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Influence of Soil Properties on the Growth and Yield of Walnut Trees in the Hawraman Area, Sulaymaniyah-Iraq

Pakhshan M. Maulood
Department of Biology/ College of Science/ University of Salahaddin /Erbil/ Iraq

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corresponding author:
Pakhshan M. Maulood
Pakhshan.maulood@su.edu.krd

ABSTRACT

A Soil Quality Index (SQI) is a quantitative or qualitative assessment tool used to evaluate soil's overall health and quality in a specific area. Condensing various soil qualities and features into a single number or rating, allows land managers, farmers, and researchers to understand and monitor soil health. Therefore, the aim of this study is to compare three widely used techniques for estimating SQI using data from 42 soil samples collected from Hawraman orchard soils at two depths (surface soil 10-30cm and subsurface soil 30-60cm). Generally, most soil indicators for both soil depths were close in values, reflecting their results on calculated SQIs that did not differ significantly at each depth investigated. Soil quality values for surface and subsurface soils were (0.38 and 0.37) for SQI_{SA}, while (0.377 and 0.379) for SQI_{W} type and (0.530 and 0.665) for SQI_{PCA}. Depending on SQI_{W} relatively similar contribution percentage was obtained for both soil depths with the highest percentage of nutrient supply capacity (NSC) at 38%, root development capacity and (RDC) water storage capacity (WSC) at nearly 25-26%, the lowest contribution percentage for biological factors (BF) was 10%. SQI_{PCA} is a more efficient model than the two others and more studies on soil quality detection are expected by this technique.

Keywords: Soil indicators, Walnut, Hawraman orchard, SQI, PCA.

INTRODUCTION

Walnut trees *Juglans* spp. are strongly related to the vitality and productivity of the soil in which they are placed. Walnuts, one of the world's most economically valuable tree crops, have special soil requirements to survive and yield abundant crops. For orchard management to be sustainable and effective, it is essential to comprehend the dynamic relationship between soil quality and walnut tree growth traits (Ali *et al.*, 2010; Salieh *et al.*, 2013; Salih, 2020).

The Soil Quality Index (SQI) tool has been gaining importance in recent years as a comprehensive and multidimensional technique to evaluate soil health and establish its suitability for specific crops (Ghaemi *et al.*, 2014). The SQI provides producers with a useful tool for improving soil management practices and maintaining the optimal conditions for walnut tree growth by measuring a variety of soil parameters, including nutrient availability, organic matter content, water holding capacity, and biological activity (Du *et al.*, 2023).

The Soil Quality Index is an efficient tool for evaluating and monitoring the productivity and health of the soil in walnut orchards. The SQI supplies a holistic perspective on soil quality by quantifying and combining several soil indicators. This enables growers to identify strengths and weaknesses and implement particular soil management approaches. Farmers may improve soil fertility, and water retention abilities, and promote good microbial activity by implementing sustainable methods that involve cover cropping, organic amendments, and accurate irrigation. All of these variables are essential for the growth and productivity of walnut trees (Du *et al.*, 2022).

Farmers must prioritize soil health first and use sustainable soil management practices as the demand for quality walnuts grows. By using the Soil Quality Index, we can better understand soil dynamics and improve soil conditions to optimize the potential of walnut orchards, which represents a paradigm shift in how farmers cultivate walnut trees (Tie *et al.*, 2021).

There are many studies conducted in Iraq to assess the soil quality or soil quality indicators of the cropland and orchards (Ameen and Salem, 2016; Hasan and Mohammed, 2018; Qadir and Azeez, 2020; Hussain, 2020; Maulood, 2022; Syman *et al.*, 2023), without applying or using the soil quality index (SQI) models, therefore, the present investigation is considered the second attempt to use SQI for evaluating the soil of walnut orchards in Iraq after study of (Maulood and Darwesh, 2020).

This study aims to examine the essential elements of soil quality and how they significantly impact the growth characteristics of walnut trees using SQI which can help farmers make decisions that improve orchard productivity.

MATERIALS AND METHODS

Soil Quality Index Calculation

1- Simple additive soil quality index (SQI_{SA}):

To calculate a simple additive soil quality index, follow the methods proposed by (Amacher *et al.*, 2007). They listed the threshold levels for each soil indicator as shown in (Table 1), according to the authors' expert opinions, and a review of the literature was used to give threshold values to soil properties. The individual index values were then summed together to calculate the total SQI (Equation 1).

$SQISA = \sum(X - MinL)/(MaxL - MinL)$ …………………. (1)

Whereas, X = field-measured soil indicator value; MinL = minimum threshold level; MaxL= maximum threshold level of soil property.

Table 1: Minimum and maximum limits for standardization of evaluated indicators.

Soil indicators	Minimum	Maximum	Scoring curve	References
pH	5.5	8.5	Optimum	(Amacher *et al.*, 2007)
EC ($\mu S.cm^{-1}$)	200	500	Lower is better	(Mukherjee and Lal, 2014)
BD ($g.cm^{-3}$)	1.12	2.2	Lower is better	(Parra-González and Rodriguez-Valenzuela, 2017)
WHC %	20	60	Higher is better	
Sand %	45	80	Optimum	
Silt %	0	28	Higher is better	(Datta *et al.*, 2017, Guo *et al.*, 2017)
Clay %	5	40	Higher is better	
Fe ($mg.kg^{-1}$)	20	50	Optimum	(Amacher *et al.*, 2007, Rahmanipour *et al.*, 2014, Tesfahunegn, 2014)
Cu ($mg.kg^{-1}$)	0.1	>1	Optimum	
Ni ($mg.kg^{-1}$)	0.1	5	Optimum	
Mn ($mg.kg^{-1}$)	1	100	Optimum	
Zn ($mg.kg^{-1}$)	2	20	Optimum	
Mo ($mg.kg^{-1}$)	0.2	10	Optimum	
CEC ($Cmole.kg^{-1}$)	≤10	20	Higher is better	
SOM %	0.5	5	Higher is better	(Buchholz *et al.*, 2004)
$CaCO_3$ %	15	30	Lower is better	
AVN ($mg.kg^{-1}$)	20	80	Higher is better	(Allen *et al.*, 1974, Guo *et al.*, 2017)
AVP ($mg.kg^{-1}$)	30	40	Higher is better	
AVK ($mg.kg^{-1}$)	40	200	Higher is better	
AVCa ($mg.kg^{-1}$)	10	1000	Lower is better	
AVMg ($mg.kg^{-1}$)	50	500	Lower is better	
R120 (μg CO_2-C/g DW	35.84	71.68	Optimum	(Buchholz *et al.*, 2004)
SB ($CFU.g*10^{-3}$)	$4*10^6$	$2*10^9$	Higher is better	(Van Elsas *et al.*, 2006)
SF ($CFU.g*10^{-2}$)	10^3	10^4	Higher is better	
UR ($\mu g.g^{-1}$ dry $soil.hr^{-1}$)	0.5	10	Lower is better	(Roldán *et al.*, 2005, Meena *et al.*, 2013)
AP ($\mu g.g^{-1}.hr^{-1}$)	40	110	Optimum	
DH (μg TPF g^{-1})	10	40	Optimum	

