Eurasian J Soil Sci 2018, 7 (1) 73 - 86

Eurasian Journal of Soil Science

Journal homepage : http://ejss.fesss.org

Evaluation of land suitability for main irrigated crops in the North-Western Region of Libya

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Abstract

Land suitability analysis can help to achieve sustainable crop production with a proper use of the natural resources. The current study was carried out on the soils of north-western area of Libya to assess their morphological, physical and chemical properties and their suitability for growing irrigated crops. The studied area lies between latitudes 32° 30′ 00.9" and 32° 57′ 34.2'' N and between longitudes 11° 35′ 08.4" and 11° 45′ 09.2" E. Two suitability methods (Sys &Verhey and Storie methods) were used to assess the land suitability of this area. According to Sys and Verhye method, the soils of the studied area varied in the suitability for irrigation between highly suitable (S1) to marginally suitable (S3). However, according to modified Storie index method the soils productivity, ranged from excellent (grade 1) for agriculture to non-agricultural (grade 6). The modified Storie index method was more effective in assessing the land suitability of this area. The drip irrigation system was also more suitable than surface irrigation method for most of the soils of the studied area. The indeces of soil suitability rating and percentage for growing alfalfa, sorghum, barley, maize, millets, wheat and safflower were higher compared to those for growing soybean, sunflower and sesame. Onion and green pepper crops were moderately suitable to be grown in 42% of the soils of the studied area while the other vegetables were not suitable to be grown in most of the soils of the studied area. The evaluated fruit trees could be arranged according to the soil suitability rating and percentage in the order of date palm > olives > guava > citrus > banana. The results also revealed that the studied area has a good potential to produce the selected crops under irrigation provided that the water requirements for these crops are met. The main limiting factors for land suitability for growing crops are soil texture, soil depth, calcium carbonate, alkaline pH and soil salinity.

Article Info

Received : 13.07.2017
Accepted : 05.09.2017

Keywords: Land evaluation, irrigation methods, suitability for crops.

Introduction

Libya is one of the developing countries that are searching for alternatives in order to increase food production due to the rapid increase of population, particularly in the northern region (Elaalem, 2010). This region has significant natural resources, such as soil, water, natural vegetation and suitable climate as well as human resources. Approximately 70 percent of Libyan people live in this region (Ben Mahmoud et al., 2000). Libya is an arid country where water resources are divided into surface water and groundwater. The groundwater represents more than 97 percent of the water resources. The country aims to obtain self-sufficiency in agricultural products (Nwer, 2005). The assessment of land response to certain uses is necessary to reach the sustainable management of the land (Kamali et al., 2012). Land evaluation is a tool of land use planning for sustainable agriculture (Shahbazzi et al., 2009).

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e-ISSN: 2147-4249
DOI: 10.18393/ejss.337218

The agricultural land suitability assessment is defined as the process of land performance assessment when the land is used for alternative kinds of agriculture (Prakash, 2003; Mu, 2006; He et al., 2011; Darwish and Abdel Kawy, 2014; Diallo et al., 2016; Ahmed, 2016). The principle purpose of the agricultural land suitability evaluation is to predict the potential land and its limitation for crop production (Pan and Pan, 2012; AbdelRahman et al., 2016). In Northern Libya, evaluating the land suitability for crops is vital for land use planning and agricultural development.

The main objective of this research is to assess the morphological, physical and chemical properties of the soils of selected areas of the north-western region of Libya and their suitability for growing the main crops (Field crops, vegetables and fruits trees) and their potentiality after correcting some limitation factors.

Material and Methods

Field description and soil sampling

The area under investigation is located in the North-Western area of Libya. It lies between latitudes of 32° 30′ 00.9" and 32° 57′ 34.2'' N and between longitudes of 11° 35′ 08.4" and 11° 45′ 09.2" E (Figure 1). Twelve soil profiles representing the area under study were selected on the basis of available geomorphologic information. These profiles were dug up to the bedrock or to the extremely hard layer and described for their morphological characteristics according to the standard procedures (Fanning and Fanning 1989; FAO, 2006; Soil Survey Staff, 2014). Soil samples were collected in clean bags from profile layers based on the morphological variations in the soil profiles. The samples were transferred to the laboratory air dried, crushed, sieved with a 2 mm-sieve and kept for different soil analysis. Soil color for both dry and moist samples was determined using Munsell color charts (Soil Survey Staff, 1975).

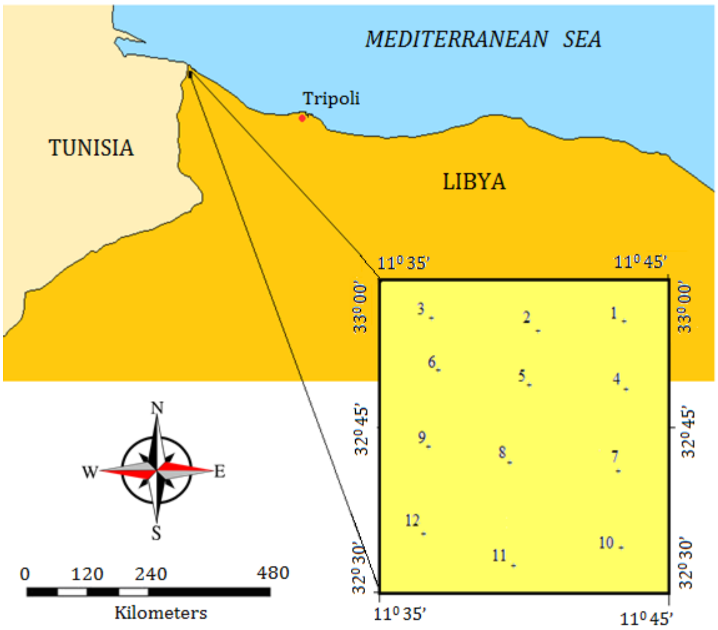


Figure 1. The location map of the study area

Climate of the Study Area

Northern Libya is situated in the Mediterranean climatic zone that is characterized by a hot and dry summer with cold and rainy winter. The most important climatic characteristics that are necessary for the suitability determination (temperature, rainfall, relative humidity, etc.) were collected from Zuara metrological station (last thirty years). The mean annual temperature was 19.4 °C, with a maximum temperature of 24.1 °C and a minimum temperature of 14.6 °C. The average annual rainfall was 188.0 mm/y and the relative humidity was 75 %, while the average annual evaporation was 1504 mm/year.

