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(Research Article)

Land suitability assessment of soils using geographic information system in the semi-arid area of Tunisia

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Abstract

Land suitability maps are useful tools for protecting soil resources. The main objective of this study was to elaborate and assess soil suitability maps for different rainfed and irrigated crops. This study was conducted in the North-East area of Tunisia, three speculations were adopted (Cereals, arboriculture and vegetable crops) in both rainfed and irrigated conditions. Arithmetic multiplication methods were used based on Food and Agriculture Organization (FAO) classification based on Free and Open Source Geographic Information System (QGIS) tools and soil pedological properties, slope, elevation and climatic data. Overall, regardless of rainfed or irrigated conditions, results showed that the studied soils were particularly suitable (S1) for cereals crops and marginal suitable (S3) for arboriculture crops with 20.44 and 23.71%, respectively. More particular, we registered an improvement in soil land suitability under irrigated conditions for cereals with 28.63%. The findings indicated that using the GIS system, the soil in the study area is more suitable for cereals and then for arboriculture under irrigated conditions, which requires some improvement in use strategies and good management of the soil resources.

In our study area, where agricultural productivity and environmental and the impact of climate change are in a struggle, classifying land on the basis of soil capacity and suitability could help define the best agricultural practices to apply in order to preserve soil functions could help define the best agricultural practices to be applied in order to preserve soil functions.

Keywords: Land suitability; Mapping; SIG; North Tunisia; FAO classification

1. Introduction

Population growth and the urbanization process have both increased the demand on agricultural resources. Therefore, an expanded food supply is needed to satisfy the food requirements of a growing world population [1]. In semi-arid climates, there are fewer agricultural fields, which puts more demand on these lands. Soil degradation risk could be considered a consequence of the irrational allocation of land use, especially when inappropriate soil is also resilient to

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degradation process [2, 1, 3]. One of the major reasons for the low yield is the difficulty in determining whether or not the land is suitable for their production. To solve this issue, a land suitability analysis is required [4]. Nowadays, land evaluation is crucial because it provides details on the limitations and potentials of land for a specific type of use to produce crops.
Land suitability evaluation is becoming more and more crucial for countries that are concerned about the effects of climate change on their soil [5]. Thereby, the land suitability was defined as ”the fitness of a given type of land for specified kind of use’’ by Food and Agriculture Organization (FAO) [6] and the adaptation of land to specific use and the capacity of a specific area of soil to support a given utilization according to Everest *et al* [3] and Feizizadeh et Blaschke [1].
In a multi-criteria assessment of land suitability, various factors are taken into account, including geological and biophysical elements, relief, atmospheric conditions, and vegetation, as well as economic and socio-cultural conditions [5, 7]. Land suitability is affected by climate change, in particular water scarcity, which requires additional irrigation [1]. For sustainable management in arid and semi-arid areas, water availability for meeting irrigation demand in accordance with crop requirements is essential [5].

The use of GIS tools was incredibly useful for assessing the suitability of the soil [3]. For many reasons, including land suitability [5]. Numerous researchers have attempted to provide a common framework for appropriate and suited agricultural land management using ArcGIS [8, 1, 9, 10] and using Qgis [11, 12]. In Tunisia, several maps have been created to assess land suitability, in particular, developed the agriculture map showing the different distribution of crops (Rainfed cereal crops, Alfa steppe *(Stipa tenac*), Rainfed cereal and the Alfa steppe (*Stipa tenacissima*) [13, 2]. To our knowledge, to create the land suitability map, the use of Qgis based on FAO classification framework in North East of Tunisia is not well explored.

The objectives of this study are to (i) assess soil suitability maps for different rainfed and irrigated crops and (ii) identify potential areas suitable for agricultural activities in North-East of Tunisia Zaghouan, using FAO classifications.