Abbreviation: EC (Electrical conductivity), BD (Bulk density), Fe (Iron), Cu (Copper), Ni (Nickle), Co (Cobalt), Mn (Manganese), Zn (Zinc), Mo (Molybdenum), CEC (Cation exchange capacity), SOM (Soil organic matter), $CaCO_3$ (Calcium carbonate), AVN (Available nitrogen), AVP (Available Phosphorus), AVK (Available Potassium), AVCa (Available Calcium), AVMg (Available Magnesium), R120 (Soil respiration 12ohrs.), SB (Soil bacteria), SF (Soil fungi), UR (Urease), AP (Alkaline phosphatase), DH (Dehydrogenase).

2- Weighted soil quality index (SQI_W):

For calculated weighted SQI each soil indicator was scored and standardized on a scale of 0 to 1 by applying the linear equation (Andrews *et al.*, 2002), using the criteria:

1) high is better (AVN, AVK, AVP, SOM, CEC, WHC, SB, SF, silt, clay) for a desirable indicator with higher levels.
2) (Equation 2) Lower is better (EC, AVCa, AVCa, $CaCO_3$, BD, UR) for an indication with lower values preferable.
3) (Equation 3) Optimum for such indicators (pH, Fe, Mn, Mo, Cu, Zn, Ni, AP, DH, R120) that have a favorable influence on soil quality up to a certain level, beyond which their influence becomes detrimental.

$$Y = \frac{(X - MinL)}{(MaxL - MinL)} \quad \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots \quad (2)$$

$$Z = 1 - \frac{(X - MinL)}{(MaxL - MinL)} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3)$$

Whereas, Y and Z are normalized score values, X = field-measured soil indicator value; MinL= minimum threshold level; MaxL = maximum threshold level of soil property.

After finding the standardized score for each soil indicator, weights were proposed based on soil function (Askari and Holden, 2014). Four groups have been formed: NSC (nutrient supply capacity) is a rating given to the soil's ability to supply nutrients (NSC, e.g. pH, EC, AVN, AVP, AVK, AVMg, CEC, Fe, Cu, Ni, Mn, Mo, Zn), BF (Biological Factors) is a score assigned to the soil ability to improve soil structure (BF, e.g., Soil bacteria, soil fungi, soil enzymes, and soil respiration), RDC (Root Development Capacity) is the soil's ability to support plant root growth (RDC, e.g., Soil texture, BD, and $CaCO_3$), WSC (water storage capacity) is the soil's ability to store water (WSC, e.g., WHC). Each soil function was given a numerical weight based on its significance in preserving and improving soil quality.

Some studies suggested the same weight of 0.25 for each function because all functions have importance (Maulood and Darwesh, 2020), however, other studies suggested more weight for functions represented by higher indicators. In this study, we favor the last suggestion and assign a weight of 0.3 to each NSC and BF function, while RDC and WSC receive a weight of 0.2; the sum of all functions must be 1. Within this network, sub-weight values were assigned to each indication depending on their significance under the specific soil functional property, field versus laboratory observations, and scope of redundancy. The sub-weight values of various soil indicators or variables were summed up to 1 for each soil functional property (Table 2). SQI_W was calculated using (Equation 4):

$$SQIw = \sum(SF * W) \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (4)$$

where W = assigned weight and Sf = soil function

Table 2: Soil quality index weighted model (Adopted from (Amacher *et al.*, 2007)

	Weight (A)	Soil Indicators	Sub-Weight (B)	Soil (10-30 cm)						Soil (30-60 cm)					
				Score (C)	B*C	∑B*C=D	D*A	%	SQI-w	Score (C)	B*C	∑B*C=D	D*A	%	SQI w
NSC	0.3	pH	0.1	0.786	0.079					0.770	0.077				
		EC	0.05	0.396	0.020	0.479	0.144	38.20		0.713	0.036	0.507	0.152	**38.32**	
		AVN	0.1	0.396	0.040					0.380	0.038				
		pH	0.1	0.400	0.040					0.597	0.060				**0.39**
		AVK	0.1	0.791	0.079				0.377	0.708	0.071				
		AVC	0.05	0.956	0.048					0.958	0.048				
		AVM	0.05	0.267	0.013					0.357	0.018				
		Fe	0.05	0.192	0.010					0.189	0.009				
		Cu	0.05	0.677	0.034					0.690	0.035				
		Ni	0.05	0.284	0.014					0.228	0.011				
		Mo	0.05	0.519	0.026					0.598	0.030				
		Mn	0.05	0.341	0.017					0.370	0.019				
		Zn	0.05	0.460	0.023					0.435	0.022				
		CEC	0.1	0.145	0.015					0.145	0.015				
		SOM	0.1	0.230	0.023					0.198	0.020				
BF	0.3	UR	0.2	0.095	0.019					0.185	0.037				
		AP	0.2	0.115	0.023	0.129	0.039	10.30		0.097	0.019	0.132	0.040	**9.964**	
		DH	0.2	0.007	0.001					0.004	0.001				
		SB	0.1	0.020	0.002					0.002	0.000				
		SF	0.1	0.099	0.010					0.100	0.010				
		R120	0.1	0.510	0.051					0.446	0.045				
		SOM	0.1	0.230	0.023					0.198	0.020				
RD	0.2	Textu	0.4	0.451	0.180					0.497	0.199				
		BD	0.4	0.380	0.152	0.475	0.095	25.22		0.345	0.138	0.531	0.106	**26.78**	
		CaC	0.2	0.712	0.142					0.972	0.194				
WS	0.2	WHC	1	0.495	0.495	0.495	0.099	26.29		0.721	0.721	0.495	0.099	**24.95**	

