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Tillage, Residues Management, and Nitrogen Fertilization Effects on Soil Organic Status, Soil Quality, and Soft Wheat in the Moroccan Semi-Arid

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ABSTRACT

Sustainable management of agricultural practices can improve soil organic status, soil quality (SQ), and yields. The study was conducted to test the impact of tillage (conventional (CT) and no-till (NT)), residues (vetch (C_1) and uncover soil (C_0)), and three nitrogen (N) fertilization rates (30, 60, and 90 N kg ha^{-1}) on soil organic carbon (SOC), total nitrogen (N), C/N ratio, soft wheat yields and SQ. The experiment was established in 2010 in the Moroccan semi-arid. After ten years, the SOC concentration was greater under NT (9.4 g/kg) compared to CT (8.4 g/kg). Crop residues also enhanced SOC (10 g/kg) contrary to C_0 (8.1 g/kg). Application of N fertilization showed profound effects on total N, increasing levels of N fertilization led to higher total N irrespective of tillage. Crop residues increased total N (0.6 g/kg) better than C_0 plots at the horizon 20–40 cm. Soft wheat revealed an improvement under NT (4213.8 kg ha^{-1}) versus CT (3785.6 kg ha^{-1}) and it responded positively to the N application. For SQ evaluation through the indexing methods (SQI), principal component analysis was done for eight soil indicators to select the minimum data set (MDS), which were subsequently normalized and integrated into the SQI, additive (SQI_{ANL}), and weighted (SQI_{WNL}). NT revealed higher scores (0.52; 0.6) than the CT (0.46; 0.53) for SQI_{ANL} and SQI_{WNL}, respectively, at the horizon 0–20 cm. the residues layer on the soil surface improved SQI_{WNL} score (0.59) compared to C_0 (0.55). Moreover, the correlation (r) with yield and the sensitivity (S), allowed us to choose SQI_{WNL}, as the best index (highest r and S) to evaluate SQ under different practices studied. Indeed, SQI_{WNL} revealed an intermediate SQ under NT and at C_1 treatments, compared to CT and C_0 (low SQ).

Keywords: no-till, residues; total organic carbon, total nitrogen, soil quality, soil quality index, semi-arid, Morocco.

INTRODUCTION

The soil is a key component to provide many important ecosystem functions. It is a complex substrate, physically and chemically heterogeneous, that supports a high diversity of microbial and faunal taxa, provides food and biomass production, and plays a major role in climate regulation (Larson and Pierce, 1991; Meng et al., 2017). Therefore, the sustainable management of soils requires a regular assessment of their status through the measurement of soil quality indicators. Farm management practices, such as crop rotation, tillage, and fertilization, modify soil properties in the mid-and long-term. Hence, these practices have an impact on crop development and productivity, and on the agricultural system.s sustainability (De La Fuente and Suárez, 2008; Zubeldia et al., 2018).

Over the decades, intensive agricultural practices and the unbalanced use of fertilizers have led to soil quality loss. Alternative systems such as no-till (NT) have emerged as a soil conservation strategy (Masto et al., 2008; Bilgili, Küçük and

Van Es, 2017). This strategy was developed mainly to control soil erosion by creating a protective crop residue layer on the soil surface. Therefore, the regular practice of this technique greatly affects the incorporation and distribution of soil organic carbon (SOC), as well as the soil functions and soil ecology (Kladivko, 2001; Blanco-Canqui and Lal, 2008; Moussadek et al., 2014). NT practices can enhance SOC and other soil nutrient stocks at two levels: (i) by reducing perturbations that promote the soil aggregate creation and preserving the SOC encapsulated in these stable aggregates against the rapid oxidation and then reduction of CO_2 emissions (Six, Elliott and Paustian, 2000) and (ii) by local edaphic environment changes (bulk density, pore size distribution, temperature, water and air regime that can also restrict the biodegradation of SOC (Kay and VandenBygaart, 2002). Conservation tillage can also contribute to a reduction in fuel use and greenhouse gas emissions by reducing and even eliminating the number of tillage operations as well as avoiding soil macro-aggregate degradation created by soil tillage (Álvaro-Fuentes et al., 2008). However, NT is generally associated with the low availability of N minerals added due to its retention by residues left on the soil surface (Bradford and Peterson, 2000). Some studies have shown that the nitrogen immobilization phase is transient and that in the long term, this immobilization is temporary, under conservation systems that reduce the possibility of mineral N leaching and loss through denitrification (Schoenau and Campbell, 1996).