2. Materiels and methods

2.1. Study area and soil sampling

The current research was carried out on a Mediterranean Climate agriculture soil in the North-East of Tunisia (Zaghouan) (Latitude 36°22'42.30"N, Longitude: 10°13'37.44"E). The study area with a total area is around 100.000 ha (Figure 1). Soil samples were taken in 2021 from the topsoil (0-20 cm). A representative sampling was adopted using a regular grid with 1 km sides and a systematic sampling approach. According to the Koppen-Geiger climate classification, the study area climate was classified as Csa, characterized by an average temperature, and rainfall of 18.6°C and 473.9 mm, respectively [14].

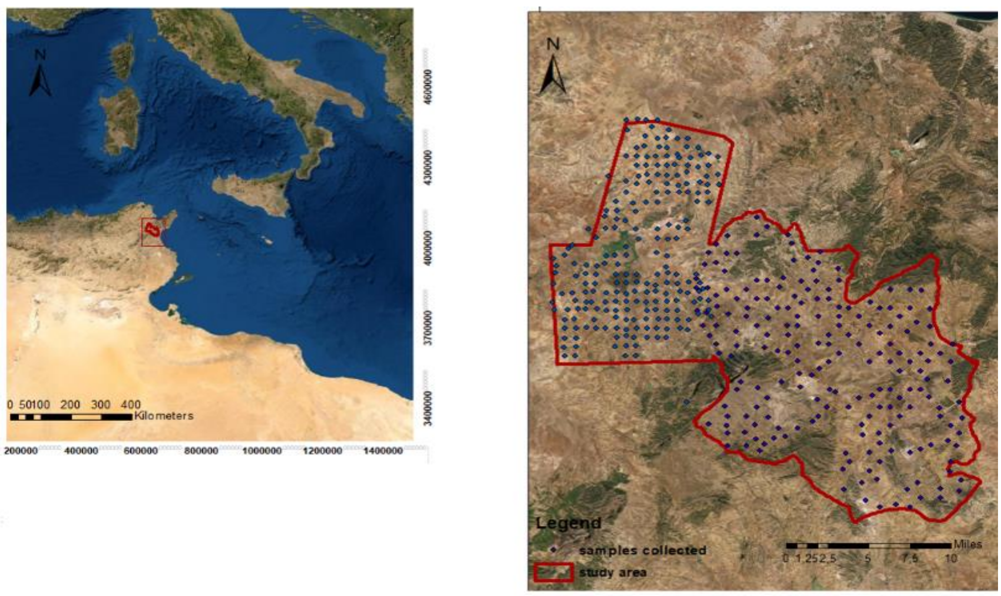


Figure 1 Geographical location of the study area: Smenja and Oued Rmel area

2.2. Thematic soil potential maps development

For each of the relevant criteria, thematic maps were created and rasterized in a Geographic information system (Figure 2). Using the FAO multiplication method classification, thematic maps relating to the main soil characteristics were obtained from existing data (limiting factors) by multiplying the class of each limiting factor and constraint emphasized in these studies [4] (Table 1).

The soil potentiality depends on several soil edaphic characteristics as salinity, texture, stony load ... and the climatic data. According to the FAO multiplication classification [15], five soil potential classes were determined (Table 1).