3- Principal component analysis model for calculating SQI (SQI_{PCA})

The PCA model is used to produce a minimum data set (MDS) in order to reduce the indicator load in the model and avoid data redundancy. The principal components (PC) with the highest eigenvalues (≥1) were chosen because they represent the maximum variation in the data set. Each component was assigned a weighting value (W) calculated by dividing the percentage of the PC variation by the cumulative variance of the most recently selected PC. Each variable had an eigenvector weight value or factor loading under a particular PC. Only the 'highly weighted' variables were retained for use in the MDS. The 'highly weighted' variables were defined as the highest weighted variable under a particular PC and an absolute factor loading value that was within 10% of the highest values under the same PC. Pearson's correlation coefficient was employed to reduce data redundancy for a retained variable within selected PCs. If the retained variable is correlated, only the variable with the largest eigenvector is selected, and the rest is eliminated; however, in the case of a non-correlated relationship, each variable is considered important and is chosen in MDS for computing SQI (Mukherjee and Lal, 2014). Each PC explained a certain amount of variation in the dataset, which was divided by the maximum total variation of all PCs chosen for the MDS to obtain a weightage value for a particular PC. The SQI was then calculated using (Equation 5). For the first component, the percentage of variance (29) was divided by the total cumulative variance (100) resulting in a weight value of 0.29. while for PC_2-PC_5 the weighted values were (0.172, 0.157, 0.155, 0.134 and 0.09) respectively (Table 3).

$$SQI\ PCA = \sum_{i=1}^{n} \mathrm{Wi} * \mathrm{Si} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \ (5)$$

Where Si = represents the indicator score for each variable I, Wi represents the PCA weighting factor, where n is the number of variables in the MDS.

Table 3: Eigenvector and percentage of variance explained by each of the principal components (PCs) for Hawraman soil orchards (10-30cm and 30-60cm) depths. The eigenvalues in bold font under each component are highly weighted and underlined ones were selected in the minimum data set

Soil depths	**Soil (10-30cm)**						**Soil (30-60cm)**				
Components	PC1	PC2	PC3	PC4	PC5	PC_6	PC_1	PC_2	PC_3	PC_4	PC_5
Eigenvalues	6.964	4.137	3.776	3.713	3.237	2.173	8.281	4.744	3.534	3.474	3.067
% of variance	29.016	17.239	15.734	15.472	13.486	9.053	34.505	19.767	14.724	14.473	12.779
Cumulative %	29.016	46.255	61.990	77.462	90.947	100	34.505	54.271	68.996	83.469	96.248
Indicators					**0.530**			**Eigenvectors**		**0.665**	
pH	-0.373	-0.342	-0.014	-0.606	0.613	-0.008	-0.837	0.388	-0.317	-0.149	-0.089
EC	0.914	0.140	-0.033	-0.367	-0.012	0.097	0.647	-0.207	0.718	0.084	-0.020
SOM	0.258	0.885	0.026	0.224	0.293	-0.118	0.572	-0.617	0.410	-0.008	-0.215
AvN	-0.789	-0.605	0.001	-0.063	0.079	-0.035	-0.832	-0.064	-0.547	-0.062	0.012
AVP	0.677	0.429	0.132	0.207	-0.127	0.530	-0.561	0.440	0.046	-0.164	-0.653
AVK	0.366	-0.108	0.286	0.435	0.663	0.380	0.212	0.664	0.671	-0.020	0.237
AVCa	-0.398	-0.762	0.030	-0.378	0.004	0.341	-0.745	0.543	0.084	-0.199	-0.286
AVMg	-0.261	0.113	-0.265	-0.209	-0.122	-0.889	0.902	0.005	0.023	0.194	0.162
CEC	0.964	0.141	0.049	-0.066	-0.021	0.208	0.654	0.073	0.278	0.192	0.667
$CaCO_3$	-0.603	-0.746	-0.037	-0.016	0.033	-0.277	0.548	0.766	-0.070	0.026	0.296
Mn	-0.291	-0.090	0.789	-0.196	0.010	0.497	0.016	-0.361	0.278	0.807	-0.190
Fe	0.170	0.220	0.899	0.305	0.045	0.139	0.105	-0.586	-0.133	0.767	0.155
Ni	-0.160	0.623	0.396	0.330	-0.553	-0.121	0.210	0.103	-0.161	0.506	0.783
Cu	0.107	-0.069	0.972	0.173	0.082	0.040	0.523	-0.325	0.687	0.333	-0.152
Zn	0.298	0.152	0.758	0.545	0.130	-0.002	0.213	0.004	0.167	0.879	0.369
Mo	-0.540	-0.505	0.595	-0.206	0.237	-0.024	0.166	0.171	0.079	0.917	0.311
WHC	-0.049	0.254	0.199	0.936	0.080	0.100	-0.057	0.989	-0.073	-0.088	0.012
BD	0.027	-0.007	-0.174	-0.101	-0.888	-0.412	-0.068	0.054	-0.918	-0.160	0.203
UR	0.951	0.199	0.037	0.012	0.222	-0.078	0.956	0.107	0.196	0.104	-0.059
AP	0.063	0.138	0.063	0.113	0.883	-0.425	-0.133	0.155	-0.179	0.104	0.936
DH	0.243	0.740	-0.032	0.334	-0.524	0.079	0.845	0.072	-0.510	0.109	-0.019
R120	0.855	0.075	0.152	0.461	0.060	0.155	0.895	0.162	0.282	0.013	0.040
Wi	0.29	0.172	0.157	0.155	0.134	0.09	0.358	0.205	0.153	0.150	0.132

4- Statistical analysis

The data was statistically analyzed using SPSS version 25 and Microsoft Office Excel 2010. For laboratory measurements, descriptive statistics were performed, and all values were given as means standard deviations (SD). Duncan test was used to compare among all different data, whereas the means which holding at least one common letter are not significant, while the means which holding completely different letters are considered to be significantly different. The retained indicators for (MDS) were subjected to PCA. A Pearson correlation coefficient test was used to determine the significance of the correlation. $P \leq 0.01$ was considered statistically significant (Morgan *et al.*, 2004).