It is important to assess soil quality to help farmers confront soil degradation and population growth challenges. Soil quality assessment can be a powerful tool to identify and detect the effects of agricultural practices to guide sustainable land management and to diagnose soil nutrient requirements (McGrath and Zhang, 2003; Chen et al., 2013). Several methods have been proposed to assess soil quality over the decades, including soil quality indices, which are certainly the most commonly used (Andrews, Karlen and Mitchell, 2002). Soil quality index (SQI) is quite a simple tool, easy-to-use, and interrelated to soil management practices (Qi et al., 2009). The SQIs reveal 3 classes of soil quality; SQI < 0.55 indicates low soil quality or degraded soil, 0.55< SQI <0.7 indicates intermediate soil quality, and SQI >0.7 indicates high soil quality (Marzaioli et al., 2010).

The impact of NT on crop yield is controversial (Pittelkow et al., 2015). Some studies report similar yields under the NT system compared to CT (Pittelkow et al., 2015; Büchi et al., 2017), some researchers report yield improvement under NT (Mrabet, 1997; Zhang et al., 2015), while others report decrease in crop yield under NT (Alvarez and Steinbach, 2009; Pittelkow et al., 2015). Remarkably, the impacts of tillage systems generally focus on average production while little attention is paid to yield stability (Macholdt and Honermeier, 2017; Knapp and Heijden, 2018). Under climate change, farmers may be more concerned about yield stability than production levels. This is a relevant topic since yield stability may increase or decrease over the long term depending on selected farming practices (Macholdt and Honermeier, 2017).

In Morocco, previous studies have shown that the SOC content in most of the soils is low (<2%), related to the intensive soil practice, and caused soil quality loss and soil degradation (Soudi et al., 2003; Barbera et al., 2012; Mrabet et al., 2012). To address this situation, the adoption of conservation agriculture including NT has been recommended as an alternative strategy to reverse the spiral of soil degradation in many parts of the world, in China (Liu et al., 2012), Europe (Cwalina-Ambroziak et al., 2016), North America (Harker et al., 2016), Australie (Malik et al., 2015) and Morocco (Ibno-Namr and Mrabet, 2004; Moussadek et al., 2011; Laghrour et al., 2016; Aboutayeb, Yousfi and El Gharras, 2020). The effect of no-tillage on SOC and NT content has been widely studied by many authors. However, until now, there has been a lack of studies using SQIs to evaluate the effect of different agricultural practices on soil quality. In this context, the present study was conducted to evaluate soil quality under different agricultural practices using the indexing method, on a Vertisol in the Moroccan semi-arid. The objectives were (i) to evaluate the impact of agricultural management practices on SOC sequestration, Total N, soil quality and, crop yields. (ii) To study and validate the choice of the indexing method to evaluate soil quality.

MATERIALS AND METHODS

Experimental site description

The study was conducted at the experimental field of the national institute for agronomic research (INRA), Safi Province (latitude 32°24.08.0’’ N, longitude 8°46.52.4’’ W; and altitude 176 m). The soils at this site are classified as Vertisols. The region is characterized by an arid climate (Alahiane, 2020) with the mean annual precipitation of 145 mm and temperature of 19.3 °C for the crop year 2019–2020.

Experimental design

This research was established in 2010 under Soft Wheat/lentil rotation to study the effect of three factors: tillage, crop residues, and 3 rates of N fertilization. The adopted experimental design was a split-split plot. The whole plot had N fertilization rates with 3 rates (30 kg N ha^{-1}, 60 kg N ha^{-1},90 kg N ha^{-1}), the split plot had two cover crops (vetch (C_1) and no cover (C_0)) and the split-split-plot had two tillage types (NT and CT). Each treatment factor had four replications.

