresponding author; email: hemami@um.ac.ir

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for determining a large number of indicators (Andrews *et al*., 2004), but also can adequately represent the total data set (Qi *et al*., 2009; Lima *et al*., 2013). The Integrated Quality Index (IQI) has been commonly used and considered as a good method for developing a meaningful Soil Quality Index (SQI) (Doran and Parkin, 1994; Andrews *et al*., 2002; Li *et al*., 2013).

Comprehensive evaluation of agricultural soil quality, which refers to the condition and capacity of farmland including its soil, weather, and biological properties, for purposes of production, conservation, and environmental management (Pieri *et al*., 1995; Stamatiadis *et al*., 1999), is essential to making wise decisions that will improve crop production and environmental sustainability. Unfortunately, one of the most limiting aspects of this evaluation is the lack of a universally acceptable method for developing soil quality indices.

Development of a universal soil quality index should follow a logical path: (1) Establish a representative indicator method; (2) Assign weights for selected indicators, and (3) Validate the index using a model. Indices formulated based on ecological principles and properly validated ones will better communicate the complexity of quality integrity. Indicators should be a combination of chemical, physical, and biological properties (Herrick *et al*., 2002; Aparicio and Costa, 2007). Several authors have proposed sets of soil quality indicators (Doran and Parkin, 1994; Karlen *et al*., 1998, Emami *et al*., 2012), and have evaluated soil quality based on the Total Data Set (TDS) that they selected. Also, representative indicators were suggested by many authors, such as the Minimum Data Set (MDS), selected according to correlation between indicators and ease of measurement (Andrews *et al*., 2002; Rezaei *et al*., 2006; Govaerts *et al*., 2006).

With the advent of precision farming, the need for understanding the relationship among spatial variability of soil properties and crop yields is getting increasingly important because of growing concern about the higher productivity of soils and more efficient application of agricultural inputs. Soil indicators provide valuable tools for us to quantify the degree of quality (Topp *et al*., 1997). The importance of soil physical quality for plant growth, as well as chemical and biological conditions of the soil has been emphasized by many researchers (Allmaras *et al*., 2003; Drury *et al*., 2003). Soil chemical and physical properties can have effect on yield and quality of crops. Some physical properties that have important role on yield are Bulk Density (BD), Mean Weight Diameter (MWD), soil and plant Available Water Contents (AWC) (Emami and Astaraei, 2012). Soil compaction, total porosity, and bulk density have been also documented as varying significantly within single fields, which have influence on the spatial distribution of crop productivity potential (Emami *et al*., 2012; Emami *et al.* 2014). The amount of soil organic matter and organic carbon in Iran is very low in many agricultural lands (Kalbasi, 1996). More than 60% of agricultural lands have less than one percent organic matter, and a significant portion of which have less than half a percent.

Saffron, one of the most costly plant products and most expensive spice, has been grown extensively in the Near East and the Mediterranean basin since the Late Bronze Age. It is produced by drying the long orange-red stigmas of the saffron crocus, an autumn-flowering geophyte (Rees, 1988; Zohary and Hopf, 1994). Saffron is currently being cultivated in Iran, Marocco, Spain, India, Pakistan, Turkey, Italy, Switzerland, and Greece. While the world's total annual saffron production is estimated at 205 tons per year, Iran with more than 47,000 ha of land under saffron cultivation, is said to produce 80% of this total (Ehsanzadeh *et al*., 2004). Khorasan Province alone accounts for 46,000 ha and 137 tons per year of this valuable spice.

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Table1. Measurement methods for soil indicators selected for the study.