Laboratory analysis

Some physical and chemical properties of the soil samples were determined. Particle size distribution was performed on the studied soils samples according to Gavlak et al. (2005). Soil reaction (pH) of a 1:1 soil to water suspension was measured using a glass electrode. Calcium carbonate ($CaCO_3$) was determined using a calibrated Collie's calcimeter (Nelson, 1982). Soil salinity (ECe) in the saturated soil paste extract was determined using a conductivity meter (Rhoades, 1982). Determination of gypsum was done in a reference to a graph showing the relation between the concentration and electrical conductivity of gypsum solution (Nelson, 1982). The exchangeable sodium percentage (ESP) was calculated. Exchangeable sodium was estimated using ammonium acetate method while the cation exchangeable capacity (CEC) was determined using the sodium oxalates method (Bashour and Sayegh, 2007). The soil organic matter was estimated using Walkley-Black method (Bashour and Sayegh, 2007).

Soil classification

The prevailing climate of the studied area is extremely arid and the dominant soil moisture regime is aridic (torric) with a thermic soil temperature regime. The soils were classified up to the sub group according to Soil Taxonomy (Soil Survey Staff, 2014).

Land capability evaluation

Qualitative land suitability studies were conducted using both simple limitation methods and other information of climatic conditions. Two methods in determining the total ranking of each specific land unit were applied and their outcomes were compared with soil productivity. These methods included i) Simple limitations and ii) modified Storie index.

1. Simple limitations method (Sys and Verhey, 1978)

To evaluate the land suitability for irrigation, the parametric evaluation system of simple limitations (Sys and Verhye, 1978) was applied using soil characteristics. These characteristics deal with the environmental factors of drainage properties, soil physical and chemical properties. They are rated and used to calculate the capability index for irrigation (Ci) according to the formula:

$$Ci = (t \times W/100 \times S1/100 \times S2/100 \times S3/100 \times S4/100 \times n/100)$$

Where: t is the topographic rating, W is the wetness rating, S1 is the soil texture rating; S2 is the soil depth rating, S3 is the soil calcium carbonate status, S4 is the soil gypsum status and n is the soil salinity and alkalinity rating.

2. Modified Storie index (O'Geen, et al., 2008).

The Storie index (Storie, 1978) is a semi-quantitative rating method of soils that is used mainly for irrigated agriculture based on crop productivity data that are collected from major California soils in the 1920s and 1930s (O'Geen et al., 2008). The Storie index assesses the productivity of the soil using four characteristics factors of A, B, C and X; with a score ranging from 0 to 100 % that is determined for each factor. So, the original Storie index has been modified (O'Geen et al., 2008), and following the modified version was used in this study.

$$\text{Storie index rating} = [(A/100) \times (B/100) \times (C/100) \times (X/100)] \times 100$$

Where: Factor A is the degree of soil profile development, factor B is the surface texture, factor C is slope and factor X is other soil and land scape conditions including drainage, alkalinity, fertility, acidity, erosion, and microrelief subfactors.

Land suitability assessment

1. Land suitability for irrigation

The comparison among the different irrigation methods based on the parametric evaluation system was carried out according to the methods suggested by Sys et al. (1991). These parameters were slope, drainage properties, electrical conductivity, calcium carbonates status, soil texture and Soil depth. The Suitability index for irrigation (Ci) was developed using the following equation:

$$Ci = (A \times B/100 \times C/100 \times D/100 \times E/100 \times F/100)$$

Where: A is the soil texture rating, B is the soil depth rating, C is $CaCO_3$ status, D is the electrical conductivity rating, E is the drainage rating and F is the slope rating.

2. Land suitability for field crops, vegetables and fruit trees

The quantitative analysis of the environmental conditions and soil characteristics were used to estimate the soil suitability for certain crops (SSCC). Ten field crops (wheat, barley, sesame, alfalfa, maize, sorghum, millets, safflower, soybean and sunflower), five vegetables crops (beans, tomato, potato, onion and green pepper) and five fruit trees (date palm, olive, guava, citrus and banana) were selected to assess their suitability to be grown in the studied area. The soil characteristics of the investigation profiles and the crop requirement parameters were matched to obtain the suitability classes according to Sys et al. (1993).

Results and Discussion

1. Morphological characteristics

The main morphological aspects of the studied soil profiles are shown in Table 1. The results reveal that the topography of the landscape is almost flat to gentle sloping. The soils have a depth which varies from deep to very deep and fairly well drained, having a sandy texture. Soil structure differs with depth. It has single grains in the top surface layers of all soil profiles and week to massive platy and subangular blocky structure in the subsoil layers. Wet consistence agrees well with soil texture and it is loose and very friable to friable while dry consistence is soft to extremely hard. The dominant soil color in the studied soil profiles is brown (7.5YR 5/4, dry to 7.5YR 4/4, moist) to strong brown (7.5YR 5/6, dry) to brown (7.5YR 4/4, moist). However, reddish yellow (7.5YR 6/6, dry) to strong brown (7.5YR5/6, moist) is also detected. In general, the soil color seems to be affected by calcium carbonate content and soil depth. The layer boundaries of all profiles are abrupt in distinctness and smooth in topography.

Table 1. Morphological description of the studied soil profiles.