For the conventional tillage, plowing and leveling were done for soil preparation before seeding by a conventional disc harrow. For the no-till system, no soil preparation was necessary before seeding. The planting was done thanks to a combined seeder. Seeds and fertilizers are placed at the same time without turning the soil. The seeding was realized using Soft wheat (Arrehane variety) in November 2019 for all the plots at a planting density of 50 kg ha^{-1}. Deep fertilization was applied to all the plots in the form of 3 composites: Di-Ammonium Phosphate 18–46 at 100 kg ha^{-1}, Ammonium Sulphate 21% at 50 kg ha^{-1}, and Potassium Sulphate 48% at 100 kg ha^{-1}. Nitrogen fertilisation was surface applied as ammonium nitrate (NH_4NO_3) 70 days after Soft wheat seeding for the plots with 60 kg N ha^{-1} and 90 kg N ha^{-1}. Residues were placed directly on the surface after tillage and seeding operations. The C_1 plots were covered by dry vetch residues (lentil crop), with 6 tons of crop residues per hectare, corresponding to 100% of surface coverage dispersed homogeneously. C_0 plots were not covered (0% surface coverage).

Sampling and analysis

In May 2020, Soil samples were collected after harvest for two depths 0–20 and 20–40 cm. The subsamples from each plot were mixed into one composite sample per plot. The samples were air-dried and ground to pass through a 2 mm sieve. Soil analyses were carried out on the following parameters for the two depths: Soil pH and Electrical conductivity (EC) were measured in deionized water. SOC was determined by (Walkley and Black, 1934). Total N was determined by the Kjeldahl method (Bremner and Mulvaney, 1992). Available phosphorus (P_{avb}) was determined by the Olsen method (Olsen et al., 1954). Exchangeable Potassium (K_{exg}) and Sodium (Na) were extracted by an ammonium acetate solution.

Soil quality assessment

Three main steps for soil quality assessment using SQI: 1) selection of a minimum data set (MDS). 2) scoring of the indicators, and 3). Calculation of SQI.

Principal component analysis

Principal component analysis was used to select MDS to reduce the size of the data while minimizing the information loss (Qi et al., 2009; Armenise et al., 2013). At every principal component (PC), only the indicators with high eigenvalues ≥1 are more representative and will be selected (Govaerts, Sayre and Deckers, 2006). If several indicators have a high eigenvalue, a correlation between these indicators is necessary, to avoid redundancy (Askari and Holden, 2015). If these selected indicators are not correlated, they will all be retained in the minimum data set (MDS), otherwise, only the indicator with the highest eigenvalue should be retained in the MDS (Andrews, Karlen and Mitchell, 2002).

Scoring of the MDS

The selected MDS indicators have different units, so it is necessary to transform them into unitless values. The non-linear approach was used for this purpose. The non-linear scoring method has been considered the appropriate method for indexing soil quality indicators (Andrews, Karlen and Mitchell, 2002; Askari and Holden, 2014; Mukhopadhyay et al., 2016; Zhao et al., 2017). Cause it.s presented soil function better than linear scoring indices, which indicated the better differentiating ability of the SQI calculation by the non-linear scoring method to land management practice (Yu et al., 2018). For this approach, a sigmoid function has been developed and used in several articles (Eq.1), based on the principle criteria "more is better", "less is better" and "optimum" (Andrews et al., 2002; Masto et al., 2008; Raiesi, 2017; Edrisi, Tripathi and Abhilash, 2019).

$$S_{NL} = a/ (1+(x/x_0)^{b}) \quad (1)$$

where: S_{NL} is the non-linear score of the indicator between 0 and 1, a is the maximum value of the score (for our case equal to 1), x is the value of the indicator, x_0 is the mean of each indicator, and slope b is -2.5 for "more is better" and +2.5 for "less is better" (Askari and Holden, 2014).

SQI calculation

The scores of the transformed indicators were integrated into an SQI using the additive and weighted methods (Fig. 1) as described by (Andrews, Karlen and Mitchell, 2002; Askari and Holden, 2014) in their studies. The additive method is the simplest approach, consisting in adding the scores of the indicators obtained by the non-linear method, divided by the total number of MDS indicators (Andrews and Carroll, 2001; Vasu et al., 2016). The weighted method is the most complex. Each PC explains a percentage (%) of the total variance of the data. Then, each parameter of the MDS will receive the factor of the principal component from which it is selected, and will be multiplied by its non-linear score. The SQI values obtained must be between 0 and 1; a high index value indicates better soil quality (Andrews et al., 2002; Ray et al., 2014; Rangel-Peraza et al., 2017). The score obtained by the nonlinear method; n: The total number of indicators in the MDS; Wi: The factor obtained from the principal component analysis.