Indicator	Method	Average	Range (CV%) [p]	Reference
BD [a] (g cm^{-3})	Paraffin Method	1.57	1.3-1.9 (9)	Gee and Bauder (1986)
AN [b] (%)	Kjeldahl	0.11	0.05-0.23 (33)	Bremner and Mulvaney (1982)
AP [c](mg kg^{-1})	Sodium bicarbonate extraction, colorimetric detection	65.5	14.1-228.2(76)	Olsen and Sommers (1982)
AK [d](mg kg^{-1})	Ammonium acetate extraction, flame photometer detection	0.04	139-1306(53)	Lu (2000)
AZn [e] (mg kg^{-1})	DTPA-TEA	0.57	0.33-1.4 (42)	Linsay and Norvel (1978)
Amn [f](mg kg^{-1})	DTPA-TEA	5.32	0.74-14.96 (57)	Linsay and Norvel (1978)
AFe [g] (mg kg^{-1})	DTPA-TEA	2.95	1-15.39 (90)	Linsay and Norvel (1978)
ACu [h](mg kg^{-1})	DTPA-TEA	0.9	0.47-1.57 (26)	Linsay and Norvel (1978)
pH	Saturation mud	7.8	7.41-8.26 (3)	Page *et al.* (1982)
EC (dS m−1)	Saturation extract	3.07	1.12-8.04 (61)	Page *et al.* (1982)
OC [i](%)	Walkley, A. and Black, I. A.	1.2	0.76-2.42 (29)	Walkley and Black (1934)
Sand (%)	Hydrometery	43.13	31.86-62.2 (17)	Gee and Bauder (1986)
Silt (%)	Hydrometery	37.37	24.64-46.85 (16)	Gee and Bauder (1986)
Clay (%)	Hydrometery	19.48	13.01-25.35 (16)	Gee and Bauder (1986)
MWD [j] (mm)	Wet sieve	0.51	0.21-1.26 (60)	Kemper and Rosenau (1986)
SAR [k]	Na/(Ca+Mg)1/2	6.33	1-14.49 (58)	Page *et al.* (1982)
RFC [l]	θ_{FC}/θ_S	0.55	0.42-0.6 (6)	Reynolds *et al.* (2009)
ECCa [m] (mg kg^{-1})	Titration with EDTA	295.8	80-660 (45)	
ECC[n] %$CaCO_3$	Titration NaOH	22.92	19.94-26.44 (8)	Page *et al.* (1982)
AWC	Pressure plate	0.125	0.1-0.15 (9)	Reynolds *et al.* (2009)

[a] Bulk Density , [b] Available N, [c] Available P, [d] Available K, [e] Available Zn, [f] Available Mn, [g]Available Fe, [h] Available Cu, [i] Organic Carbon, [j] Mean weight diameter, [k] Sodium Adsorption Ratio, [l] Relative Field Capacity, [m] Equivalent calcium Ca, [n] Equivalent calcium carbonate, [o] Available Water Capacity, [p] Coefficient of Variation.

Economic yield of saffron flowers is usually based on the amount of saffron flower weight or weight of dry saffron harvested per unit area. Saffron includes the dried stigma and cream, so in some cases production is based on the weight of both components per unit area (Kafi *et al.*, 2002).This study aimed to determine the relationship between soil quality indicators and economic yield of saffron, due to the economic importance and nutritional value of the crop as well as the lack of scientific data on optimal soil quality for its growth and development.

MATERIALS AND METHODS

Study Area

Since Ghayen region is known all over the world for the saffron quality, it was chosen as an area of our study. This area is located between (59° 10′ 10"- 59° 11′ 38" E, 33° 43′ 35"- 33° 44′ 02" N). According to the climate data for 2011–2012, the mean annual temperature was 14.5°C and mean annual precipitation was103 mm.

Soil Sampling and Analysis

Thirty saffron fields with essentially the same management practices were chosen as sampling sites and 30 soil samples were collected from each field. Soil samples were collected randomly from the 0–25 cm (plow layer) in each field. Samples were air-dried and passed through a 2 mm sieve before measuring the chemical and physical properties. The analytical method for each indicator is presented in Table1. Soil samples were collected at the beginning of the reproductive stage in five to six years old plants, at the end of August in 2012. The daily economic yield (weight of flower) of saffron in studied farms (kg ha^{-1}) during a 10-day period was recorded.

Evaluation of Soil Quality

Indicator Scoring

To combine the indicators into a general index, they were scored to create unitless/dimensionless numbers. Fuzzy membership functions were used for each indicator (Torbert *et al*., 2008; Qi *et al*., 2009). Scoring functions were developed for the individual indicators, following work by Andrews *et al*. (2004). Each indicator is assigned a score between 0 and 1. Optimum values of indicators are obtained when their scores reach the highest values (Qi *et al*., 2009). For all indicators, scoring functions were developed separately based on data distributions.