RESULTS AND DISCUSSION

1- Soil quality indicators:

More than 20 soil properties were evaluated which can affect the functions of nutrient cycles, water storage, biological activities, soil structure maintenance, carbon transformation, mineralization, and buffer capacity, were regarded as indicators. (Table 4) shows the studied soil properties range, mean and standard errors (S.E). Soil pH was slightly alkaline maximum value 7.98, non-significant differences ($P \geq 0.05$) were observed between both soil depths. It may come from calcareous of parent rocks that originated from limestone and dolomite of different formations (Buringh, 1960). The availability of essential nutrients to plants is affected by soil pH. Certain nutrients, such as iron, phosphorus, and manganese, may become less available to plants in alkaline soils, leading to nutrient deficiency. This can have an effect on plant health and growth (Zhao *et al.*, 2011). The electrical conductivity (EC) value for surface soil 10-30cm ranged from 237 to 718 $\mu S.cm^{-1}$, while it was 209 to 464 $\mu S.cm^{-1}$ for subsurface depth. Statistically significant differences ($P \leq 0.05$) were observed between both depths. Soil EC is an important characteristic that can influence plant growth, soil structure, and microbial activity. (Jacobs and Timmer, 2005; Verma *et al.*, 2015) reported that high EC values have been observed to harm plant growth, particularly the availability of essential nutrients to plants. High levels of sodium in the soil can interfere with nutrient uptake by plant roots, resulting in nutritional imbalances in which some nutrients become less available while others become more available, such high sodium levels can displace other cations like calcium and magnesium, which are necessary for plant health.

Table 4: Descriptive statistics of all soil indicators for Hawraman orchard soil, minimum and maximum values (Mean±S.E).

Soil properties	Surface (10-30cm)	Sub-surface (30-60cm)
pH	7.60-7.98^{a} 7.86-0.13	7.60-7.95^{a} 7.81-0.13
EC ($\mu S.cm^{-1}$)	237-718^{a} 381-16.1	209-464^{b} 285-10.4
SOM %	0.17-2.69^{a} 1.53-0.07	0.17-3.19^{a} 1.30-0.09
AVN ($mg.kg^{-1}$)	209-230^{a} 221-7.15	223-236^{b} 230-4.90
AVP ($mg.kg^{-1}$)	1.20-10.3^{a} 5.03-0.33	0.43-32.1^{b} 13.2-0.13
AVK ($mg.kg^{-1}$)	104-328a 163-7.25	75.6-232a 135-4.97
AVCa ($mg.kg^{-1}$)	13.0-23.0^{a} 18.0-0.27	13.0-18.0^{b} 21.5-0.59
AVMg ($mg.kg^{-1}$)	38.5-78.5^{a}	28.5-83.5^{b}

	59.9-1.27	46.3-1.97
Fe ($mg.kg^{-1}$)	26367-34512[a] 31004-28.42	24910-35911[a] 31471-36.5
Cu ($mg.kg^{-1}$)	32.7-66.5[a] 51.9-1.07	36.1-74.3[a] 50.2-1.24
Zn ($mg.kg^{-1}$)	51.7-88.4[a] 69.1-1.21	46.6-72.6[a] 65.2-0.83
Ni ($mg.kg^{-1}$)	24.1-55.3[a] 35.7-1.02	13.1-55.7[a] 38.5-1.46
Mn ($mg.kg^{-1}$)	1229-1554[a] 1385-12.6	1176-1462[a] 1333-9.20
Mo ($mg.kg^{-1}$)	3.35-6.34[a] 4.91-0.09	0.00-5.45[a] 4.13-0.18
CEC ($Cmole.kg^{-1}$)	55.1-79.8[a] 64.9-0.90	55.9-71.7[a] 64.9-0.61
BD ($g.cm^{-3}$)	1.57-1.71[a] 1.64-0.04	1.56-1.84[a] 1.67-0.08
$CaCO_3$ %	10.8-25.2[a] 19.3-0.47	7.33-23.7[b] 14.5-0.59
WHC %	6.60-13.2[a] 10.1-0.21	1.37-11.4[b] 5.53-0.31
UR (µg.g dry $soil.hr^{-1}$)	17.4-147.6[a] 78.8-4.31	5.82-114.1[b] 48.3-3.56
DH (µg TPF g^{-1} soil)	290-26649[a] 4070-94.45	289-27203[a] 8007-12.24
AP ($µg.g^{-1}.hr^{-1}$)	38.3-52.2[a] 48.1-0.49	41.3-53.7[a] 46.8-0.53
R120 (µg CO_2-C/g DW per 120hr.)	50.0-187.6[a] 106.3-5.32	37.5-168.8[a] 109.1-5.13

Basal soil respiration (R120) means values 106.3 and 109.1 µg CO_2-C/g DW per 120hr. Pass the optimum levels for soil quality, which coincided with high soil enzymes, microbial numbers, and high nutrient supplies. Basal soil respiration is an important soil quality indicator that provides knowledge regarding the potential for plant growth in a particular soil ecosystem. Their levels represent microbial

SOM ranged from 0.17 to the highest value of 3.19% for both surface and subsurface soil depths respectively, which can be classified as having a very low to moderate organic matter content. Depending on mean values (1.53 and 1.3%) it is regarded as a low type of organic matter content. It comes in accordance with the results of (Maulood and Darwesh, 2020; Maulood, 2022). Soil organic matter is essential for increasing soil structure, nutrient retention, water-holding capacity, and overall soil fertility. the availability of nutrients is functionally dependent on organic matter, it serves as a reservoir for these nutrients supply.