Evaluation of indexing methods

The indexing procedures were evaluated by the correlations coefficients between the SQIs and the crop production, and the sensitivity (S) calculation (Sheidai Karkaj et al., 2019). Sensitivity has been calculated as follows (Eq. 2):

$$S = SQI_{max}/SQI_{min} \quad (2)$$

where: SQI_{max} and SQI_{min} are the maximum et minimum SQI obtained for each index calculation method (Masto et al., 2008).

Statistical analysis

The normality test was performed on all data sets before the statistical analysis, using the Kolmogorov-Smirnov test and visual examination of the histograms. Data were subjected to variance analysis based on the General Linear Model (GLM) for the split-split-plot design. The other processing treatments concern a PCA, Pearson correlation, non-linear scoring, and SQI equations were performed by SPSS software version 20, and Excel 2016. The least significant difference (LSD at 5%) test was used to compare means and SQI methods.

RESULTS

Total organic carbon, total nitrogen and C/N ratio

Table 1 demonstrates the effect of tillage systems, residues and 3 nitrogen fertilization rates on SOC, total N and C/N ratio for the two soil horizons (0–20 and 20–40 cm). The results showed that tillage and residues have a significant effect on SOC. The SOC concentration was higher under NT (9.37 g/kg) compared to CT system (8.42 g/kg) at the 0–20 cm horizon. While SOC at the 20–40 cm horizon did not show any differences across tillage. Crop residues at 0–20 cm allowed to increase the SOC contents (10.01 and 9.50 g/

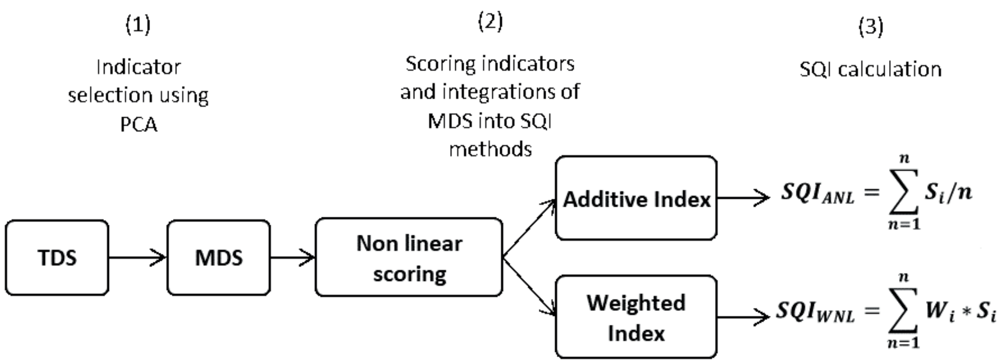

Figure 1. Process for SQI assessment in this study Si

Table 1. Soil organic carbon (SOC), Total Nitrogen (N), and C/N ratio under tillage, residues and N fertilization rates

Indicators	SOC		Total N		C/N ratio	
Units	g/kg		g/kg		-	
Depth	0–20	20–40	0–20	20–40	0–20	20–40
Factors						
Tillage (T)						
CT	8.42 B	8.18 A	0.59 A	0.56 A	14.55 B	14.80 A
NT	9.73 A	9.40 A	0.60 A	0.54 A	16.31 A	17.77 A
Residues (R)						
C_0	8.14 B	8.09 B	0.60 A	0.52 B	13.73 B	16.01 A
C_1	10.01 A	9.50 A	0.59 A	0.59 A	17.13 A	16.56 A
N rates (N)						
N_{30}	9.59 A	8.08 A	0.54 B	0.52 A	17.92 A	15.81 A
N_{60}	9.19 A	8.54 A	0.57 B	0.55 A	15.72 B	16.01 A
N_{90}	8.45 A	9.76 A	0.66 A	0.59 A	12.65 C	17.04 A
Interaction						
T*R	n.s					
T*N R*N						
T*R*N						

