Soil fertility status for wheat crop production based on its soil organic matter and nitrogen contents

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ABSTRACT

The study was conducted to show the role of organic carbon and total content of available nitrogen on soil suitability for wheat production. The study area located in central of Iraq, in Al-Kufa – Alnajaf province situated approximately between 32° 00’ N to 32° 10’ N and 44° 20’ E to 44° 35’ E with total area of 27664 ha. Thirty five sites were selected representing all variations within the study area and located on landsat 8 image using GPS. Soil samples were taken from each of the selected sites and analyzed in laboratory to determine some physical and chemical properties. The results revealed that most soils of the study soils are Haplosalids and to some extend the presence of Torrifluvents. Most of soils have high salt accumulation. Rating scores for soil properties were evaluated using FAO, 2007 system to determine the suitability class for each soil site .The results indicated four suitability classes for wheat production in the study area including S3, N1 and N2 with, about 37% of the total area of the study site are not suitable for wheat production due, mainly to the effect of high salinity level and to some extent to low content of organic carbon and total available nitrogen. Also, the results demonstrated the effects of organic carbon and available nitrogen on the spatial distribution pattern of soil suitability classes for wheat production.
Introduction

The population of the planet is growing dramatically. In order to meet the increasing demand for the food the farming community has to produce more crops mainly cereal types. Under present situations, where the land is a limiting factor, it is impossible to bring more area under cultivation, so farming community should tackle this challenge of producing more food. One approach to this point can be followed through using some conservation practices represented by land suitability evaluation systems. Further, land suitability analysis is needed for various purposes in the context of the present day agriculture. Land suitability evaluation is the prerequisites for sustainable agricultural production. It involves evaluation of the criteria ranging from soil, terrain to socio-economic, market and infrastructure (Prakash, 2003). According to the FAO general framework for land suitability evaluation (1976), the land suitability classification consists of assessing and grouping the land types in orders and classes according to their capacity. The results are intended to be used for land resource related decision making, both strategic land use planning by policy/planning institutions such as extension agencies, and specific local land allocation by the direct land users, that is, the farmers. Suitability of land is assessed considering rational cropping system, for optimizing the use of a piece of land for a specific use (FAO, 1976; Sys et al., 1991). The suitability is a function of crop requirements and land characteristics and it is a measure of how well the qualities of land unit match the requirements of a particular form of land use (FAO 1976). Land evaluation is a process of predicting land performance over time according to the specific types of use (Lee and Yeh, 2009; Martin and Saha, 2009; and Sonneveld et al., 2010). Agriculture land suitability assessment is defined as the process of assessment of land performance when used for alternative kinds of agriculture (He et al., 2011; Prakash, 2003). The principle purpose of agriculture land suitability evaluation is to predict the potential and limitation of the land for crop production. Conceptually, land evaluation requires matching of the ecological and management requirements of relevant kinds of land use with land qualities, whilst taking local economic and social conditions into account. Land evaluation provides practical answers to such questions as "What other uses of land are physically possible and economically and socially relevant?", "What inputs are necessary to bring about a desired level of production?", and "What are the current land uses and what are the consequences if current management practices stay the same?". In order to reach such aims, this study was conducted to meet the following objectives: 1- To evaluate land characteristic for wheat according to FAO, 2007 system, 2- to develop regression model to predict wheat production suitability using some spectral indices and 3- To show the impact of soil organic carbon and available nitrogen on the spatial distribution pattern of wheat suitability classes in the study area.

Materials and Methods
Study Site

The study area located in central of Iraq, in Al-Kufa – Al Nagaf province lying between latitude 32° 00' N to 32° 10' N and longitude 44° 20' E to 44° 35' E with total area of 27664 ha (Figure 1). Land of the study area are used for some crops production including wheat, barley and corn.

Field Work

Thirty five locations in the study area were selected to represent all variations in local conditions (Figure 1). Soil samples were taken from fifteen pedons and twenty auger holes, and from all horizons or layers and described morphologically in the field according to Soil Survey Division Staff, 1993. Some physical, chemical and fertility properties for all soil samples were determined in laboratory using the common analysis methods mentioned by Bouyoucos (1962); Page et al. (1982); Hesse (1971); Papanicolaou, (1976) and Jackson (1958). Soils were classified according to Soil Survey Staff, (2012).

Satellite and ancillary data

The Landsat 8 OLI image (acquisition date: 1 Mar 2015) obtained from the USGS EROS centre was used in this study. The OLI image consists of eleven spectral bands with a spatial resolution of 30 meters for bands 1 to 7 and 9. The resolution for band 8 (panchromatic) is 15 meters. The time of acquisition corresponded closely to the field trips, and occurred while the main cereal crop (wheat) was in the growing stages. Atmospheric correction for Landsat image was done using the FLAASH model (Perkins...
et al. 2005) to correct both additive and multiplicative atmospheric effects. The corrected image was used to produce the following indices using ENVI 5 (Table 1).