We used the following values to set the threshold for rating soil health indicators: (i) 0-30 corresponds to deficiency of an indicator; (ii) > 30-< 70 corresponds to the intermediate region of the indicator, and (iii) 70–100 indicates that the indicator value is at an optimal level. Scoring curves for soil quality assessment generally follow three types of functions which are:

More is better: In this situation, the higher value of the indicator, the higher score until a maximum level is attained. Indicators falling in this class include *MWD, AWC*, N, OC, and K.

Less is better: The scoring curve in this case gives higher scores to lower values of the indicator. Soil measurements in this group include BD, EC, and SAR.

c. Optimum curve: In this case, the curve rises to the highest level with increasing indicator values and remains stationary at the maximum score. As the indicator value increases, the scores start decreasing. Indicators that were scored this way are pH, *RFC*, Zn, Mn, Fe, Cu, and P.

Selecting the Indicators

Representative indicators are crucial for soil quality evaluation. The important aspect is that they should cover a wide range of characteristics that reflect soil quality (Wang and Gong, 1998). The Total Data Set (TDS) consisted of 20 soil physical and chemical properties that included sand, silt, clay, *BD*, Ca, *MWD*, *SAR*, *EC*, pH, OC, N, P, K, micro elements (Cu, Fe, Mn, Zn), $CaCO_3$, *RFC* and *AWC* (Table 1). It is common knowledge that farm management practices, such as fertilization, irrigation, and crop residue incorporation affect soil quality (Huang *et al*., 2006), especially in intensive production systems. Fertilization and crop residue incorporation can be represented by soil fertility (N, P, K), micro nutrients (Cu, Zn, B, Mn), and soil organic carbon (OC).

Selection of the Minimum Data Set

In the *TDS* indicator method, 20 soil physical and chemical properties were included (Table 1). To select a representative Minimum Data Set (MDS), the Principle Component Analysis (PCA) method was used to reduce the number of required indicator

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measurements (Doran and Parkin, 1994) Table 3. The PCA method was employed as a data reduction tool to select the most appropriate indicators from the list of indicators in studied area. Based on the *MDS* selection procedure described by Andrews *et al*. (2002) and Govaerts *et al*. (2006), only the PCs with eigenvalues ≥1 were considered for the *MDS*. Within each PC, highly weighted indicators were defined as those with absolute values within 10% of the highest weighted loading. When more than one variable was retained in a PC, each was considered important and was retained in the *MDS* if they were not correlated (r< 0.60) (Andrews *et al*., 2002). Among well-correlated variables within a PC, the variable having the highest correlation sum was selected for the MDS (Andrews and Carroll, 2001).

Weight Assignment

In this research, weights of *TDS* and *MDS* indicators, which were used for determination of *IQI* index, were assigned by communality of each indicator (Table 2), which were calculated by mathematical statistics of standardized Factor Analysis (FA) (Sun *et al*., 2003; Shukla *et al*., 2006). The ratio of indicator communality to accumulative communality of total indicators for individual *TDS* and *MDS* were considered as weight of each indicator (Qi *et al*., 2009). The communality and factor analysis of each indicator were calculated by Jump8 software.

Calculation of Soil Quality Index

After indicators were scored and weighted, soil quality indices were calculated using the Integrated Quality Index equation [IQI, Equation (1)] (Doran and Parkin, 1994) and the Nemoro Quality Index equation [NQI, Equation (2)] (Han and Wu, 1994), using every possible combination of index and indicator method.

$$IQI = \sum_{i=1}^{n} W_i N_i \qquad (1)$$

Where, *Wi* is the assigned weight of each indicator, *Ni* is the indicator score, and *n* is the number of indicators.

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

Where, P_{ave} is the average scores of the selected indicators in each site, P_{min} is the minimum scores of the selected indicators in each site, and *n* is the number of indicators.