The means followed by the same letter within the same column are not significantly different (significant difference at $p < 0.05$).

kg) compared to the uncovered soil (8.14 and 8.09 g/kg), for the two horizons 0–20 and 20–40 cm respectively. However, nitrogen fertilization did not show a significant effect on SOC for the two depths. Tillage and residues did not report a significant effect on total N. However, nitrogen fertilization showed a significant effect on total N in the 0–20 cm horizon. Indeed, the highest concentration (0.66 g/kg) was found under the plots with 90 kg N ha^{-1}. The lowest concentration (0.54 g/kg) was recorded in the plots with 30 kg N ha^{-1}. Total N at the horizon 20–40 cm, showed a significant difference across residues, the maximum concentration (0.59 g/kg) was found under cover plots.

C/N ratio also varied with tillage and residues. At 0–20 cm horizon, the highest value (16.31) was found under NT compared to CT (14,55). C/N ratio was higher under vetch cover (17.13) compared with uncovered plots (13.73). The nitrogen fertilisation marked a significant effect on the C/N ratio. Increasing rates allowed to reduce the C/N ratio. The ratio showed a value of 17.92; 15.72 and 12.65 respectively for the plots with 30; 60 and 90 kg N ha^{-1}. However, at 20–40 cm horizon, tillage, residues and nitrogen fertilisation did not report a significant difference.

Grain yield

Wheat grain yield was significantly influenced ($p<0.05$) by tillage and nitrogen fertilization (Table 2). Yield was higher under NT with the means of 2005.02 kg per hectare compared to CT (1565.58 kg per hectare). On the other

Table 2. Effect of tillage, residues, and nitrogen fertilization on soft wheat yield (the crop year 2019–2020)

Treatment	YIELD (kg/ha)	ANOVA
Tillage (T)		
CT	1565.58	0.006
NT	2005.02	
Residues (R)		
C_0	1662.19	0.111
C_1	1908.40	
N rates (N)		
N_{30}	1486.43	0.002
N_{60}	1690.75	
N_{90}	2178.71	
ANOVA		
T*R		0.795
T*N		0.636
R*N		0.364
T*R*N		0.799

Significant difference at $p < 0.05$.

hand, a higher grain yield was found at 90 kg N ha^{-1} (2178.71 kg/ha) and the lowest at 30 kg N ha^{-1}(1486.43 kg/ha). Residues showed an insignificant effect on grain yield (p>0.05). The interaction between tillage, residues and N rates didn't show any significant effect on yield.

Evaluation of soil quality using the indexing methods

Principal component analysis

Principal component analysis (PCA) was done for 8 physicochemical indicators (Table 3). At the horizon 0–20 cm, the PCA results indicated four main components with eigenvalues ≥1 and explained 80.56% of the total variance from the total data set (TDS) (Table 3). The first main component (PC1) explained 28.76% of the total variance. PC2 and PC3 explained 22,02% and 16.27% of the total variance, respectively. The last PC4 explained 13.53% of the total variance. The selected indicators from PC1 were SOC and C/N ratio. However, a strong Pearson correlation (Table 4) was found between these two parameters, SOC was chosen as MDS. Exchangeable K (k_{exg}) and Na were chosen from PC2 and k_{exg} was included in MDS after Pearson's correlation. From PC3, P_{avb} and pH were selected and only P_{avb} was considered in MDS based on Pearson.s correlation. EC and total N were selected from PC4 and the correlation between these two indicators shows no relationship and therefore these two indicators were retained in MDS. The indicators retained in MDS after the multivariate correlation (Table 4) are SOC, K_{exg} and total N, EC, respectively from PC1, PC2 and PC4. For the horizon 20–40 cm, PCA reported four PCs with eigenvalues ≥1 (Table 3), these PCs explained 82.76% of the total variance. PC1, PC2, PC3 and PC4 respectively explained 33.5%, 19%, 17.28% and 12.95% of the total

Table 3. Principal component (PC) analysis of soil quality indicators for the two soil depths 0–20 and 20–40 cm