**Table 1: Formulae of the vegetation indices.**

| Index | Full name | Formula | References |
|-------|-----------|---------|------------|
| SAVI  | Soil-Adjusted Vegetation Index | \( \frac{(1+L)(\rho_{NIR} - \rho_R)}{(\rho_{NIR} + \rho_R + L)} \) | Huete (1988) |
|       |           | Low vegetation, \( L = 1 \), intermediate, \( 0.5 \), and high 0.25 |           |
| EVI   | Enhanced Vegetation Index | \( G = \frac{(\rho_{NIR} - \rho_R)}{(\rho_{NIR} + C1*\rho_R - C2*\rho_B + L)} \) | Huete et al. (1997) |
|       |           | \( \rho_B \) = reflectance of blue band, \( G = 2.5 \), \( C1 = 6 \), \( C2 = 7.5 \) and \( L = 1 \) |           |
| GDVI  | Generalized Difference Vegetation Index | \( \frac{(\rho^n_{NIR} - \rho^n_R)}{(\rho^n_{NIR} + \rho^n_R)} \) | Wu (2012) |
|       |           | \( n \) is power number, an integer of the values of 1, 2, 3, 4... \( n \). |           |

Note: \( \rho_{NIR} \) and \( \rho_R \) are reflectance of the near infrared (NIR) and red (R) bands; \( \rho_B \) and \( \rho_{MIR} \) are respectively that of blue band and of the middle infrared band (like TM band 5).

**Land suitability Evaluation:**

All soil properties were evaluated for wheat production and suitability classes were determined according FAO, 2007 (Equation 1) Table 2). Land suitability analysis and classes map for the study area were developed using ArcGIS.

\[
I = A \times \frac{B}{100} \times \frac{C}{100} \times \frac{D}{100} \times \frac{E}{100} \times \frac{F}{100} \times \frac{G}{100} \times \frac{H}{100} \times \frac{J}{100} \times \frac{K}{100} \times \frac{L}{100} \times \frac{M}{100} \ldots \ldots [1]
\]

where:
- \( I \) = suitability rating score
- \( A \) = soil depth (cm)
- \( B \) = soil texture
- \( C \) = rock fragment
- \( D \) = calcium Carbonate
- \( E \) = CEC
- \( F \) = PH
- \( G \) = O.C.
- \( H \) = EC
- \( J \) = ESP
- \( K \) = Slope %
- \( L \) = Drainage
- \( M \) = Gypsum

**Table 2. Land Suitability classes for wheat production (FAO, 2007).**

| Index | Definition | Symbol |
|-------|------------|--------|
| 80-100| Highly Suitable | S1     |
| 60-80 | Moderately Suitable | S2     |
| 40-60 | Marginally Suitable | S3     |
| 25-40 | Currently not Suitable | N1     |
| 0-25  | Permanently not Suitable | N2     |
Statistical Prediction Model

A Pearson correlation analysis was applied to compute the best statistical regression models for wheat suitability using some vegetation indices included EVI, SAVI, and GDVI (Table 1). The prediction accuracy was verified by comparing the predicted and the measured values of the studied soil properties using the 35 randomly selected field observations. The results of the best fitting correlation (Equation 1) was used to develop map for the pattern of spatial distribution for wheat suitability classes in the study area.

Map of the spatial distribution pattern of wheat suitability classes was developed using geostatistical analysis - ordinary Kriging model, according to Webster and Oliver, 2007 and using ArcGIS 10.1.

Results and Discussion

Soils of the study area

The results of the physical and chemical properties of the studies soils indicated that the soils of the study area don’t show some evidences for the formation of illuvial subsurface (Bt) and other horizons due to the effect of the dominant soil forming factors including dry climatic, high level of ground water and young calcareous parent materials. The results of physical and chemical soil properties revealed that the dominate soil types in the study area are Haplosalids and Torrifuvents. Most of the soils are affected by salt accumulation with low content of organic matter and available Nitrogen (Table 3).