Profile No	Depth (cm)	Soil Color			Texture (I)	Soil Structure (II)			Consistence (III)		Boundary (IV)
		Hue	Dry	Grade		Grade	Size	Type	Dry	Moist	
1	0 -25	7.5 YR	6/6	5/6	S	-	-	sl	so	loose	as
	25 - 70	7.5 YR	7/6	6/6	S	1	f	pl	slh	friable	as
	70 - 95	7.5 YR	8/3	7/3	S	2	m	pl	slh	friable	as
	95 - 160	7.5 YR	7/6	6/6	S	3	m	pl	h	friable	-
2	0 - 35	7.5 YR	5/6	4/4	S	-	-	sl	so	loose	as
	35 - 115	7.5 YR	5/6	4/4	LS	1	f	pl	slh	v-friable	as
	115 - 160	7.5 YR	6/4	5/6	SL	2	m	pl	h	friable	-
3	0 - 20	7.5YR	7/6	5/6	SL	-	-	sl	so	loose	as
	20 - 40	5YR	7/6	5/6	S	1	f	sbk	h	friable	as
	40 - 110	7.5YR	7/4	6/6	SL	2	m	sbk	vh	friable	-
4	0 - 25	7.5 YR	6/8	5/8	LS	-	-	sl	so	loose	as
	25 - 120	7.5 YR	6/6	5/6	S	-	-	sl	so	loose	as
	120 - 150	7.5 YR	6/6	5/6	S	1	f	pl	slh	friable	-
5	0 - 30	7.5 YR	6/8	5/8	LS	-	-	sl	so	loose	as
	30 - 50	7.5 YR	6/6	5/6	LS	2	m	pl	exh	friable	-
6	0 - 20	7.5 YR	5/4	4/4	S	-	-	sl	so	loose	as
	20 - 65	7.5 YR	5/4	4/4	S	1	f	sbk	slh	v-friable	as
	65 - 130	7.5 YR	5/4	4/4	S	2	m	sbk	vh	friable	-
7	0 -30	7.5 YR	5/4	4/4	S	-	-	sl	so	loose	as
	30 - 65	7.5 YR	5/4	4/4	SL	1	f	pl	slh	v-friable	as
	65 - 100	7.5 YR	5/6	4/4	LS	1	f	sbk	h	friable	as
	100 - 150	10 YR	5/4	3/3	LS	2	m	sbk	h	friable	-
8	0 - 20	7.5 YR	5/6	4/4	S	-	-	sl	so	loose	as
	20 - 60	7.5 YR	5/4	4/4	LS	1	f	pl	h	friable	as
	60 - 90	7.5 YR	5/8	4/4	LS	2	m	pl	h	friable	as
	90 - 150	7.5 YR	5/4	4/4	LS	3	co	sbk	vh	friable	-
9	0- 30	7.5YR	7/6	6/6	S	-	-	sl	so	loose	as
	30 - 50	5YR	6/6	5/6	S	-	-	sl	exh	loose	-
10	0 -15	7.5 YR	5/6	4/4	SL	-	-	sl	so	loos	as
	15 - 50	7.5 YR	6/4	5/6	SL	1	f	sbk	slh	v-friable	as
	50 - 150	7.5 YR	6/4	5/6	S	2	m	sbk	h	friable	-
11	0 - 40	7.5 YR	5/4	4/4	LS	-	-	sl	so	loos	as
	40 - 90	7.5 YR	5/4	4/4	SL	1	f	sbk	slh	v-friable	as
	90 - 120	7.5 YR	5/4	4/4	SL	2	m	sbk	h	friable	-
12	0 - 35	7.5 YR	5/6	4/4	SL	-	-	sl	so	loos	as
	35 - 70	7.5 YR	5/6	4/4	SL	1	f	pl	vh	friable	-

Abbreviations:

Texture (1) : S = Sand, LS= Loamy Sand and SL= Sandy Loam.

Soil structure (II) : 1= weak, 2= moderate, 3=strong, f=fine m=medium, co= coarse, sl=structureless, pl=platy, sbk= subangular blocky.

Consistence (III) : so = soft, slh = slightly hard, h= hard, vh= very hard, and exh = extremely hard.

Boundary (IV) : as = abrupt smooth

2. Soil properties

Selected soil physical and chemical properties of the study area are shown in Tables 2 and 3. Soil texture throughout the entire depth of these soil profiles is coarse and varies between sand to sandy loam. Most of soil samples are dominated by free calcium carbonate (<100 g/kg) with a few exceptions (subsurface layers of profiles 3, 7 and 11) that are slightly or moderately calcareous (>100 g/kg) (FAO, 2006). The results also reveal that the gypsum content is very low and ranges between 0.1 and 49 g/kg, with a few exceptions of the subsurface layers of profile 5 and 6 that have a medium level of gypsum of 74.5 and 73.1 g/kg, respectively, (FAO, 1988).

Table 2. Soil texture, calcium carbonate ($CaCO_3$) and gypsum contents as well as calcification of the investigated soil profiles

Profile No.	Depth, cm	Soil Texture, Grade	$CaCO_3$, g/kg	Gypsum, g/kg	Classification
1	0 -25	Sand	34	0.1	Typic Torripsamments
	25 - 70	Sand	49	0.4	
	70 - 95	Sand	94	0.5	
	95 - 160	Sand	20	0.4	
2	0 -35	Sand	10	0.6	Typic Torripsamments
	35 - 115	Loamy Sand	22	0.6	
	115 - 160	Sandy Loam	80	0.3	
3	0 – 20	Sandy Loam	56	0.9	Typic Haplocalcids
	20 – 40	Sand	86	1.9	
	40 - 110	Sandy Loam	329	32	
4	0 – 25	Loamy sand	41	0.8	Typic Torripsamments
	25 - 120	Sand	26	6.9	
	120 – 150	Sand	40	0.5	
5	0 – 30	Loamy sand	86	0.6	Lithic Petrogypsids
	30 – 50	Loamy sand	23.6	74.5	
6	0 -20	Sand	30	0.3	Typic Haplogypsids
	20 – 65	Sand	77	0.9	
	65 130	Sand	35	73.1	
7	0 – 30	Sand	26	0.7	Typic Natrargids
	30 – 65	Sandy Loam	44	6.6	
	65 – 100	Loamy sand	72	43.7	
	100 – 150	Loamy Sand	158	41.2	
8	0 – 20	Sand	26	1.0	Typic Haplosalids
	20 – 60	Loamy Sand	85	36.2	
	60 – 90	Loamy Sand	96	43.6	
	90 - 150	Loamy Sand	70	43.4	
9	0 - 30	Sand	57	0.4	Lithic Torripsamments
	30 - 50	Sand	49	0.5	
10	0 – 15	Sandy Loam	42	0.6	Typic Torriorthents
	15 – 50	Sandy Loam	15	0.5	
	50 – 150	Sand	27	0.5	
11	0 – 40	Loamy Sand	59	0.5	Typic Haplocalcids
	40 – 90	Sandy Loam	82	1.0	
	90 - 120	Sandy Loam	23	49	
12	0- 35	Sandy Loam	69	0.4	Typic Torriorthents
	35- 70	Sandy Loam	42	48.2	

Soil reaction (pH) varies considerably between 7.4 and 8.6, indicating a slight to moderate alkaline soil reaction (FAO, 2006). Most values of soil salinity (EC_e) indicate non-saline or slightly saline soils (FAO, 1988) except those of profiles 4, 7 and 8 that are moderate to highly saline (11.9 to 35.6 dSm^{-1}). Also, the worst soil salinity values were belonged to profile 8 (30.7-35.6 dSm^{-1}). Moreover, the soils generally have low organic matter content (less than 10 g/kg) due to the prevailing arid climate and barren nature of the soils. In addition, the coarse-textured soils of the study area has a low cation exchangeable capacity (CEC < 7 cmol (+)/ kg).