Depth (cm)	0–20				20–40			
	Component							
Principal components	PC1	PC2	PC3	PC4	PC1	PC2	PC3	PC4
Eigenvalue	2.88	2.20	1.63	1.35	2.68	1.52	1.38	1.04
Variance explained %	28.77	22.01	16.27	13.52	33.53	18.1	17.28	12.95
Cumulative %	28.77	50.77	67.04	80.56	33.53	52.53	69.81	82.78
pH	0.042	-0.113	-0.722	0.073	0.185	0.052	-0.172	0.888
EC (µs/cm)	-0.240	-0.057	0.233	0.624	-0.161	0.869	-0.057	-0.188
SOC (g/kg)	0.964	0.022	0.126	-0.148	0.915	-0.051	0.039	0.256
Total N (g/kg)	-0.150	-0.103	0.137	-0.848	-0.338	-0.303	0.537	0.465
C/N	0.873	0.059	-0.136	0.403	0.953	0.138	-0.239	-0.050
P_{avb} (mg/kg)	0.216	0.135	0.774	0.252	-0.279	-0.639	0.411	-0.192
Na (mg/kg)	-0.019	0.511	-0.644	0.094	0.302	0.646	0.449	0.313
K_{exg} (mg/kg)	0.041	0.983	0.074	0.020	-0.076	-0.015	0.892	-0.201

Table 4. Pearson correlation coefficient for highly weighted parameters in the Principal for the horizon 0–20 cm

0–20 cm	pH	EC	SOC	Total N	C/N	P_{avb}	Na	K_{exg}
pH	1							
CE	0.006	1						
SOC	-0.039	-0.176	1					
TN	-0.008	-0.145	0.063	1				
C/N	0.077	-0.064	0.738**	-0.544**	1			
P_{avb}	-0.317*	0.259	0.267	-0.085	0.134	1		
Na	0.293*	0.021	-0.060	-0.105	0.102	-0.326*	1	
K_{exg}	-0.209	-0.037	0.059	-0.119	0.078	0.331*	0.327*	1
*Correlation is significant at the 0.05 level (2-tailed)								
**Correlation is significant at the 0.01 level (2-tailed)								

Table 5. Pearson correlation coefficient for highly weighted parameters in the Principal component for the horizon 20–40 cm

20–40 cm	pH	EC	SOC	Total N	C/N	P_{avb}	Na	K_{exg}
pH	1							
CE	-0.153	1						
SOC	0.317*	-0.143	1					
TN	0.074	-0.203	-0.006	1				
C/N	0.190	0.024	0.850**	-0.502**	1			
P_{avb}	-0.237	-0.413**	-0.285*	0.306*	0-.414**	1		
Na	0.295*	0.327*	0.259	-0.034	0.238	-0.252	1	
K_{exg}	-0.256	-0.062	-0.130	0.328*	-0.282	0.333*	0.221	1
*Correlation is significant at the 0.05 level (2-tailed)								
**Correlation is significant at the 0.01 level (2-tailed)								

variance. The indicators selected and retained in MDS after the multivariate correlation (Table 5) are C/N, EC, K_{exg} and pH.

Scoring the MDS and SQIs calculation

The soil quality indices were calculated for the indicators selected in MDS for the two horizons studied (0–20 and 20–40 cm). The MDS was then transformed based on the non-linear scoring functions, considering the contribution of the MDS in the soil functions. The "more is better" criteria was applied to soil pH, when the pH values in all treatments are less than 7 or "less is better" when the pH values are greater than 7. The "more is better" criteria has been applied for SOC, K_{exg} and total N for their positive influence at high concentrations on agricultural production. "less is better" criteria has been applied for EC and C/N since the high values of these indicators are considered destructive of soil quality (Wienhold et al., 2006). After scoring the MDS, the final step is to combine the MDS indicators into the index methods (Fig. 1), the non-linear additive method (ANL) and the non-linear weighted method (WNL). Two indices were compared the non-linear additive index (SQI_{ANL}) and the non-linear weighted index (SQI_{WNL}) (Qi et al., 2009). Our results showed that the mean values of the SQIs studied indicate a low to medium soil quality at the 0–20 cm soil and medium soil quality at 20–40 cm.