IQI and *NQI* indices were calculated using both *TDS* and *MDS*. Therefore, for each soil sample four indices, *i.e.*, IQI_{TDS}, IQI_{MDS}, NQI_{TDS} and NQI_{MDS}, were obtained. In order to determine the *MDS* efficiency as representative of *TDS*, the correlations between IQI_{TDS} and IQI_{MDS} and between NQI_{TDS} and NQI_{MDS} were studied. Statistical analyses for the correlation between indices were conducted by JMP8 software.

RESULTS AND DISCUSSION

Selection of the Minimum Data Set

The *TDS* was divided into six PCs with Eigen values≥ 1. This process explained 80% of the variation among soil indicators (Table 3).The first PC had two highly weighted variables and explained 25% of the variation (Table 3). The two indicators (sand and RFC) were highly correlated with each other (Table 4). Sand was retained in the *MDS* due to its higher factor loading. *RFC* was also included even though it was highly correlated with sand. For PC2, PC4 and PC6 there was only one variable with a high loading factor (Zn, Ca and bulk density, respectively). Each was retained in the *MDS*. For PC5, there were two highly weighted variables (Fe and $CaCO_3$). Both were retained in the *MDS* because of their importance for saffron growth.The third PC had also three highly weighted variables and explained 13% of the variation. The three indicators (EC, SAR and P) showed a high correlation between *EC* and *SAR* (Table 4), therefore, they were selected. We selected *SAR* to represent the PC3 because of its high

Table 2. Estimated communality and weight value of each soil quality indicator in TDS and MDS indicator methods.

Indicators	TDS		MDS	
	COM	Weight	COM	Weight
pH	0.419	0.047		
EC[a]	0.344	0.039		
Ca	0.146	0.017	0.157	0.039
SAR[b]	0.324	0.037	0.396	0.098
Fe	0.126	0.014	0.241	0.060
Cu	0.501	0.057		
Zn	0.690	0.078	0.675	0.168
Mn	0.562	0.064		
%OC	0.654	0.074		
%N	0.533	0.063		
%P	0.278	0.031		
%K	0.330	0.037		
%CaCO3	0.396	0.045	0.750	0.186
BD[c]	0.013	0.002	0.066	0.016
MWD[d]	0.051	0.006		
AWC[e]	0.435	0.049		
%Clay	0.484	0.055		
%Sand	0.935	0.106	0.850	0.211
%Silt	0.741	0.084		
RFC[f]	0.854	0.097	0.895	0.222

[a] Electrical Conductivity, [b] Sodium Absorption Ratio, [c] Bulk Density, [d] Mean Weight diameter of Aggregates, [e] Available water Content, [f] Relative Field Capacity.

Table 3. Results of Principal Component Analysis (PCA) of soil quality indicators.

PCs[a]	PC1	PC2	PC3	PC4	PC5	PC6
Eigen value	5.055	3.782	2.634	2.070	1.303	1.128
Percent	25.274	18.911	13.169	10.349	6.515	5.642
Cumulative percent	25.274	44.185	57.354	67.702	74.218	79.86
Eigen vectors						
pH	0.02132	-0.33178	0.18374	0.31764	0.07051	-0.00225
EC	0.24187	-0.11350	0.43740	-0.18083	0.12072	-0.01750
Ca	0.14932	0.09445	0.19281	-0.51674	0.08901	0.01429
SAR	0.16913	-0.21759	0.43851	0.10257	0.12863	-0.21889
Fe	-0.09515	0.14602	0.16242	0.24223	-0.44407	0.29051
Cu	0.29577	0.12418	-0.26310	0.01605	0.36662	-0.06597
Zn	0.13963	0.39551	0.05670	0.11501	-0.03739	-0.15391
Mn	0.25759	0.24454	-0.17437	-0.16316	0.03476	-0.08587
%OC	0.19767	0.34727	0.05226	0.13512	0.19086	0.22207
%N	0.21887	0.28689	-0.01387	0.19211	0.35891	0.23517
%P	0.12862	0.22679	0.39756	0.27515	-0.02328	0.01885
%K	0.23537	0.11493	0.10293	0.15113	-0.23545	0.08448
%$CaCO_3$	-0.07312	-0.31239	0.03339	-0.04646	0.46673	0.21786
BD	-0.04805	-0.02128	0.28086	-0.23397	-0.05142	0.62089
MWD[b]	-0.03748	-0.10830	0.08060	0.45431	0.19046	-0.20847
AWC[c]	0.24049	-0.19420	-0.33856	0.20009	-0.16238	0.23864
%Clay	0.30560	-0.05644	0.10511	-0.16579	-0.24307	-0.31067
%Sand	-0.38175	0.22890	0.07922	0.01569	0.10954	-0.08759
%Silt	0.312913	-0.25499	-0.15472	0.06869	-0.00699	0.27428
RFC[d]	0.38066	-0.17939	-0.04767	-0.02426	-0.21517	-0.08278