Table 3. Some physical and chemical properties of the study area.

| Site | pH | dS.m⁻¹ | g.kg⁻¹ | Textural name | g.kg⁻¹ | cmol_⁻² | ESP% | mg.kg⁻¹ |
|------|----|--------|--------|---------------|--------|---------|------|--------|
|      |    |        |        | Ece | Sand | Silt | clay | Lime | Gypsum | SOC | CEC | T.N |
| P1   | 7.23 | 28.04 | 160.28 | 505.81 | 333.91 | SiCL | 227.57 | 1.45 | 3.15 | 26.11 | 32.25 | 30.09 |
| P2   | 7.57 | 6.14  | 366.79 | 425.21 | 208.00 | L    | 201.51 | 0.47 | 5.79 | 23.17 | 12.00 | 44.90 |
| P3   | 7.02 | 41.23 | 116.45 | 510.52 | 373.03 | SiCL | 241.21 | 1.93 | 1.73 | 26.67 | 35.41 | 25.08 |
| P4   | 7.44 | 13.98 | 220.21 | 497.32 | 282.47 | CL   | 208.90 | 0.78 | 4.78 | 24.68 | 24.38 | 34.87 |
| P5   | 7.56 | 5.64  | 387.27 | 406.31 | 206.42 | L    | 200.50 | 0.46 | 5.93 | 23.20 | 11.19 | 45.54 |
| P6   | 7.60 | 4.18  | 348.64 | 493.30 | 158.06 | SiL  | 201.37 | 0.42 | 6.13 | 22.90 | 6.90  | 48.65 |
| P7   | 7.25 | 27.00 | 163.28 | 508.30 | 328.41 | SiL  | 227.06 | 1.39 | 3.19 | 26.00 | 31.83 | 28.38 |
| P8   | 7.04 | 40.13 | 65.01  | 558.97 | 376.02 | SiCL | 238.49 | 1.88 | 1.92 | 26.76 | 35.36 | 25.42 |
| P9   | 7.57 | 6.08  | 487.02 | 333.81 | 179.17 | L    | 201.78 | 0.44 | 5.74 | 22.93 | 10.51 | 45.95 |
| P10  | 7.60 | 3.59  | 518.27 | 333.87 | 147.86 | SL   | 199.35 | 0.40 | 6.05 | 22.43 | 5.05  | 49.90 |
| P11  | 7.59 | 4.35  | 325.29 | 514.00 | 160.71 | SiL  | 199.81 | 0.42 | 6.03 | 22.72 | 7.36  | 48.29 |
| P12  | 7.59 | 3.30  | 494.32 | 363.20 | 142.48 | L    | 199.10 | 0.39 | 6.09 | 22.30 | 3.89  | 50.66 |
| P13  | 7.19 | 29.83 | 154.43 | 505.91 | 339.66 | SiCL | 229.53 | 1.54 | 2.97 | 26.16 | 32.74 | 27.58 |
| P14  | 7.39 | 18.58 | 216.44 | 478.85 | 304.71 | CL   | 216.10 | 1.01 | 4.33 | 25.36 | 27.75 | 32.15 |
| P15  | 7.08 | 36.59 | 117.93 | 514.35 | 367.72 | SiCL | 234.58 | 1.78 | 2.37 | 26.63 | 34.66 | 26.14 |
| A1   | 7.61 | 5.43  | 367.87 | 466.82 | 165.31 | L    | 203.05 | 0.37 | 5.58 | 22.70 | 9.19  | 46.87 |
| A2   | 7.61 | 5.61  | 404.28 | 427.97 | 167.75 | L    | 203.14 | 0.37 | 5.56 | 22.74 | 9.54  | 46.60 |
| A3   | 7.53 | 10.18 | 284.53 | 475.72 | 239.75 | L    | 208.88 | 0.57 | 4.98 | 24.24 | 20.68 | 37.96 |
| A4   | 7.57 | 8.15  | 317.07 | 455.27 | 227.67 | L    | 207.15 | 0.51 | 5.15 | 23.94 | 18.53 | 39.73 |
| A5   | 7.16 | 33.18 | 168.74 | 491.01 | 340.25 | SiCL | 235.39 | 1.48 | 2.27 | 26.16 | 33.22 | 26.77 |
| A6   | 7.48 | 13.68 | 215.73 | 513.69 | 270.58 | SiL  | 212.55 | 0.69 | 4.60 | 24.72 | 24.04 | 35.13 |
| A7   | 7.59 | 7.12  | 364.80 | 414.90 | 220.30 | L    | 204.43 | 0.42 | 5.44 | 23.25 | 13.47 | 43.69 |
| A8   | 7.60 | 6.65  | 294.32 | 490.07 | 215.61 | L    | 204.13 | 0.42 | 5.46 | 23.15 | 12.70 | 44.27 |
| A9   | 7.62 | 5.15  | 384.07 | 453.56 | 162.37 | L    | 202.89 | 0.37 | 5.29 | 22.63 | 8.61  | 47.29 |
| A10  | 6.91 | 49.51 | 27.58  | 594.01 | 378.41 | CL   | 252.72 | 2.07 | 0.53 | 26.72 | 36.49 | 23.57 |
Data of the weighted soil properties (Table 3) were evaluated for wheat suitability using FAO, 2007 and Sys et al., 1993 (Fable 4). The results show that salinity and ESP are the most limiting factors for wheat suitability, while lime, SOC and drainage show slight or moderately effects on the evaluation of wheat suitability in the study area.