Table 6. Soil quality index (SQI) across tillage, crop Residue and N fertilization

Parameter	SQI_{ANL}		SQI_{WNL}	
depth (cm)	0–20	20–40	0–20	20–40
Factors				
Tillage (T)				
CT	0.46 B	0.59 A	0.53 B	0.57 A
NT	0.52 A	0.64 A	0.60 A	0.59 A
Residues (R)				
C_0	0.48 A	0.59 A	0.55 B	0.56 A
C_1	0.5 A	0.64 A	0.60 A	0.6 A
N rates (N)				
N_{30}	0.48 A	0.61 A	0.58 A	0.58 A
N_{60}	0.5 A	0.62 A	0.58 A	0.59 A
N_{90}	0.48 A	0.65 A	0.55 A	0.57 A
Interactions				
T*R	n.s			
T*N R*N				
T*R*N				

Soil quality evaluation

Differences in SQI_{ANL} across tillage were found at 0–20 cm under soft wheat crop, NT revealed a higher SQI_{ANL} score (0.52) than the CT (0.46). However, residues and N fertilization and their interaction did not show any significant effect on SQI_{ANL}. At the 20–40 cm horizon, tillage, residues and nitrogen fertilization did not report a significant effect on SQI_{ANL} (Table 6).

SQI_{WNL} at 0–20 cm showed a significant difference between tillage and residues. NT showed a higher score (0.6) than CT (0.54). The plots under vetch cover reported a higher SQI_{WNL} score (0.59) than the uncovered plots (0.55). However, nitrogen fertilization showed an insignificant difference on SQI_{WNL}. At 20–40 cm, tillage, residue and nitrogen fertilization did not report a significant difference on SQI_{WNL} (Table 6).

SQI validation

The two soil quality indexing methods used in assessing soil quality under the experimental plots were evaluated based on the SQIs correlation with the wheat grain yield, and the sensitivity index (S).

The correlation coefficients (Table 6) between SQI_{ANL}, SQI_{WNL} and the grain yield are generally low for the two depths (r <0.2). The sensitivity (Tab.6) of the different indexing method decreases in the following order: $SQI_{WNL\ 20–40}$ > $SQI_{WNL\ 0–20}$ > $SQI_{ANL\ 0–20}$ > $SQI_{ANL\ 20–40}$. SQI_{ANL} had a thinner range and therefore had the lowest sensitivity, while SQI_{WNL} had a wider range and therefore higher sensitivity. Thus, SQI_{WNL} was the most sensitive and the best correlated with soft wheat grain yield.

DISCUSSION

The effect of tillage, residues management and nitrogen fertilization on SOC, total N, C/N ratio and grain yield

In this long-term experiment (10 years), SOC in the 0–20 cm increased under NT compared to CT. This complies with many studies showing that SOC decrease under intensive soil tillage, due to rapid decomposition of organic matter (Lal, 2002 ; Busari et al., 2015). Similar results were found in previous studies which reported that SOC mineralization are reduced compared to conventional tillage (Alvarez and Steinbach, 2009; Blanco-Moure et al., 2013; Goleman, Boyatzis and Mckee, 2019; Xu et al., 2019). Moussadek et al. (2011); Laghrour et al. (2015) detected the improvement of SOC under NT at the soil surface after 7 and 10 years of experimentation. Same results realize by several auteurs (Bessam and Mrabet, 2003; Mrabet and Ibno-Namr, 2008; Mrabet et al., 2012). On the other hand, surface crop residues have improved SOC and total N in this study. Some authors have portrayed a positive correlation between SOC, total N and residues and that the humus is one of source of carbon and nitrogen in the soils (Rasmussen and Collins, 1991; Naman et al., 2015). The highest value of the C/N ratio was reported under NT, explains the slow decomposition of residues due to changes in environmental conditions (oxygenation, temperature, humidity) (Mrabet et al., 2001; Blanco-Canqui and Lal, 2008; Askari and Holden, 2015).