Table 3. Some chemical properties of the studied soil profiles

Profile No.	Depth, cm	pH (1:1)	EC_e, dSm^{-1}	OM, g/kg	CEC, cmol (+)/Kg	ESP , %	SAR
1	0 -25	7.4	0.3	2.4	3.6	3.1	0.3
	25 - 70	7.8	1.9	0.5	3.8	1.1	0.6
	70 - 95	7.7	2.7	1.4	4.6	1.3	2.0
	95 - 160	7.6	3.2	1.9	2.0	5.0	2.1
2	0 -35	8.1	0.3	3.8	3.1	6.8	0.6
	35 - 115	7.6	0.3	3.6	2.9	7.5	0.4
	115 - 160	8.2	1.9	2.1	3.0	5.7	8.2
3	0 – 20	8.3	0.3	1.9	4.4	4.6	0.4
	20 – 40	8.3	0.3	6.6	3.9	5.6	0.4
	40 - 110	8.3	0.3	2.4	4.4	4.4	0.4
4	0 – 25	7.8	11.9	2.4	2.8	2.5	11.8
	25 - 120	8.8	12.2	2.5	3.9	7.7	8.5
	120 – 150	8.4	19.5	1.7	5.1	6.1	18.1
5	0 – 30	7.7	7.2	5.3	5.9	5.8	10.9
	30 – 50	7.5	6.1	3.5	3.7	4.7	8.2
6	0 -20	8.0	0.8	6.0	3.1	4.4	0.5
	20 – 65	8.0	0.6	2.8	2.8	5.1	1.2
	65 130	7.9	0.8	1.5	2.7	4.6	0.8
7	0 – 30	8.5	0.6	6.4	3.6	1.9	1.3
	30 – 65	8.3	13.6	5.7	4.2	39.6	13.2
	65 – 100	8.4	15.2	5.2	6.3	20.9	11.8
	100 – 150	7.8	7.0	2.8	2.9	10.5	9.3
8	0 – 20	8.6	33.7	4.3	2.7	5.1	31.5
	20 – 60	8.2	35.4	5.4	3.6	9.0	24.1
	60 – 90	7.9	30.7	8.3	4.4	5.8	27.6
	90 - 150	7.4	35.6	6.6	4.3	5.6	25.9
9	0 - 30	8.1	0.6	6.0	2.6	2.0	0.4
	30 -50	7.4	0.4	4.8	2.7	2.1	0.5
10	0 – 15	8.1	0.3	6.9	3.4	5.7	0.4
	15 – 50	7.8	0.7	6.9	3.4	7.3	2.0
	50 – 150	8.3	0.3	4.5	2.8	8.2	0.8
11	0 – 40	7.7	0.4	4.8	3.8	11.0	0.3
	40 – 90	7.5	0.8	6.2	6.5	3.3	1.6
	90 - 120	7.5	0.5	3.4	4.9	2.7	1.0
12	0- 35	7.6	3.1	3.3	4.1	5.1	0.2
	35- 70	7.7	2.3	2.3	4.8	5.0	0.3

Abbreviations:
EC_e: Electrical conductivity, OM: Organic matter, CEC: Cation exchangeable capacity, ESP: Exchangeable sodium percentage
SAR: Sodium adsorption ratio

The exchangeable sodium percentage (ESP) of these soils ranges from 1.1 to 11.0 % for most of the samples except two subsurface layers of profile 7 which has ESP of 20.9 and 39.6 %. The sodium adsorption ratio (SAR) values of these soils are less than 13, except the four layers of profile 8 (24.1- 31.5) and the third layer of profile 4 (18.1) and the second layer of profile 7 (13.2). The high SAR values seemed to be associated with the ECe values due to the domination of sodium in the soil solutions of these samples (profiles 4, 7 and 8). Therefore, most soil profiles that show low ESP and SAR values indicate a low sodicity hazard (FAO, 2006).

3. Soil Classification

The prevailing climate of the studied area is extremely arid and the dominant soil moisture regime is aridic (torric) with a thermic soil temperature regime. These soils are classified according to Soil Survey Staff (2014) as Typic Torripsamments, Typic Torriorthents, Lithic Torripsamments, Typic Haplosalids, Typic Natrargids, Typic Haplocalcids, Typic Haplogypsids and Lithic Petrogypsids (Table 2 and Figure 2).

4. Land Capability Assessment

a. Sys and Verheye (1978) method

The limiting factors as well as the land capability classes and subclasses of the studied area are present in Tables 4 and 5 and are illustrated in Figure 3.