The AVN is high in both soil depths that exceed the maximum limits in the soils (Table 1). The availability of nitrogen in the soil regulates several aspects of tree growth and ecosystem dynamics. It is a necessary component for chlorophyll synthesis, essential for the production of protein required for plant tissue growth, and has an important role in leaf and root development; its deficiency results in nutrient imbalance and decreased uptake of other nutrients. AVP was considered a deficient nutrient in the soil with mean values of 5.03 and 13.3 $mg.kg^{-1}$, which was less than the minimum level for a healthy soil (Table 1). It may be coming from high soil pH that causes AVP shortage and reduces their availability for plant growth (Walpola and Yoon, 2013). AVP deficiency harms tree growth by causing poor root development, reduced photosynthesis rate, delayed flowering and fruit production, and soil nutrient imbalance (Khan *et al.*, 2018). Both available Ca and Mg values are relatively within the normal range. Generally, soil heavy metals (Fe, Cu, Ni, Mo, Mn, Cu) exceeded their standard ranges as mentioned in (Table 1). These metals are necessary micronutrients for plant growth and play important roles in a variety of physiological processes.

When present in high concentrations, however, they can be toxic to plants and have harmful effects on plant growth and development. Statistically non-significant differences ($P \geq 0.05$) were found between both depths. High levels of heavy metals have very harmful effects on plant growth. Fe toxicity can cause leaf bronzing, reduced root growth, and stunted plant development. While high Mn and Cu concentrations can cause leaf necrosis, decreased root growth, and restricted nutrient uptake. It can also interfere with photosynthesis. However, Zn and Ni toxicity was reported on leaf and root damage, reduced root growth, and impaired nutrient absorption (Prasad *et al.*, 1999; El-Meihy *et al.*, 2019).

Studied orchard soils characterized by high CEC exceeding the maximum standardized levels for soil quality (Table 1) with a mean value of 64.9 $Cmole.kg^{-1}$. (Raman and Sathiyanarayanan, 2009) reported that CEC is an important property for determining soil quality and supporting optimal plant growth. Soils with higher CEC are more fertile, have better nutrient retention and water-holding capacity, greater buffering capacity, and are most suitable for agriculture and horticulture. The results of bulk density (BD) in both soil depths were lower than the maximum level (2.2 $g.cm^{-3}$) and the mean values are 1.64 and 1.67 $g.cm^{-1}$, respectively (Table 4).

Bulk density is an important function in soil quality and agriculture management because it provides information about soil structure, porosity, compaction, and overall health. It has a direct impact on plant growth, water availability, and nutrient cycling, making it an important tool for measuring and assessing soil quality (Imhoff *et al.*, 2016). Bulk density is inversely related to soil porosity and water retention. High BD produces soil compaction and inhibits root growth (Tanure *et al.*, 2019). The soil texture for the Hawraman walnut orchard is classified as sandy clay loam. The same results were mentioned by (Maulood and Darwesh, 2020). WHC was lower than the minimum limits for soil quality standards and their values were less than 10%. The mean value was 10.1 and 5.53% for both soil depths, with statistically significant differences ($P \leq 0.05$) between them. Low water content may affect most other soil functions, microbial activities and root growth. Water holding capacity is an important soil indicator that influences plant growth through regulating water availability, drought tolerance, nutrient availability, root growth, and overall soil health. Proper soil moisture management can result in healthier and more productive plant conditions (Xia *et al.*, 2017).

Soil enzymes are essential elements of soil biology and play a crucial role in a variety of soil functions that are directly related to plant growth and overall soil health. These enzymes facilitate chemical reactions in the soil, regulating nutrient cycling, organic matter decomposition, and the availability of essential nutrients for plants (Kumar *et al.*, 2021). Both measured UR and DH enzymes are higher than the maximum limits of soil quality standards (Table 1), and their mean values for surface and subsurface soils are (78.8 and 43.3 µg.g dry $soil.hr^{-1}$) and (4070 and 8007 µg TPF g^{-1}) soil respectively (Table 4). Significant differences ($P \leq 0.05$) for UR content between both soil depths were recorded, with higher UR values in surface soil (10-30cm) than in subsurface soil (30-60cm). High soil UR enzyme coincided with high AVN content in orchard soil. UR plays an important role in the nitrogen cycle and their availability (Adetunji *et al.*, 2017). However, DH enzyme is responsible for SOM decomposition, nutrients mineralization and nutrients cycling (Wolińska and Stępniewska, 2012). Microbial activities and Basal soil respiration (R120) is directly related to DH enzyme.

On the other hand, the optimum level of AP enzyme was measured in both soil depths and never passed the maximum levels in soil quality standards. It may be due to optimum soil pH values (lower than pH 8) and deficiency of AVP during the studied period. The same results were referred to it by (Maulood and Darwesh, 2020).

activity, nutrient availability, organic matter decomposition, and ecosystem functioning (Mustafa *et al.*, 2022).

2- SQI Models:

The soil quality index was divided into five classes: Very low (<0.38 as class V), low (0.38-0.48 as class IV), moderate (0.48-0.58 as class III), high (0.58-0.68 as class II), and very high (>0.68 as class I) soil quality (Isong *et al.*, 2022). The SQI for Hawraman walnut orchard soil under investigation was varied Fig. (1). Based on additive SQI values for both depths, the SQI values of 0.38 reported in surface soil 10-30cm regarded as class V as low type, while subsurface soil 30-60cm with SQI value 0.37 classified as Class V very low type.