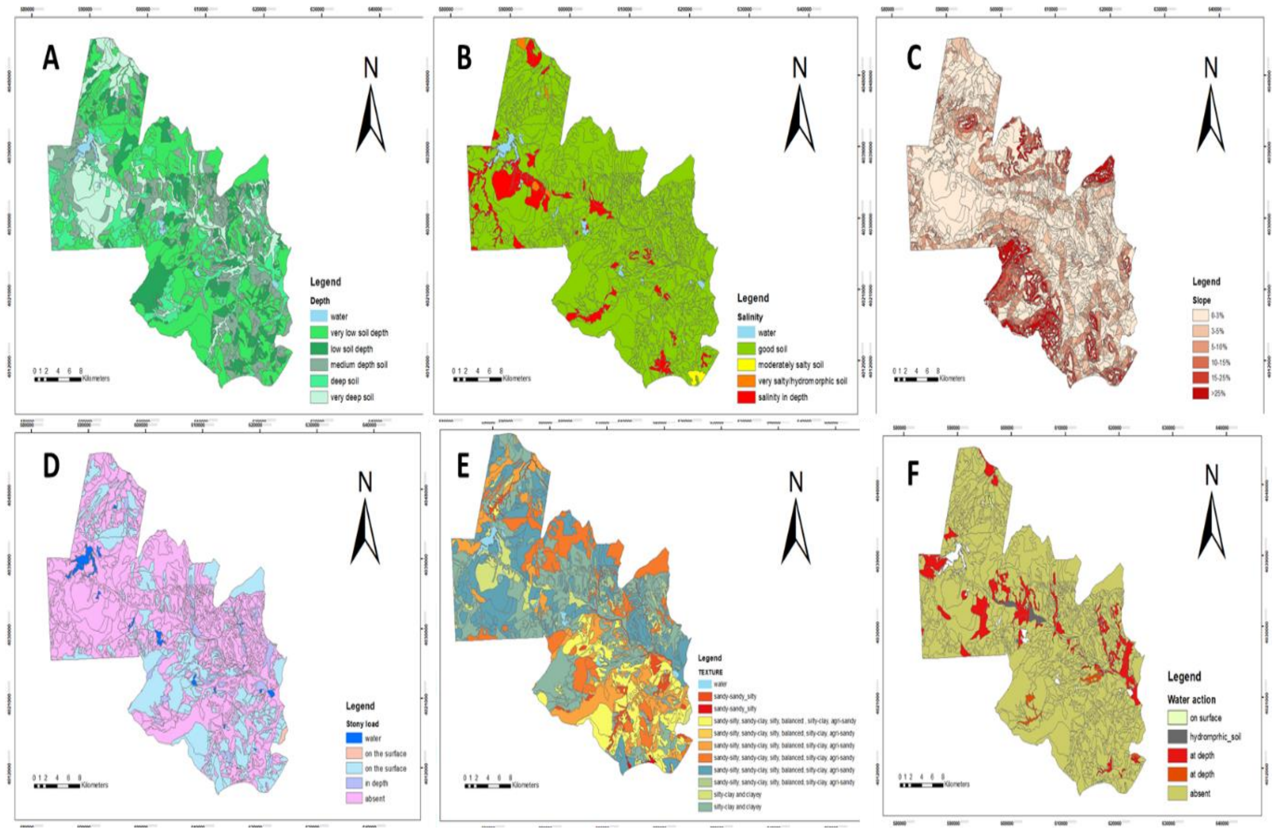


Figure 2 The six thematic maps : A: depth map; B: salinity map; C: slope map; D: stony load; E: texture map and F: water action map.

Table 1 Overall score and description of different soil potentiality classes

Soil potentiality class	Overall score (by FAO multiplication)	Description
Class I	>80	Very good quality soils
Class II	60-80	Soils of good quality, without too many constraints, but development is less easy because of the presence of medium slopes or other constraints
Class III	40-60	Soils may have constraints that limit the choice of crops
Class VI	20-40	Low production potential requiring extensive work
Class V	<20	Limiting factors are very restrictive and difficult to improve respectively

2.3. Land suitability maps

According to FAO [16] framework for land evaluation, five categories were found:

Highly suitable (S1), moderately suitable (S2), marginally suitable (S3), current unsuitability (N1) and permanent unsuitability (N2).

- Highly suitable (S1): Very suitable soil potential, allowing for highly productive land use without prior management.
- Moderately suitable (S2): Physical potential with certain constraints, the practice of certain construction work allows for a reclassification to a higher category of suitability.
- Marginally suitable (S3): Soil potential is limited by important constraints, so technical improvement is more difficult.
- Current unsuitability (N1): Soil with limitations that are manageable with time, but that cannot be corrected in the present state of knowledge at an acceptable price. These limitations are so serious as to prevent the success of any particular continuous land use.
- Permanent unsuitability (N2): Soil with very serious limitations that are difficult to improve and that seem to prohibit any possibility of success of such or such use [5, 17].