[a] Principle Component numbers, [b] Mean Weight diameter of Aggregates, [c] Available water Content, [d] Relative Field Capacity. Underlines means high loading factor of soil indicators.

Table 4. Correlation coefficients and correlation sums for highly weighted variables under Principal Components (PC) with multiple high factor loadings.

PC variables	Sand	RFC	
PC1 variables			
Correlation coefficient			
Sand	1.00	-0.91	
RFC	-0.91	1.00	
Correlation sums	0.09	0.09	
PC3 variables	EC	SAR	P
Correlation coefficient			
EC	1.00	0.79	0.37
SAR	0.79	1.00	0.42
P	0.37	0.42	1.00
Correlation sums	2.16	2.21	1.79
PC5 variables			
Correlation coefficient	Fe	$CaCO_3$	
Fe	1.00	-0.24	
$CaCO_3$	-0.24	1.00	
Correlation sums	0.76	0.76	

correlation sum. Therefore, the refined *MDS* included the following indicators: sand, *RFC*, Zn, *SAR*, Ca, $CaCO_3$, Fe and *BD*.

The studied fields had been under saffron cultivation at least in the past 5 years, so our assumption was that saffron management was indeed influencing the various soil indicators and the relationships among them. In addition, the studied area is wide enough, therefore, the soil forming factors, especially parent material and even topography and management practices in different fields, are varied and soil quality indices in the studied fields are different.

Soil texture was the most fundamental qualitative physical property of soil (Schoenholtz *et al*., 2000), and was regarded as the most effective soil quality indicator (Li *et al*., 2013). Sand percentages in all of the soil samples were over 32%. Saffron can grow in a wide range of soils, but, where saffron is cultivated, soil should have a medium texture and natural drainage. Since saffron corms are retained in the cultivated bed for long time, the soil should have sandy texture, in addition be able to supply adequate food, and corms can resist against the specific conditions of the region. Thus, for optimum plant growth and more production, loam or sandy-loam soils are preferred (Shahande, 1990). Accordingly, our results suggest that soil texture was not a constraint limiting the productivity in our study area.

Based on the results, relative field capacity and bulk density, as important physical properties affecting soil quality, were retained in the *MDS* based on PCA (Table 3). Relative Field Capacity (RFC) and Bulk Density (BD) can have effect on crop yield. For example, low bulk density and high *RFC* lead to better aeration for the corms. Also, improvement in available soil water combined with a general increase in fertility and soil health may increase the crop yield (Karlen *et al*., 1994; He *et al*., 2007). Besides, increasing bulk density has negative effect on the root system, the exchange of air and water, and plant nutrients (Doran, 2002).

According to the data in Table 3, another important quality indicator of the saffron fields was the percentage of calcium carbonate, which had a negative and significant correlation ($P< 0.01$) with saffron yield (data not shown here). All the 30 saffron fields had calcareous soils and 20-27% calcium carbonate, which can affect the

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uptake of essential nutrients by plants, especially micro nutrients, in calcareous soil. In such soils, the availability of nutrients like iron, manganese, and phosphorous is limited and poses a serious threat to successful crop production (Dahiya and Singh, 1982). Application of lime to acid soils is a widely adopted approach to increase soil pH and increase crop yield (Scott *et al*., 1999), since liming is often associated with an increase in soil pH and a reduction in plant uptake of Al and Mn (Helyar and Anderson, 1974; Hemphill and Jackson, 1982; Smyth and Cravo, 1992). Therefore, calcium carbonate is an important indicator for assessing the soil quality in calcareous soils.