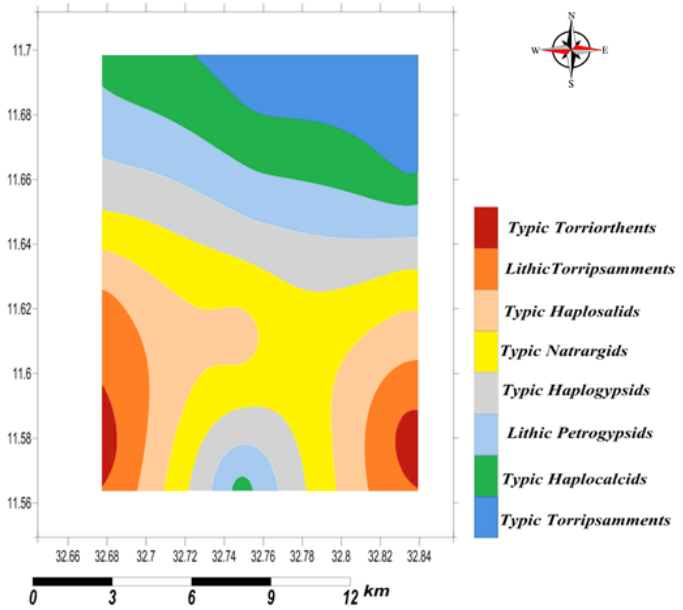
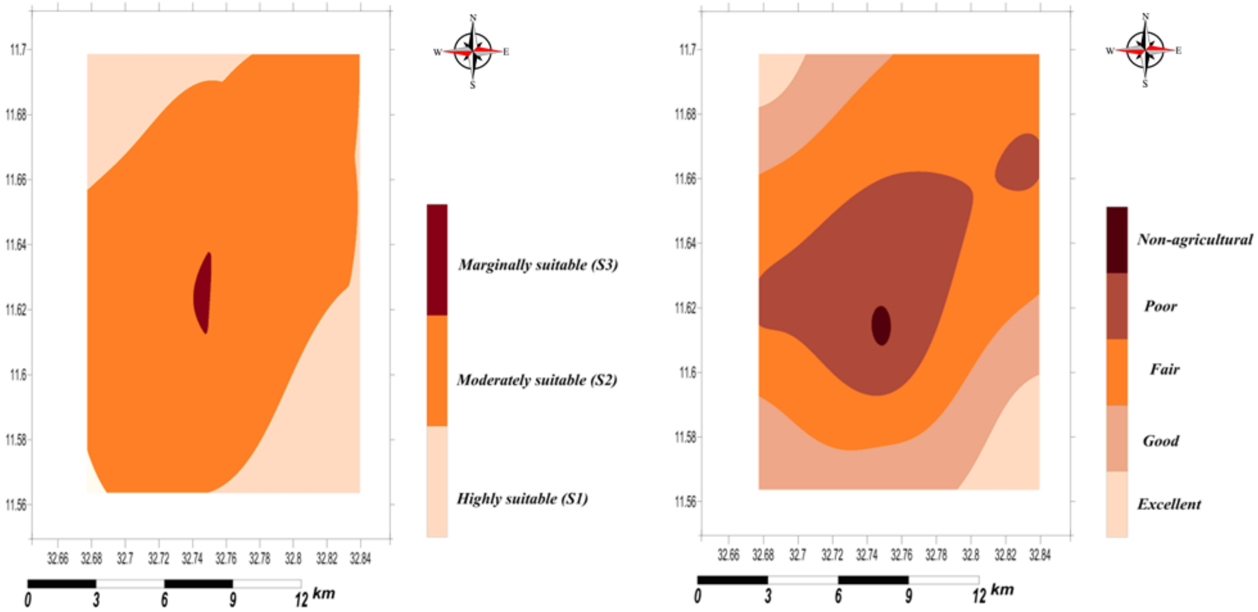


Figure 2. The soil classification map (subgroup level) of the study area



Sys and Verhey (1978) method Modified Storie index (2008) method

Figure 3. Land capability map of the study area

It is clear that none of the studied land profiles was observed to be unsuitable (N) in this area. Accordingly, the studied area could be classified into the following three capability classes:

Class S1:

This class includes the soils which are highly suitable with capability index (Ci) that is higher than 75 % (79%). The soils of this class occupy 17 % of the total studied area. The soils of this class are slightly affected by some limitations such as texture and calcium carbonate content (profiles 3 and 10).

Class S2:

This class comprises the soils that are moderately suitable with capability index (Ci) that are varies between 50 and 75% (52 to 71%). Five subclasses were recorded in this class. These subclasses contain the moderately suitable soils which employ an area of 58% of the total studied area. The soils of this class are slightly to moderately affected by some limitations and could be distinguished into the following subclasses:

S2 s1: The soils of this subclass are affected by the coarse texture that ranges from sand to sandy loam (profiles 1, 2 and 11)

S2 s1, n: These soils are moderately suitable and are represented by the soil profile 4 which has a coarse texture and salinity and alkalinity limitations.

S2 s1, s4: These soils are moderately suitable and are delineated by the soil profile 6 that show a coarse texture and gypsum limitations.

S2 s2, s4: The soils of this subclass are moderately suitable and are represented by the soil profile 12 that has soil depth and gypsum limitations.

S2 s1, s4, n: The soils of this subclass are moderately suitable and are described by the soil profile 7 which has a coarse texture with gypsum, salinity and alkalinity limitations.

Class S3:

This class includes the soils which are marginally suitable and have moderate limitations with capability index (Ci) that varies between 25 and 50% (33 to 39 %). The soils of this class occupy 25% of the studied area. They are affected by moderately and slightly sever limitations and are distinguished into the following subclasses:

S3 s1, s2: The soils of this subclass marginally suitable and are represented by the soil profiles 5 and 9 which are of coarse texture and soil depth limitations.

S3 s1, s4, n**:** These soils are marginally suitable and are described by soil profile 8 that shows a coarse texture with gypsum, salinity and alkalinity limitations.

Table 4. Land evaluation of the studied soil profiles according to Sys and Verhey (1978)

Profile No.	Limiting factors							(Ci)	Order	Class	Sub-class (Sx)
	Slope (t)	Drainage (D)	Texture (S1)	Depth, cm (S2)	$CaCO_3$, % (S3)	Gypsum, % (S4)	Salinity &Alkalinity (n)				
1	100	100	70	100	95	100	100	67	S	S2	S2s1
2	100	100	75	100	95	100	100	71	S	S2	S2s1
3	100	100	91	100	92	94	100	79	S	S1	S1, s3
4	100	100	75	100	95	100	90	64	S	S2	S2s1, n
5	100	90	80	55	95	95	98	35	S	S3	S3s1, s2
6	100	100	70	100	95	93	100	62	S	S2	S2s1, s4
7	100	100	79	100	95	93	93	65	S	S2	S2s1, s4, n
8	100	100	77	100	95	88	60	39	S	S3	S3s1, s4,n
9	100	90	70	55	95	100	100	33	S	S3	S3s1, s2
10	100	100	83	100	95	100	100	79	S	S1	S1s1
11	100	90	84	100	95	98	100	70	S	S2	S2s1
12	100	90	90	75	95	90	100	52	S	S2	S2s2, s4