3. Results

3.1. Soil potential map

To assess the soil potentiality map, based on the FAO multiplication method classification and the percentage calculated of the area occupied by each class, our results revealed that the study area was occupied by the five classes. More particularly, the obtained big surface area was dominated by the fourth class (CVI), followed by the first class (CI) with 32.14% and 25.44%, respectively. These two classes (CVI and CI) were characterized by a low production potential requiring major land use and a very good quality (Figure 3 and 4).

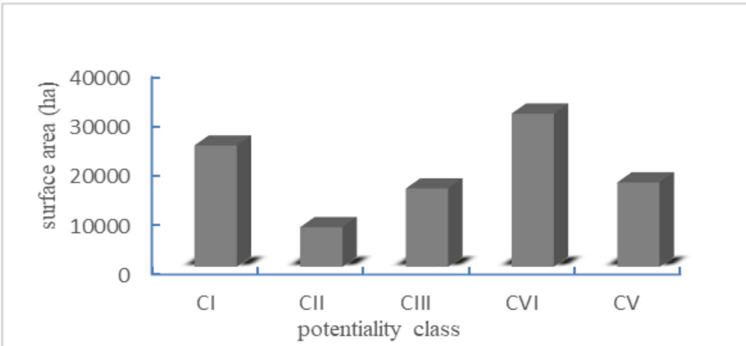


Figure 3 Surface area and percentage occupied by each class for the soil potential maps obtained by FAO classification

Figure 4 Soil potential map of the study area Oued Rmal, Zaghouan

3.2. Assessment of soil suitability map

3.2.1. Changes of classes' suitability according to system conditions

Based on the FAO multiplication method classification and the percentage of the area occupied by each class, to assess soil suitability, our results showed an improvement in soil quality in the case of irrigated areas. In fact, we noted an increase in the second and the third classes with 11.25% and 17 %, respectively, and a decline in the non-suitable soil quality (N2) class with 65.6% (Figure 5).

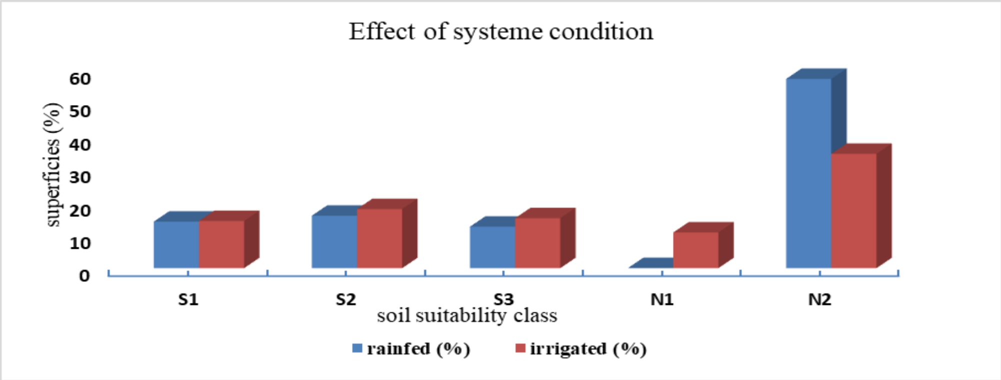


Figure 5 Soil suitability class superficies (%) for field crops in rainfed and irrigated conditions.

*Highly suitable (S1), Moderately suitable (S2), Marginally suitable (S3), Current unsuitability (N1) and Permanent unsuitability (N2).

3.2.2. Changes of classes according to crop.

Comparing the suitability of our soil for field crops and arboriculture (Figure 6), regardless of the system conditions, our obtained data showed that the soil is more suitable for field crops with 17.92% and 19.3% for S1 and S2 respectively, whereas the soil is more marginally suitable for arboriculture with than field crops with 21% for S3.