SAR was highly correlated with *EC* (Table 4). There was a large difference in SAR values between different fields, ranging from 1 to 14.5. The water used for irrigation in these saffron fields had high salinity and *SAR*, which is one reason for the high *SAR* in these fields and why *SAR* was retained in the *MDS*. Soil salinity affects plants through its osmotic effects (Grattan and Grieve, 1999) and often causes “physiological drought” if it exceeds the critical limits for the crop. SAR is also used to assess the potential of Na for soil structure deterioration. There was a negative correlation between yield and *SAR* showing that with a decline in *SAR*, the yield would increase and vice versa. Rasouli *et al.* (2012) also found the linear regression between wheat (*Triticumaestivum*) yield and SAR such that for every unit of *SAR* reduction, grain yield increased 161 kg ha^{-1}. Furthermore, on the basis of this equation, 65% of this variation can be attributed to the reduction of *SAR* (r^2= 0.65).

Nutrient concentrations in soil solution have been of interest for many decades as indicators of soil fertility in agriculture (Hoagland *et al*., 1920). Micronutrients such as Fe and Zn are necessary for plants growth (Fageria, 2002). Zn and Fe were also retained in *MDS* because of their high loading factors (eigenvectors). Zn is a micronutrient needed in small amounts by crop plants, but its importance in crop production has increased in recent years. It is considered to be the most yield-limiting micronutrient in crop production in various parts of the world (Cakmak *et al*., 1996). Zn content in the soils varies significantly depending on type of soil, management practices adopted by the farmers, climatic conditions, crop species planted, and cropping intensity (Lindsay and Norvel, 1978). Zn content of the lithosphere is approximately 80 mg kg^{-1}, and the common range for soils is 10–300 mg kg^{-1} with an average content of 50 mg kg^{-1} (Lindsay and Norvel, 1978). Presumably, the reason for leaf length reaction to Zn application is that Zn is necessary for producing chlorophyll and forming carbohydrate. It is also closely involved in N-metabolism of the plant (Akbarian *et al*., 2013). Khorramdel *et al.* (2015) evaluated the influence of three corm weight grades (< 5 g, 5–10 g, and > 10 g) and various levels of foliar fertilizer (0, 5, 10, 15, and 20%) of Dalfard15 foliar spraying (specific fertilizer for saffron farms in Iran containing 12% N as NO3−, 8% P, 4% K, 2,000 mg L^{-1} iron chelate, 1,000 mg L^{-1} Zn, 1,000 mg L^{-1} Mg and 500 mg L^{-1} Cu) on growth and yield of saffron (*Crocus sativus L.*) and concluded that 15% of foliar fertilizer significantly increased the stigma dry weight of flowers derived from mother corm class 5–10 g weight. Therefore, application of nutrients, especially Zn, in adequate amounts is essential for obtaining optimal crop yields and maintaining soil fertility for sustainable crop production.

Iron was the other micro nutrient selected for the *MDS*. It has many functions in plants; however, its main role is participation in many plant metabolic functions, and it is also a component of many enzymes (Akbarian *et al*., 2012). The quantity of iron uptake by plants is greater than for all other essential micronutrients (Fageria, 2002). Any factor that decreases the availability of Fe in a soil or compete in absorption processes can contribute to Fe deficiency by plants (Fageria, 2002). Both micronutrients, (i.e., Zn and Fe) increase the photosynthesis

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and thus saffron yield. Iron is also essential for the synthesis of chlorophyll. The reduction of photosynthesis observed in zinc-deficient plants can also be due, in part, to a major decrease in chlorophyll content and the abnormal structure of chloroplasts (Alloway, 2004). Zinc deficiency reduces water use efficiency, which can lead to loss of turgidity and reduced growth (Duffy, 2007).