Table 5. Land capability classes and subclasses of the studied area according to Sys and Verhey (1978)

Suitability index (Ci)	Suitability class	Suitability subclass (Sx)	Profile No.	Area (%)
>75	S1	S1, s3 S1s1	3 10	17
50 -75	S2	S2 s1 S2 s1, n S2 s1, s4 S2 s2, s4 S2 s1, s4, n	1, 2, 11 4 6 12 7	58
25 - 50	S3	S3 s1, s2 S3s1, s4,n	5, 9 8	25

Where:
Sx = S1, S2, ...etc.
Sx = Soil limitations (s1= soil texture,s2= soil depth, s3= calcium carbonate, s4= gypsum and n = Salinity and / or alkalinity limitation)

b. Modified Storie index (2008) method

According to the Storie index modified by O'Geen et al. (2008), the studied area has capability classes excellent, good, fair, poor and non-agricultural due to different limiting factors (Tables 6 and 7, Figure 3).

Table 6. Land capability and modified Storie index rating of the studied area according to O,Geen et al. (2008)

Profile No.	Slope	Gravel	Depth (cm)	Texture	pH	SAR	EC_e (dSm^{-1})	Erosion	Drainage	Index	Capability
1	98	100	98	60	100	100	100	100	100	58	Fair
2	98	100	98	60	100	100	100	100	100	58	Fair
3	98	100	93	95	100	100	100	100	100	87	Excellent
4	98	100	97	80	100	75	56	100	100	32	Poor
5	98	100	53	80	100	77	75	100	90	24	Poor
6	98	100	95	60	100	100	100	100	100	56	Fair
7	98	100	97	60	100	100	100	100	100	57	Fair
8	98	100	97	60	94	56	19	100	100	6	Non-agricultural
9	98	100	53	60	100	100	100	100	90	28	Poor
10	98	100	97	95	100	100	100	100	100	90	Excellent
11	98	100	95	80	100	100	100	100	90	67	Good
12	98	100	68	95	100	100	99	100	100	63	Good

Abbreviations: SAR: Sodium adsorption ratio, EC_e: Electrical conductivity

Table 7. Land capability classes and soil limitations of the studied area according to O,Geen et al. (2008)

<table>
<tr><th>Capability index (Ci %)</th><th>Capability class (Soil grade)</th><th>Soil limitation</th><th>Profile No.</th><th>Area (%)</th></tr>
<tr><td>80 - 100</td><td>Excellent</td><td>---</td><td>3, 10</td><td>17</td></tr>
<tr><td rowspan="2">60 - 79</td><td rowspan="2">Good</td><td>texture</td><td>11</td><td rowspan="2">17</td></tr>
<tr><td>depth</td><td>12</td></tr>
<tr><td>40 - 59</td><td>Fair</td><td>texture</td><td>1, 2, 6, 7</td><td>33</td></tr>
<tr><td rowspan="3">20 - 39</td><td rowspan="3">Poor</td><td>texture, SAR, EC_e</td><td>4</td><td rowspan="3">25</td></tr>
<tr><td>texture, depth, drainage</td><td>9</td></tr>
<tr><td>texture, depth, SAR, EC_e, drainage</td><td>5</td></tr>
<tr><td>20 ></td><td>Non-agricultural</td><td>texture, SAR, EC_e, pH</td><td>8</td><td>8</td></tr>
</table>

Some of these limiting factors are not correctable, such as soil depth and soil texture, while salinity and SAR factors can be correctable. Accordingly, the studied area could be classified into the following five classes:

Excellent (grade 1): These soils are deep and medium textured, with having no, or insignificant limitations to the given type of use. They are represented by soil profiles 3 and 10 and occupy an area of 17% of the total studied area.

Good (grade 2): These soils are also deep and medium textured and are suitable for most crops. Yields are generally good to excellent. They are delineated by soil profiles 11and 12 and have an area 17% of the total area.

Fair (grade 3): These soils are deep and coarse-textured and generally of fair quality, with a less wide range of suitability than both grades 1 and 2. They may give good results with certain specialized crops. They are described by soil profiles 1, 2, 6 and 7 and employ an area 33% of the total studied area.

Poor (grade 4): These soils are deep and coarse textured, that are moderately affected by the alkalinity and have poor nutrient levels. They are represented by soil profiles 4, 5 and 9 and occupy an area of 25% of the total studied area.

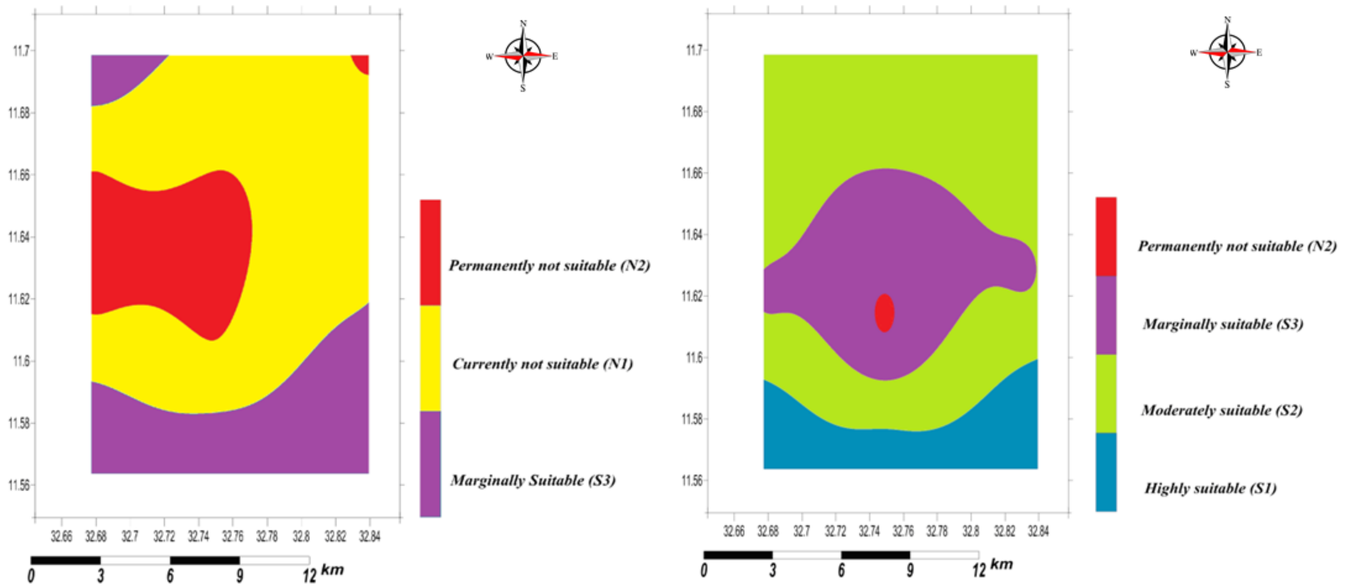
Non-agricultural (grade 6): These soils are deep to very shallow and coarse textured. They have moderate to strong limitations that are affected by the alkalinity and show poor to very poor nutrient levels. They are described by soil profile 8 and have an area of 8% of the total area.