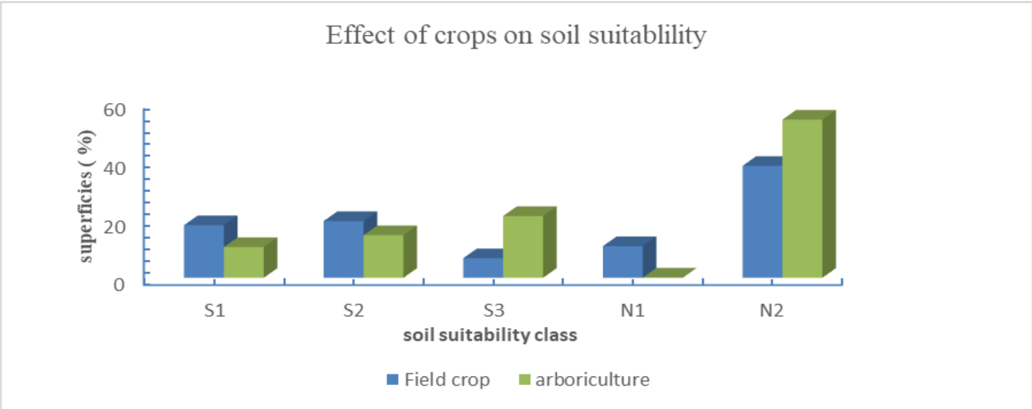


Figure 6 Soil suitability class superficies (%) for field crops in rainfed and irrigated conditions.

*Highly suitable (S1), Moderately suitable (S2), Marginally suitable (S3), Current unsuitability (N1) and Permanent unsuitability (N2).

3.2.3. Soil suitability variation according to the interaction between system condition and crops

Overall, regardless of the crop types, the soil suitability was improved in the case of irrigated areas. In the case of the field crops under irrigated conditions, we have noted an enhancement of the soil quality, whiles, under rainfed conditions this domination was mainly marked by the prevalence of the third class with an increase of 100%. Differently, in the case of arboriculture crops under rainfed conditions, we registered an improvement in soil suitability showing an important suitability and a good quality (S1) (Figure7)