Soil Quality Indices Based on *TDS* and *MDS* Indicators

The results of correlation analysis for soil quality indices are shown in Table 5. Generally, for total soil samples, the correlation coefficients (r^2) for NQI_{TDS}-NQI_{MDS} (0.89), were equal and slightly higher than those for IQI_{TDS}-IQI_{MDS} (0.88) and they were significant at $P< 0.01$. Qi *et al.* (2009) reported the significant correlations for IQI_{TDS}-IQI_{MDS} (r^2= 0.652) and NQI_{TDS}-NQI_{MDS} (r^2= 0.570). The significant correlation between individual soil quality index (IQI or NQI) obtained by *MDS* and *TDS* showed that soil quality indices may be successfully calculated using *MDS* instead of *TDS*.

We compared two sets of indicators i.e., *TDS* and *MDS*, and two different indices i.e. *IQI* and *NQI*, to evaluate soil quality in saffron fields in Ghayen area. Correlation analysis showed significant correlation between IQI_{TDS}-IQI_{MDS} and NQI_{TDS}-NQI_{MDS} (Table 5). This correlation showed that the *MDS* set for soil quality indicators in both models (NQI, IQI) can reliably assess soil quality. Therefore, the *MDS* indicators could be used as a suitable tool for evaluating soil quality in these fields. It was concluded that using the *NQI* index and the *MDS* method can adequately represent the *TDS* method (r^2= 0.89) and, thus, reducing the number of indicators may also save time and cost.

Means of soil quality indices, *i.e.*, IQI_{TDS}, IQI_{MDS}, NQI_{TDS} and NQI_{MDS}, for total soil samples are presented in Table 6. Based on literature review, IQI_{TDS} model is the best combination for assessing soil quality (Doran and Jones, 1996; Qi *et al.*, 2009). Soil quality was divided into four grades by Qi *et al.* (2009). Grade I is considered most suitable for plant growth; grade II is suitable for plant growth but with some limitations; grade III has more severe limitations than grade II; and grade IV soil has the most severe limitations for plant growth. For example, in grade III, the value of IQI_{TDS} was ≥ 0.56, $IQI_{MDS}\geq 0.58$, $NQI_{TDS}\geq 0.35$, and $NQI_{MDS}\geq 0.6$ (Qi *et al.*, 2009). The results of Table 6 according to Qi *et al.* (2009) classification showed that the soils of saffron fields in Ghayen area were classified as grade III, but NQI_{MDS} classified them as grade IV and posed severe limitations to plant growth.

Correlation between Economic Yield of Saffron and Soil Quality Indices

Correlation coefficients between soil quality indices (IQI_{TDS}, IQI_{MDS}, NQI_{TDS} and NQI_{MDS}) and economic yield of saffron are shown in Table 7. The results of correlation analysis for soil quality indices and economic yield of saffron showed that IQI_{TDS} and NQI_{TDS} had significant correlation at P<0.05, but IQI_{MDS} and NQI_{MDS} did not have significant correlation with economic yield of saffron. Correlation analysis showed that the *IQI* performed better than the *NQI* in two indicator selection methods (TDS and MDS) and the correlation coefficient of *IQI* was more than *NQI*, especially for *TDS*.

Table 5. Correlation coefficients between soil quality indices, obtained by Minimum Data Set (MDS) and Total Data Set (TDS), for soil samples collected from saffron fields.

Soil samples	Nemero quality index	Integrated quality index
Total	0.89**	0.88**

** Significant at P<0.01.

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Table 6. Means of Nemero Quality Index (NQI) and Integrated Quality Index (IQI), obtained by Minimum Data Set (MDS) and Total Data Set (TDS), for soil samples collected from agricultural and pasture lands.

Soil samples	IQI_{MDS}	IQI_{TDS}	NQI_{MDS}	NQI_{TDS}
Total	0.594	0.561	0.484	0.491

Table 7. Correlation coefficients between soil quality indices and economic yield of saffron.

Economic yield	IQI_{MDS}	IQI_{TDS}	NQI_{MDS}	NQI_{TDS}
Total	0.307	0.444*	0.140	0.418*

* Significant at P<0.05.