The two methods do not vary in assessing the land suitability of this studied area. However, modified Storie index method is more accurate and realistic. In case of modified Storie method, numbers of land classes are much higher than in the other method. Generally, the main limitations in the studied soils profiles 6 and 7 were the soil texture of the surface layer and soil depth as well as salinity, alkalinity, gypsum, drainage and fertility levels. Drainage, soil salinity and alkalinity problems could be corrected. However, soil depth and texture cannot be changed. From the agriculture point of view, the soils of the studied area are considered promising ones (Elaalem, 2010). Evaluating their capability is an essential stage for future practical use. By improving the soil properties such as salinity and alkalinity and applying modern irrigation systems, the soils can attain a potential capability (high) and be high suitable to moderately suitable for the agricultural use. One of the best ways to improve light soils (sandy soils) is through additions of organic materials. Good sources of organic matter include manures, leaf mold, sawdust, and straw. Many farmers enrich the soils with natural fertilizers, such as animal manure, green manure, and compost. Continuous agriculture use of these soils will upgrade their suitability in the future.

5. Land Suitability Assessment

a. Land suitability for different irrigation systems

Several parameters of the field data are used to compare the land suitability for different irrigation systems. The results of soil evaluation for surface (gravity) and drip (localized) irrigation systems are present in Table 8 and illustrated in Figure 4. They show that the drip irrigation system is more suitable for the studied area than the surface irrigation one. Hence, changing the irrigation method to be pressurized (drip) irrigation in the study area is proposed. With using the surface irrigation, there is not any area that is classified as highly suitable (S1) or moderately suitable (S2). Only, 33% of the study area are slightly suitable (S3) using the surface irrigation and located in profiles 3, 10, 11 and 12. Most of the soils of this study are classified that are currently not suitable (N1, 25 %) and permanently not suitable (N2, 42 %) using the surface irrigation. The limiting factors in this study are mainly the soil salinity and soil texture that is mostly sand. In some cases, the soil depth and the calcium carbonate content also handicap the land use for surface irrigation.



Surface irrigation method Drip irrigation method

Figure 4. Land suitability classes for surface and drip irrigation

Table 8. Suitability index distribution of the surface (Gravity) and drip (localized) irrigation according to Sys et al.(1991)

Suitability index	Suitability class	Surface irrigation		Drip irrigation	
		Profile No.	Area (%)	Profile No.	Area (%)
>80	S1	---	---	10, 11, 12	25
60-80	S2	---	---	1, 2, 3, 4, 6	42
45-60	S3	3, 10. 11, 12	33	5, 7, 9	25
30-45	N1	2, 4, 7	25	---	---
<30	N2	1, 5, 6. 8, 9	42	8	8
---	Total	---	100	---	100

Using the drip (localized) irrigation, the soils of the study area are classified as highly suitable (S1, 25%), moderately suitable (S2, 42%) and marginally suitable (S3, 25 %).Only, a few proportion of the studied soils is almost not suitable (N2, 8%) and mainly located in the area represented by profile 8. Therefore, it would be more beneficial to irrigate these soils using drip or localized irrigation method. However, the area represented by profile 8 is unsuitable for both irrigation methods. It should not be used for crop production. Moreover, due to the insufficient surface water and ground water resources as well as the arid climate of the study area, only the drip and sprinkle irrigation methods are highly recommended for the sustainable use of this natural resource. The drip irrigation system is more suitable and recommended than the surface irrigation one in most of the areas in the Mediterranean and arid regions (Briza et al., 2001; Mbodj et al., 2004; Dengiz, 2006; Albaji et al., 2009; Nasab et al., 2010; Mehdi et al., 2012; Sayed, 2013). The drip irrigation can obviously be a way to improve the practice on light-textured soils. The main land use limitation factors for the drip irrigation method in this study are the salinity and the soil texture.

b. Land suitability for field crops, vegetables and fruit trees

The land suitability assessment for annual field crops, vegetables and fruit trees was shown in Tables 9, 10.

Table 9. Suitability rating of the studied soil profiles for growing some crops, vegetables and fruit trees according to Sys et al. (1993).

Crops		Profile No.											
		1	2	3	4	5	6	7	8	9	10	11	12
Field crops	Alfalfa	S2	S2	S3	N	S3	S3	N	N	S3	S2	S1	S2
	Sorghum	S2	S2	S2	S3	S3	S2	N	N	S2	S2	S2	S3
	Maize	S2	S2	S3	S2	S3	S3	N	N	S3	S2	S2	S2
	Millets	S3	S2	S3	N	S3	S3	N	N	N	S3	S2	S1
	Wheat	S3	S2	S3	N	N	S3	N	N	N	S2	S2	S2
	Barley	S3	S3	S3	N	S3	S3	N	N	N	S2	S2	S2
	Safflower	S3	S2	S3	N	S3	N	N	N	N	S3	S2	S2
	Sunflower	S3	S2	S3	N	N	N	N	N	N	S3	S2	S3
	Sesame	S3	S2	S3	N	N	N	N	N	N	S3	S2	S2
	Soybean	S3	S2	N	N	N	N	N	N	N	S3	S2	S3
Vegetables	Onion	S2	S2	N	N	S3	N	N	N	S3	S2	S2	S2
	Green pepper	S2	S2	N	N	N	S3	N	N	N	S2	S2	S2
	Potato	S3	S2	N	N	N	S3	N	N	N	S3	S2	S2
	Tomato	S3	S2	N	N	N	N	N	N	N	S3	S2	S3
	Beans	S3	S3	N	N	N	N	N	N	N	S3	S2	N
Fruits	Date palm	S2	S2	S2	S2	N	S2	S3	N	N	S2	S1	S2
	Olives	S2	S1	S2	S2	N	S2	N	N	N	S2	S1	S3
	Guava	S3	S2	S3	N	N	S3	N	N	N	S2	S2	S2
	Citrus	S2	S2	N	N	N	N	N	N	N	S2	S2	N
	Banana	N	N	N	N	N	N	N	N	N	N	S3	N