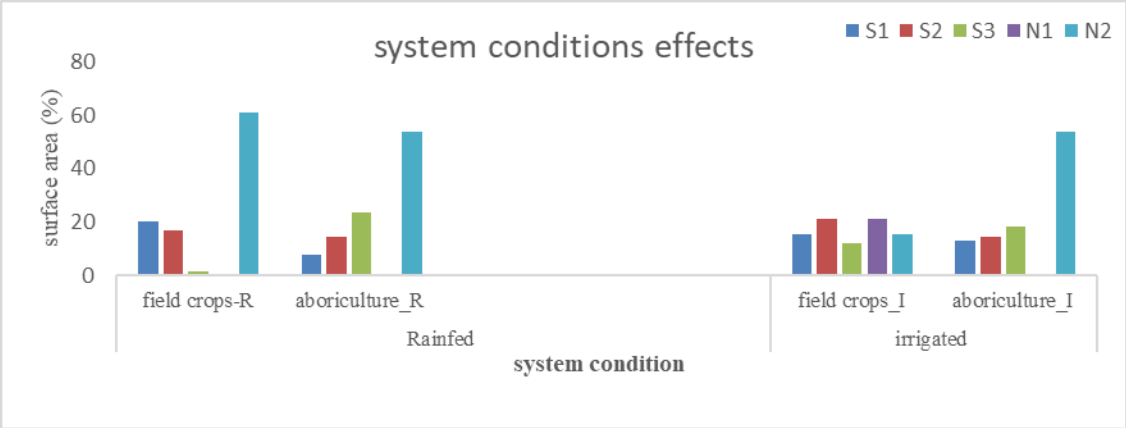
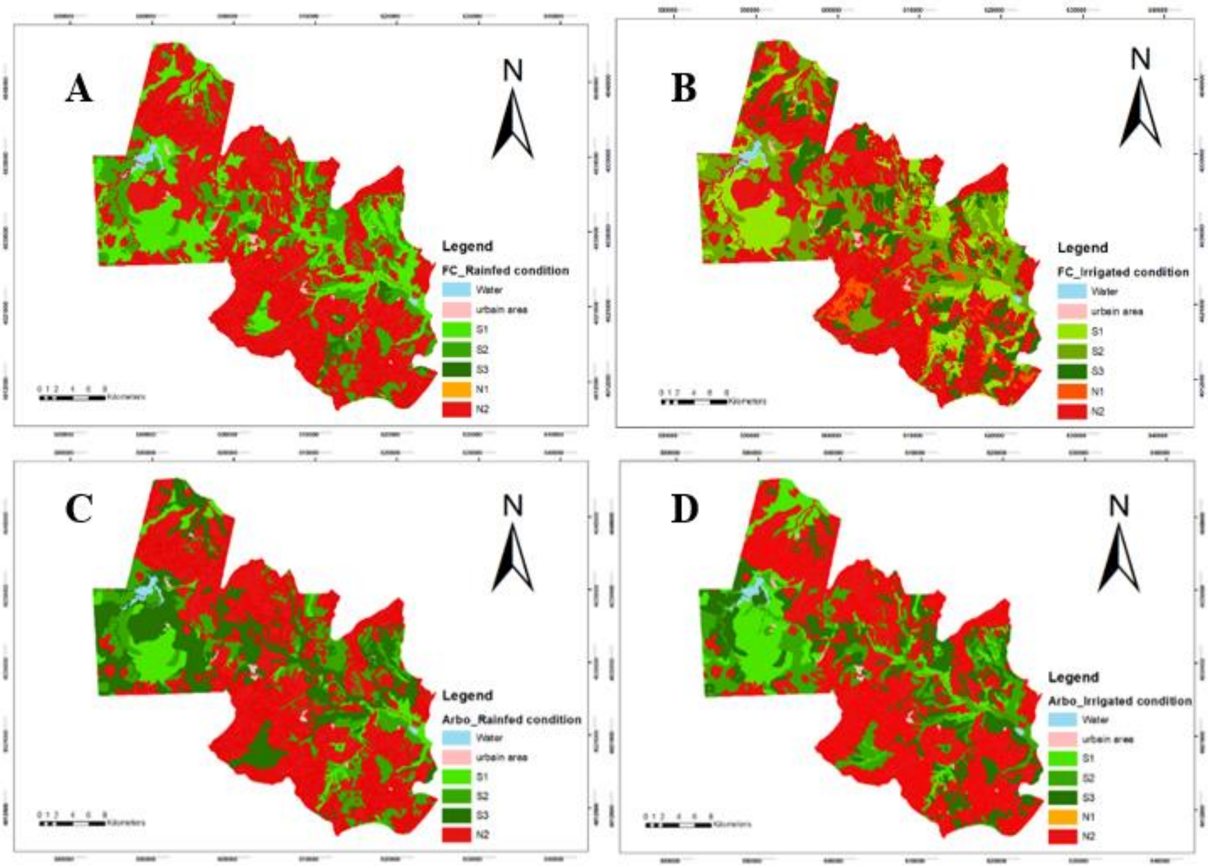


Figure 7 Distribution of the areas in percentage (%) among the suitability classes for rainfed and irrigated crops.

*R: in rainfed system condition, I: in irrigation system condition



*Arbo: arboriculture crops; FC: field crops Highly suitable (S1), Moderately suitable (S2), Marginally suitable (S3), Current unsuitability (N1) and Permanent unsuitability (N2).

Figure 8 Soil suitability maps according to FAO classification; A: Field crop in rainfed condition; B: Field crop in irrigated condition. C: Arboriculture crop in rainfed condition; D: Arboriculture crop in irrigated condition.

4. Discussion

In recent years, the effects of climate change and the over use and mismanagement of land have had negative effects on the suitability of cultivated land, regardless of the cropping system (rainfed or irrigated). The application of Geographic Information Systems is therefore an effective tool used to monitor and evaluate the potentiality and suitability of croplands, particularly in the context of Tunisia's semi-arid climate.