Based on correlation analysis (Table 7), the correlation coefficients between economic yield of saffron with the IQI_{TDS} and NQI_{TDS} models were 0.44 and 0.41, respectively (Table 7). Additionally, the correlation coefficient between IQI_{MDS} and economic yield was calculated at r^2= 0.3, and for the NQI_{MDS} with economic yield was r^2= 0.14; but they were not significant correlations. Since the *MDS* with fewer measurements couldn't give similar results to *TDS* (more measurements and costly), *TDS* is more suitable than the *MDS* method in our study.

Both IQI_{TDS} and NQI_{TDS} have some distinct advantages over other indices: (1) Ssoil researchers, managers, and farmers easily understand both types of indices, due to their intuitive nature as mentioned by Wang and Gong (1998) and Sun *et al.* (2003); (2) Both indices based on mathematical methods, which lead to increased confidence in the results; and (3) Both indices can serve as a platform for planning other agricultural research.

CONCLUSIONS

To evaluate soil quality for saffron fields, 20 soil physical and chemical properties were determined as *TDS*. The results showed that only sand, *RFC*, Zn, *SAR*, Ca, $CaCO_3$, Fe and *BD* were retained in the refined *MDS* based on the PCA. This study suggests that using soil quality indices to evaluate agricultural soil quality can provide similar results even when different indicator methods and models have been used in the study area. In this study, IQI_{TDS} was determined to be the most accurate method for evaluation of soil quality, because it took all soil parameters into consideration and gave the most consistent results. Use of the *TDS* is costly due to more measurements of soil indicators, therefore, for other areas, the accuracy and precision of *MDS* for evaluating the soil quality and yield of other plants should be investigated. We suggest using the *IQI* index with the *TDS* indicator method to evaluate agricultural soil quality for saffron fields because of its highest correlation with economic yield of saffron.

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ارزیابی کیفیت خاک در بعضی از مزارع زعفران ایران

ا. رنجبر، ح. امامی، ر. خراسانی، و ا. ر. کریمی کارویه

چکیده

اطلاعات کمی درباره کیفیت خاک به ویژه در مزارع زیر کشت زعفران در ایران وجود دارد. اهداف این تحقیق شامل ۱) ایجاد مجموعه حداقل داده‌ها (MDS) برای کمی نمودن کیفیت خاک در مزارع زعفران، ۲) ارزیابی کیفیت خاک با استفاده از دو شاخص کیفیت مرکب (IQI) و شاخص کیفیت نمورو (NQI) و ۳) بررسی رابطه‌ی بین کیفیت خاک و عملکرد اقتصادی زعفران بودند. ۳۰ نمونه خاک از منطقه قاین واقع در خراسان رضوی جمع‌آوری و ویژگی‌های فیزیکی و شیمیایی آن‌ها اندازه‌گیری شد. تجزیه مولفه‌های اصلی (PCA) برای تعیین MDS شامل ویژگی‌های شن، ظرفیت نسبی رطوبت زراعی (RFC)، روی، نسبت جذب سدیم (SAR)، کلسیم (Ca)، کربنات کلسیم ($CaCO_3$)، آهن و جرم مخصوص ظاهری (BD) مورد استفاده قرا گرفت. کیفیت خاک با استفاده از شاخص‌های IQI و NQI در دو مجموعه کل داده‌ها (TDS) و MDS ارزیابی شد. چهار شاخص کیفیت خاک (یعنی IQI_{TDS}، IQI_{MDS}، NQI_{TDS}و NQI_{MDS}) برای ارزیابی کیفیت خاک در مزارع زعفران این منطقه به کار گرفته شدند. همبستگی معنی‌داری ($P < 0.05$) بین IQI_{TDS} ($r=0.44$) و NQI_{TDS} ($r=0.41$) با عملکرد اقتصادی زعفران مشاهدهد شد. آنالیز همبستگی نشان داد که کاربرد IQI_{TDS} در مقایسه با NQI_{TDS} برای ارزیابی کیفیت خاک بهتر بود. استفاده از TDS با شاخص IQI روش موثری برای ارزیابی کیفیت خاک در مزارع زعفران بود.