Fig. (2) shows the overall percentage of various soil functional influences in SQI_W. The main participation % for soil functions in this model were NSC at 38.2%, WSC at 26.3, RDC at 25.2%, and BF at 10.3% for surface soil 10-30cm. While, subsurface soil 30-60cm depth has nearly the same contribution percentage as surface soil with values of 38.4, 24.9, 26.7, and 10% for NSC, WSC, RDC, and BF respectively. No clear variations in soil function contribution percentage were observed between both soil depths. Most influences % for SQIw models comes from NSC whereas, BF had the lesser effect. The results above have had an effect on the SQIw value. For surface soil SQIw value was 0.377 considered as Class V and classified as very low type soil quality. Meanwhile, the subsurface soil depth SQIw value was slightly higher than 0.397 with the Class V category and low type soil classification. One of the weaknesses of this model is the reliance on the opinion of the researcher or literature review for setting weight values for the soil indicators, which may not reflect the reality of the soil for this place, or it may be due to the use of a number of soil indicators for calculate SQI, which may not be essential or of great importance. The same finding was reported by (Mukherjee and Lal, 2014; Maulood and Darwesh, 2020).

For SQI_{PCA} type (surface soil 10- 30cm), six PCs were retained that explained 100% of the variance from the original data with an eigenvalue of more than one (Table 3). The highest eigenvectors under each PC were retained for MDS (boldface value). For the first component, the highly weighted variables were: CEC, UR, EC, R120, AVN, AVP, and $CaCO_3$. PC_2 is represented by SOM, DH, Ni, AVN, AVCa, and $CaCO_3$. For PC_3 each of Cu, Fe, Mn, and Zn was highly weighted. While WHC and pH were selected under PC_4. Meanwhile, PC_5 is represented by each of BD, AP, pH, and AVK. Finally, PC_6 candidate by only AVMg. As mentioned before for selecting MDS all variables were subjected to the Pearsons correlation coefficient test. When the retained variables were correlated, only the highest eigenvector weight was chosen and the others eliminated, however the non-correlated indicator for each PC was considered essential and remained for MDS. The results of the correlation between soil indicators are shown in (Table 5), (the boldface values represent soil surface 10-30cm). Highly significant correlation ($P \leq 0.01$) between CEC and each of EC, R120, UR, AVN, AVP, and $CaCO_3$ with correlation values of (0.944, 0.844, 0.925, -0.850, 0.819, and -0.746) respectively. Also, a significant correlation between soil indicators retained in PC_2 to PC_6 was found. Then only the highest eigenvectors for each PC were selected for MDS (boldface underlined values), CEC> SOM> Cu> WHC> BD> AVMg, and used for SQI_{PCA} calculation.

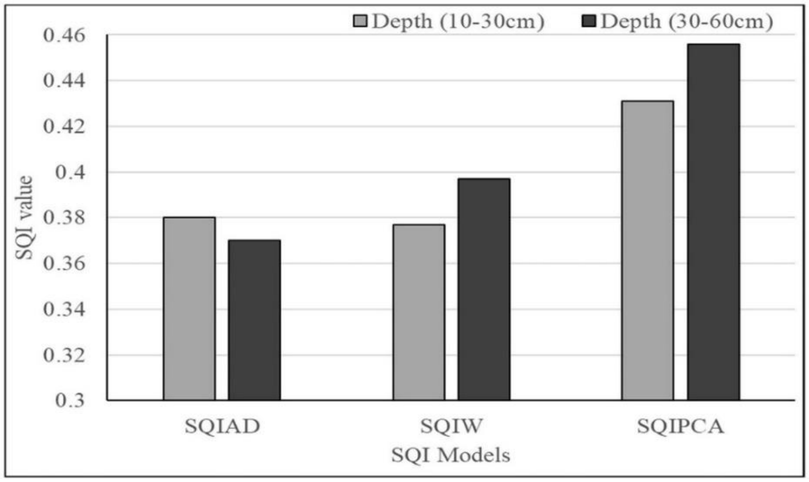

Fig. 1: Values of soil quality index for the soil of Hawraman orchard at two depths.

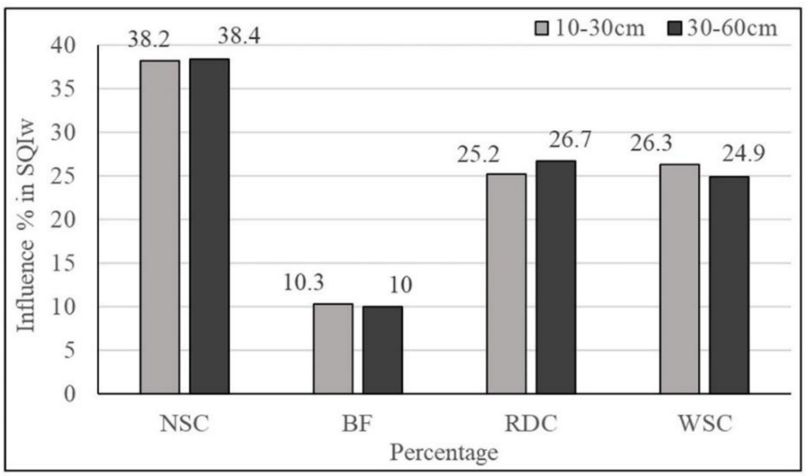

Fig. 2: The percentage participation of each soil function in SQI_W under different soil conditions. Abbreviation: NSC stands for nutrient storage capacity, BF stands for biological factor, RDC stands for root development capacity, and WSC stands for water storage capacity.

These retained soil indicators under each PC are important for the interpretation and assessed condition of the soil in order to manage the orchard soil in the correct manner. PC_1 represents nutrient holding capacity Fig. (3). The PC_2 corresponds to nutrient supply and biological activities. Heavy metals and nutrient supply are explained in PC_3. While PC_4 is interpreted by water storage and retention. PC_5 and PC_6 root resistant capacity.

For subsurface soil 30-60cm, only five PCs was remained with 96.24% explained of cumulative variance (Table 3). The high weighted eigenvectors under PC_1 obtained are: UR, AVMg, DH, R120, pH, EC, AVN, CEC, and AVCa. The PC_2 represented by WHC, $CaCO_3$, AVK, and SOM. For PC_3 high retained variables are BD, Cu, AVK, and EC with values (-0.918, 0.687, 0.671 and 0.718) respectively.