The information in the soil map and its extracts such as (texture, slop, depth, salinity maps...) maintained by QGIS enabled the identification of sites belonging to various land capability and suitability classes.

In our research, we found that the soil in the study area is particularly suitable (S1) for cereal crops and marginally suitable (S3) for arboriculture. This demonstrates that rainfall provides a significant role in enhancing the suitability, which is in line with the research of Taghizadeh-Mehrjardi et al [4], that rainfall is among the limiting factors that induce low suitability for cropland due to rainfall limitations. In Tunisia, Mbodj *et al*[18] studied the suitability of land for rainfed agriculture in the Oued Rmal catchment and showed that rainfed crops are the most widespread local cropping system followed by high suitability for arboriculture (olive trees) and field crops (wheat).

Moreover, the depth and slope have contributed to the presence of a class N1 and N2 of the land for some cultivation. The CVI and CV classes showed that the lands are recommended for the forest, where there is less depth and more slope [3]. Furthermore, in our investigation, we found that the permanent unsuitability (N2)soil class is always high (above 40%), which is explained by the presence of more than two major limiting factors such as slope and shallow depth and other characteristics such as texture and high salinity [5]. In addition, the vulnerability of several crops to climate change and lack of water, make the area completely unsuitable for growing them in the oued ramel catchment (Tunisia) [18]. This is in line with the study carried out by Aydi *et al* [19] in Tunisia (Fernann region), unsuitable areas are typically caused by several reasons citing; rock outcrops, salinity, active wind erosion dynamics or wind accumulation and in particular thick limestone crusts [2]. Given that the majority of the soil in the study area is of high quality, the comparison of dry and irrigated soil potential in our case reveals that the main constraint is water supply. In semi-arid areas, Tunisia, the 4th largest olive producer in the world, is among the countries with limited water resources. Due to the poor management of waters irrigation (traditional management) for tree cultivation, mainly olive oil, has induced a decrease of about 8.5% of its world olive production, compared to the first three countries (Spain at 36%, Italy at 24% and Greece at 17%) [19, 20].

In addition to water availability, depth and rock load contribute also to reduce the suitability of the soil and hinder the proper development of plants, which is consistent with a study conducted by Mazahreh et al [8] in the Alghadeer alabyad watershed in Al Mafraq, Jordan. The latter study confirmed that the potential suitability of rainfed annual plants could be strongly limited and influenced by low rainfall. Apart from that, the presence of stones on the surface and shallow soil depth reduced the suitability of trees in a drip irrigation system by 39% and 33% of the total area.

These limitations are the main reasons why the suitability of the study area for rainfed fields and tree crops is lower than the potential suitability of the land for these crops under irrigation. Irrigation has led to a net improvement in soil quality and subsequently in its suitability for cultivation, according to Habibie *et al*[5], water availability is crucial to have highly suitable(S1) land use but also good land management is still required [4].

Therefore, to accomplish a good land management, land improvement activities such as revegetation, increasing organic matter in soils through farmyard manure, green manure, and cover crops, supplementary irrigation, and gravel collection are needed and desired to improve the soil suitability for cultivated land and boost its productivity in the semi-arid area.

5. Conclusion

Recent research highlights the relevance of land suitability management in order to handle crops and improve their yields. Land suitability assessment is a prerequisite to define crop management strategies that can boost land productivity by identifying the primary issues that are limiting agricultural production. Therefore, suitability analysis enables decision-makers to make appropriate decisions about managing land in a sustainable way. The creation of soil potentiality maps and subsequent crop suitability maps using soil properties data and the QGIS Tool is carried out in this work.

Several limiting factors are present in the study area such as slope, limited depth, and soil salinity, which have contributed to the unsuitable soil classes especially N2 for cultivation. Climate change and low rainfall reduce the cultivation capacity for all crops, but it has been possible to improve the land quality using irrigation system, especially for field crops as well as for arboriculture.

Compliance with ethical standards

Acknowledgments

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Disclosure of conflict of interest

The authors declare no conflict of interest.

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