Abbreviations: S1 = Highly suitable (Ci >65), S2 = Moderately suitable (Ci 35-64), S3 = Marginally suitable (Ci 20-34), N = Not suitable (Ci<20)

Soil suitability evaluation for growing field crops

The area understudy has a good potential to produce selected crops under irrigation provided that the water requirements for each crop are met. The results indicate that only 9 and 8% of this area are highly suitable (S1) for alfalfa and millets, respectively. The soils that are moderately suitable (S2) for alfalfa, sorghum, maize, millets, wheat, barley, safflower, sunflower, sesame and soybean production represent 33, 58, 50, 17, 33, 25, 25, 17, 25 and 17% of the total studied area, respectively. However, 33, 25, 33, 42, 25, 33, 33, 33, 25 and 25% of the studied area are marginally suitable for alfalfa, sorghum, maize, millets, wheat, barley, safflower, sunflower, sesame and soybean respectively. In addition, 42, 42, 42, 50, 50 and 58% of the study area are currently not suitable (N1) for wheat, barley, safflower, sunflower, sesame and soybean production, respectively. Hence, the area under consideration has a good potential to produce alfalfa, millets, sorghum and maize followed by wheat, barley and safflower and then, sunflower, sesame and soybean under irrigation, provided that the water requirements of these crops are met.

Table 10. Soil suitability rating and percentage for growing some field crops, vegetables and fruit trees according to Sys et al. (1993)

Field crops (%)										
Rating suitability	Alfalfa	Sorghum	Maize	Millets	Wheat	Barley	Safflower	Sunflower	Sesame	Soybean
S1	9	--	--	8	--	--	--	--	--	--
S2	33	58	50	17	33	25	25	17	25	17
S3	33	25	33	42	25	33	33	33	25	25
N	25	17	17	33	42	42	42	50	50	58

	Vegetable crops (%)					Fruits trees (%)				
Rating suitability	Onion	Green pepper	Potato	Tomato	Beans	Date palm	Olives	Guava	Citrus	Banana
S1	--	--	--	--	--	9	17	--	--	--
S2	42	42	25	17	8	58	42	33	33	--
S3	17	8	25	25	25	8	8	25	--	8
N	41	50	50	58	67	25	33	42	67	92

Abbreviations: S1 = Highly suitable (Ci >65), S2 = Moderately suitable (Ci 35-64), S3 = Marginally suitable (Ci 20-34), N = Not suitable (Ci<20)

Soil suitability evaluation for growing vegetables

The results reveal that the study area is moderately suitable and marginally suitable for growing onion (42 and 17%, respectively), green pepper (42 and 8%, respectively) and potato (25 and 25%, respectively) production. However, most of the investigated area is not suitable for tomato (58%) and beans (67%) production. Therefore, the area under consideration shows a good potential to produce onion, green pepper and potato but it is not suitable for other vegetable crops. The high soil pH, ESP and salinity are the major limitation factors of this area for vegetable production which can be improved using specific management.

Soil suitability evaluation for growing fruit trees

Only 9 and 17% of the study area are highly suitable (S1) for growing date palm and olive, respectively. In addition, 58, 42, 33 and 33% of this area are moderately suitable (S2) for date palm, olive, guava and citrus production. However, most of the soils are not suitable (N) for banana (92%) and citrus (67%). High soil pH, salinity and ESP are the major limitations which may deter the farmers from cultivating these soils.

Generally, the area understudy has a good potential to produce the selected crops under irrigation provided that the water requirements of these crops are met. Some crops are considered unsuitable (N1 and N2) for growing due to moderate to severe soil limitations of fertility, salinity, alkalinity, soil depth and coarse texture. The coarse texture, ESP, calcium carbonate content, salinity and alkaline pH of most soil profiles are the main limiting factors for growing crops, especially vegetable crops and some fruit trees. Proper fertilization can improve the soil suitability for various crops under consideration. Correcting some soil limiting factors such as pH, salinity and alkalinity through the application of fertilizers and amendments which can reduce soil alkalinity and increase soil fertility is recommended. Also, additions of manures and crop residues to the soils can increase the soil organic matter and nutrient levels.

Conclusion

The study aims to evaluate the soil suitability of the north-western area of Libya and identify the factors that hinder the cultivation process. Qualitative evaluation for the actual soil parameters was employed to realize a precise and objective interpretation for this area and its suitability for a wide range of crops. The most effective soil parameters that influence the suitability classification of the studied area are texture, calcium carbonate content, ESP, alkaline pH and salinity. According to the Sys and Verhey (1978) method, about 17% of the studied area are highly suitable, 58% are moderately suitable and only 25 % are marginally suitable for agriculture. In addition, according to the modified Storie index method, 17%, of the investigated area are excellent, 17% of this area is good, 33% of this area is fair and 25% of this area is poor for agricultural use, and 8% of the studied area is non-agricultural. Moreover, this method is found to be more effective in assessing land capability. Concerning the irrigation systems, using the drip irrigation system in the area understudy is more suitable than the surface irrigation. It is clear that the drip irrigation in arid and semi-arid regions is mostly appropriate, because of water shortage. From the agricultural point of view, the soils of the studied area are considered promising ones. The potential capability of some soils of this area can be improved with cultural management. Meanwhile, the soils of this area are moderately suitable to marginally suitable for growing field crops and some fruit trees. On the other hand, the soil maps for agricultural suitability designed in this research can be helpful in carrying out the management processes.

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