While Mo, Zn, Fe, and Mn with highly weight were selected in PC_4. However, PC_5 characterized by other variables such as AP, Ni, CEC, and AVP with high eigenvectors value. If return to (Table 5) it was found that all variables under each PC have a significant correlation ($P \leq 0.01$) with each other. So, only the highest eigenvectors will be selected for SQI calculation. The first two components represented the biological activities and water storage in the orchard soil. While PC_3 corresponded to soil compact, water retention, and soil health assessment. PC_4 related directly to nutrient supply by heavy metals. Meanwhile, PC_5 interpreted nutrient storage capacity (Gelaw *et al.*, 2015).

Most researchers prefer to calculate SQI with PCA statistical tools because of its accuracy and decrease soil indicators to a lesser within MDS by giving weighting for each component that avoids resorting to the opinions of authors who may sometimes not be accurate in giving weights to some soil indicators (Estrada-Herrera *et al.*, 2017; Monsalve Camacho *et al.*, 2021). Generally, SQI_{PCA} obtained higher SQI values than the other two previous models. For surface soil 10-30cm the SQI value was 0.530 categorized as Class III and classified as moderate soil quality type. Whereas subsurface soil 30-60cm gets a greater value of 0.665 classified as high soil quality with the Class II categorization. These may be good results for walnut trees because adult walnut trees have a shallow root network compared to young trees with deep root types. (Germon *et al.*, 2016) mentioned that the mature walnut trees, develop a more extensive lateral root system closer to the surface. This lateral root system allows the tree to acquire nutrients and moisture from the top layers of soil in addition to making the tree more stable in windy conditions.

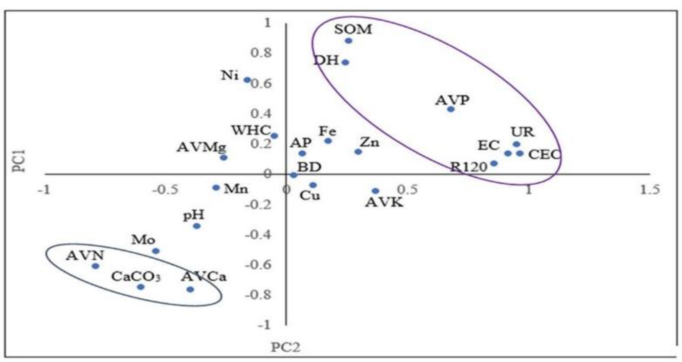

Fig. 3: Principal component analysis (PCA) scatterplot for soil indicators (10-30cm depth).

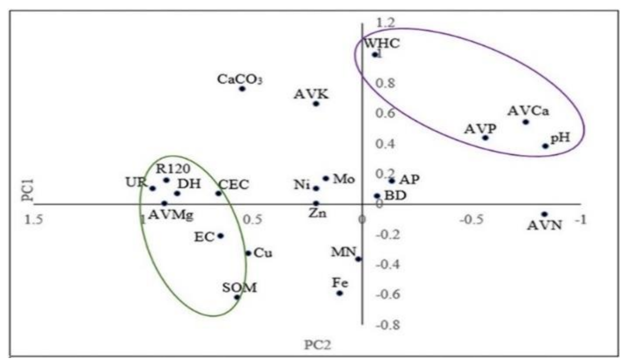

Fig. 4: Principal component analysis (PCA) scatterplot for soil indicators (30-60cm depth).

Table 5: Pearson correlation coefficients (r) were calculated for surface soil (10-30cm) in bold and subsurface soil (30-60cm) in italic font.