Intensive agricultural practices have been associated with reduced SOC and total N and an increase in C/N ratio, leading to soil quality degradation and lower crop productivity. The effect of this intensity influenced each indicator differently, chemical indicators such as SOC and total N reacting to change at medium intensity and physical properties reacting at high intensity. Difference in C/N ratio between intensity classes could reflect the impact on organic matter intake and decomposition rate (Mary et al., 1996; Karaca et al., 2010; Askari and Holden, 2014). Our results show that grain yield increased under NT and fertilization in response to SOC and NT improvement (Cassman, 1999; Quiroga et al., 2006; Alvarez and Steinbach, 2009) confirmed these results in their studies.

SQI under tillage, nitrogen fertilization and residues

No-till systems have the ability to reduce the negative effects of agricultural intensification on soil properties. However, the knowledge of long-term impacts of no-till systems on all the soil properties is insufficient. It is essential to know which soil quality indicators are the most sensitive to management practices in each particular environment (Sokolowski et al., 2020). SQI is one of the powerful tools to determine which soil indicators affect the most of the soil quality.

PCA and Pearson correlation indicated that SOC, K_{exg}, total N and EC are the key indicators that contribute to soil quality for the horizon 0–20

Table 7. Evaluation of soil quality indices (SQI) using Pearson correlation and sensitivity coefficient

Depth (cm)	Indices	Range	Sensitivity	Correlation
0–20	SQI_{ANL}	0.30–0.62	2.06	0.086
	SQI_{WNL}	0.36–0.75	2.08	0.046
20–40	SQI_{ANL}	0.44–0.81	1.84	0.015
	SQI_{WNL}	0.37–0.80	2.16	0.105

cm and C/N, CE, K_{exg} and pH for the horizon 20–40 cm. These indicators were considered to be the most sensitive to changes in agricultural practices in the experimental field. Common soil quality indicators were included in our MDS list were mentioned by several researchers (Masto et al., 2007; Qi et al., 2009; Li et al., 2013; Mukherjee and Lal, 2014; Mbuthia et al., 2015; Bilgili, Küçük and Van Es, 2017; Amorim et al., 2020). SQI_{ANL} and SQI_{WNL} could differentiate soil quality across tillage systems at the soil surface 0–20 cm. NT showed higher soil quality compared to CT (Aziz, Mahmood and Islam, 2013) confirmed these results and showed that SQI improved under No-till and reduced under conventional tillage overtime. Related mainly to the effect of SOC and NT included in MDS on soil quality. In our study SQI_{WNL} under vetch cover was higher at 0–20 cm indicating good soil quality compared to uncovered soil, which has also been observed by (Mbuthia et al., 2015). However, SQI_{ANL} couldn't differentiate between soil quality across crop residues. According to these results, the SQI_{WNL} approach was more effective to show the differences in soil quality under the treatments studied than the SQI_{ANL} approach. The weighted method had the best discrimination and the greater sensitivity in assessing soil quality under different land-use treatments compared to the additive method (Askari and Holden, 2015; Yu et al., 2018). Furthermore, the index evaluation through the sensitivity index and the correlation coefficients showed that SQI_{WNL} was the most sensitive and the best correlated with the grain yield.

CONCLUSION

From 10 years of experimentation in the semi-arid region of Morocco, the results indicated that no-tillage and residue management positively improved SOC and total N and reduced residues mineralization, which led to increased soil productivity and improved soil quality. This improvement was noticed especially in the topsoil (0–20 cm). However, these indicators alone do not control soil quality, and their intercorrelations must be taken into account, since soil nutrient availability and soil quality are also affected by other soil indicators. The assessment of soil quality through SQI and using the non-linear scoring function. PCA and correlation were used to extract the MDS (SOC, K_{exg}, Total N, C/N, pH and EC) that have the greatest impact on soil quality. These MDS were transformed and integrated into the index equations based on two methods ANL and WNL. SQI_{WNL} and SQI_{ANL} showed an improvement in soil quality under no-till, while SQI_{WNL} indicated a higher soil quality under residue. The sensitivity index and correlation between SQIs and soft wheat grain yield reported that SQI_{WNL} was most correlated with a greater range and therefore a higher sensitivity. Thus, it has a better ability to differentiate the soil quality among the studied treatments. As a result, the non-linear weighted scoring method was considered as the appropriate method to assess the soil quality within the experimental site.

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