	pH	EC	SOM	AVCa	AVMg	$CaCO_3$	AVN	AVP	AVK	CEC	Mn	Fe	Ni	Cu	Zn	Mo	WHC	BD	UR	AP	DH
pH		-0.174	-0.345	0.638**	0.121	0.531*	0.588**	-0.608**	0.036	-0.383	0.249	-0.310	-0.697**	-0.089	-0.425	0.636**	-0.591**	-0.486*	-0.249	0.404	-0.868**
EC	-0.877**		0.262	-0.300	-0.222	-0.676**	-0.787**	-0.652**	0.180	0.944**	-0.184	0.058	-0.198	-0.005	0.067	-0.513*	-0.350	0.037	0.881**	-0.018	0.218
SOM	-0.789**	0.762**		-0.900**	0.048	-0.778**	-0.726**	0.505*	0.253	0.329	-0.234	0.327	0.446*	0.049	0.391	-0.545*	0.439*	-0.239	0.499*	0.474*	0.628**
AVCa	0.883**	-0.564**	-0.622**		-0.215	0.720**	0.788**	-0.491*	-0.087	-0.394	0.451*	-0.276	-0.568**	-0.012	-0.418	0.688**	-0.489*	-0.116	-0.559**	-0.313	-0.764**
AVMg	-0.851**	0.655**	0.389	-0.804**		0.329	0.172	-0.663**	-0.693**	-0.418	-0.545*	-0.451*	0.113	-0.375	-0.390	-0.038	-0.305	0.534*	-0.195	0.229	-0.048
$CaCO_3$	-0.151	0.125	-0.213	-0.068	0.503*		0.491**	-0.888**	-0.241	-0.746**	0.080	-0.342	-0.374	-0.059	-0.325	0.698**	-0.208	0.082	- 0.695**	0.001	-0.742**
AVN	0.853**	-0.923**	-0.664**	0.547*	-0.773**	-0.466*		-0.835**	-0.212	-0.850**	0.281	-0.287	-0.311	-0.047	-0.351	0.765**	-0.172	-0.066	-0.851**	-0.056	-0.708**
AVP	0.682**	-0.399	-0.485*	0.851**	-0.574**	-0.198	0.416		0.447*	0.819**	0.090	0.459*	0.286	0.217	0.462*	-0.589**	0.339	-0.135	0.667**	-0.203	0.655**
AVK	-0.139	0.465*	-0.041	0.207	0.216	0.659**	-0.582**	0.036		0.389	0.239	0.511*	-0.282	0.469*	0.631**	0.085	0.509*	-0.828**	0.459*	0.499*	-0.172
CEC	-.0708**	0.622**	0.273	-0.667**	0.774**	0.585**	-0.704**	-0.771**	0.520*		-0.138	0.247	-0.082	0.136	0.307	-0.559*	-0.044	-0.045	0.925**	-0.031	0.342
Mn	-0.300	0.316	0.470*	-0.243	0.032	-0.279	-0.195	-0.225	-0.084	0.060		0.650**	0.173	0.729**	0.391	0.703**	0.015	-0.338	-0.304	-0.205	-0.194
Fe	-0.384	0.140	0.363	-0.586**	0.219	-0.299	-0.023	-0.573**	-0.424	0.228	0.807**		0.525*	0.939**	0.277	0.530*	-0.281	0.241	0.113	0.265	0.463*
Ni	-0.261	0.054	-0.244	-0.472*	0.490*	0.420	-0.115	-0.631**	0.162	0.740**	0.109	0.464*		0.332	0.456*	-0.188	0.498*	0.430	-0.122	-0.298	0.800**
Cu	-0.801**	0.916**	0.845**	-0.514*	0.485*	-0.030	-0.814**	-0.383	0.324	0.462*	0.653**	0.401	-0.010		0.863**	0.539*	0.344	-0.272	0.140	0.134	-0.038
Zn	-0.412	0.340	0.064	-0.443*	0.473*	0.221	-0.318	-0.469*	0.219	0.613**	0.644**	0.712**	0.782**	0.446*		0.132	0.696**	-0.294	0.377	0.265	0.275
Mo	-0.264	0.201	-0.054	-0.297	0.384	0.331	-0.245	-0.366	0.257	0.527*	0.641**	0.657**	0.750**	0.343	0.971**		-0.160	-0.294	-0.540*	0.130	-0.719**
WHC	0.476**	-0.311	-0.655**	0.598**	-0.088	0.743**	0.030	0.456*	0.606**	-0.001	-0.429	-0.632**	0.051	-0.424	-0.103	0.076		-0.244	0.033	0.179	0.449*
BD	0.414	-0.767**	-0.411	0.020	-0.181	0.163	0.567**	-0.142	-0.520*	-0.218	-0.350	0.029	0.153	-0.734**	-0.272	-0.161	0.161		-0.148	-0.631**	-0.406
UR	-0.851**	0.765**	0.533*	-0.663**	0.929**	0.588**	-0.916**	-0.431	0.377	0.681**	0.079	0.064	0.220	0.626**	0.326	0.271	0.017	-0.310		0.320	0.259
AP	0.156	-0.280	-0.391	-0.091	-0.020	0.365	0.203	-0.532*	0.191	0.501*	-0.137	0.169	0.758**	-0.326	0.353	0.375	0.190	0.412	-0.219		-0.343
DH	-0.545*	0.186	0.208	-0.662**	0.801**	0.539*	-0.435*	-0.454*	-0.129	0.433	-0.092	0.184	0.328	0.097	0.196	0.207	0.044	0.367	0.742**	-0.034	
R120	-0.740**	0.712**	0.604**	-0.524*	0.720**	0.649**	-0.911**	-0.504*	0.521*	0.677**	0.134	0.016	0.130	0.644**	0.224	0.220	0.109	-0.219	0.884**	-0.046	0.598**

*Correlation is significant at 0.05 levels **Correlation is significant at 0.01 levels.

Hawra … luctivity in
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efficient technique for soil quality assessment is SQI_{PCA} than the other two applied models. From the obtained results, it can be suggested that the use of SQI and PCA in fields related to assessing soil quality, whether for soil productivity or pollution, helps the specialists more easily in decision-making.

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تأثير خصائص التربة على النمو وإنتاجية أشجار الجوز في منطقة هورامان، السليمانية- العراق

بخشان مصطفى مولود

قسم علوم الحياة/ كلية العلوم/ جامعة صلاح الدين/ أربيل/ العراق

الملخص

دليل نوعية التربة (SQI) هو أداة تقييم كمية أو نوعية تستخدم لتقييم الصحة العامة ونوعية التربة في منطقة معينة. تركيز صفات وخصائص التربة المختلفة في رقم أو تصنيف واحد، يسمح لأداري الأراضي والمزارعين والباحثين بفهم ومراقبة صحة التربة. لذلك، فإن الهدف من هذه الدراسة هو مقارنة ثلاث تقنيات مستخدمة على نطاق واسع لتقدير دليل جودة التربة (SQI) باستخدام بيانات من 42 عينة تربة تم جمعها من تربة بساتين قرية بلخة في منطقة هورامان على عمقين (التربة السطحية 10–30 سم والتربة تحت السطحية 30–60 سم). بشكل عام، كانت معظم مؤشرات التربة لكلا عمقي التربة متقاربة في قيمها، مما انعكس نتائجها على دلائل جودة التربة المحسوبة التي لم تختلف بشكل كبير عند كل عمق تم فحصه. كانت قيم دليل التربة للتربة السطحية وتحت السطحية (0.38 و0.37) لـ SQI_{SA}، بينما (0.377 و0.379) لنوع SQI_W و (0.530 و0.665) لـ SQI_{PCA}. اعتمادًا على SQI_W، تم الحصول على نسبة مساهمة متشابهة نسبيًا لكلى عمقي التربة مع أعلى نسبة من سعة إمداد المغذيات (NSC) بنسبة 38%، وسعة نمو الجذور (RDC) وسعة تخزين المياه (WSC) عند حوالي 25–26%، وهي أدنى نسبة وكانت نسبة المساهمة للعوامل البيولوجية (BF) 10%. يعد SQI_{PCA} نموذجًا أكثر كفاءة من النموذجين الآخرين، ومن المتوقع إجراء المزيد من الدراسات حول الكشف عن دليل التربة من خلال هذه التقنية.

الكلمات الدالة: مؤشرات التربة، شجرة الجوز، بساتين منطقة هورامان، دليل نوعية التربة، تحليل مكونات الرئيسة.