**Table 4. Rating scores of soil properties of the study area for wheat suitability**

| Site | Depth | Frag. | Tex. | Lime | CEC | pH | S.O.C. | ECe | ESP% | Slope | Drain. | Gyp. | Wheat Suit. |
|------|-------|-------|------|------|-----|----|--------|-----|------|-------|--------|-----|-------------|
|      |       |       |      |      |     |    |        |     |      |       |        |     | Value       |
|      |       |       |      |      |     |    |        |     |      |       |        |     | Class       |
| P1   | 100.0 | 1.00  | 1.00 | 0.90 | 1.00| 0.75| 0.25   | 0.7 | 1.00 | 0.70  | 1.00  |    | 8.27 | N2          |
| P2   | 100.0 | 1.00  | 0.95 | 0.90 | 0.95| 1.0 | 0.95   | 0.40| 0.95 | 1.00  | 1.00  | 1.00| 29.32 | N1          |
| P3   | 100.0 | 1.00  | 0.90 | 1.00 | 0.90| 1.0 | 0.60   | 0.25| 0.76 | 1.00  | 0.70  | 1.00| 7.18  | N2          |
| P4   | 100.0 | 1.00  | 0.90 | 1.00 | 1.00| 0.85| 0.25   | 0.8 | 1.00 | 1.00  | 1.00  | 1.00| 15.30 | N2          |
| P5   | 100.0 | 1.00  | 0.95 | 0.90 | 0.95| 1.0 | 0.99   | 0.60| 0.95 | 1.00  | 1.00  | 1.00| 45.84 | S3          |
| P6   | 100.0 | 1.00  | 0.95 | 0.90 | 0.95| 1.0 | 1.00   | 0.65| 0.95 | 1.00  | 1.00  | 1.00| 50.16 | S3          |
| P7   | 100.0 | 1.00  | 0.95 | 0.90 | 1.00| 1.0 | 0.75   | 0.25| 0.7 | 1.00  | 0.70  | 1.00| 7.86  | N2          |
| P8   | 100.0 | 1.00  | 0.95 | 0.90 | 1.00| 1.0 | 0.60   | 0.25| 0.6 | 1.00  | 0.70  | 1.00| 5.67  | N2          |
| P9   | 100.0 | 1.00  | 0.95 | 0.90 | 0.95| 1.0 | 0.95   | 0.40| 0.95 | 1.00  | 1.00  | 1.00| 29.32 | N1          |
| P10  | 100.0 | 1.00  | 0.60 | 0.90 | 0.95| 1.0 | 1.00   | 0.85| 0.95 | 1.00  | 1.00  | 1.00| 41.42 | S3          |
| P11  | 100.0 | 1.00  | 0.95 | 0.90 | 0.95| 1.0 | 1.00   | 0.80| 0.95 | 1.00  | 1.00  | 1.00| 61.73 | S2          |
| P12  | 100.0 | 1.00  | 0.95 | 0.95 | 0.95| 1.0 | 1.00   | 0.85| 0.99 | 1.00  | 1.00  | 1.00| 68.35 | S2          |
| P13  | 100.0 | 1.00  | 0.90 | 1.00 | 0.90| 1.0 | 0.75   | 0.25| 0.7 | 1.00  | 0.70  | 1.00| 8.27  | N2          |
| P14  | 100.0 | 1.00  | 1.00 | 0.90 | 1.00| 1.0 | 0.85   | 0.25| 0.8 | 1.00  | 1.00  | 1.00| 15.30 | N2          |
| P15  | 100.0 | 1.00  | 1.00 | 0.90 | 1.00| 1.0 | 0.60   | 0.25| 0.6 | 1.00  | 0.70  | 1.00| 5.67  | N2          |
| A1   | 100.0 | 1.00  | 0.95 | 0.90 | 0.95| 1.0 | 0.95   | 0.60| 0.95 | 1.00  | 1.00  | 1.00| 43.98 | S3          |
| A2   | 100.0 | 1.00  | 0.95 | 0.90 | 0.95| 1.0 | 0.95   | 0.60| 0.95 | 1.00  | 1.00  | 1.00| 43.98 | S3          |
| A3   | 100.0 | 1.00  | 0.95 | 0.90 | 1.00| 1.0 | 0.90   | 0.25| 0.85| 1.00  | 1.00  | 1.00| 16.35 | N2          |
| A4   | 100.0 | 1.00  | 0.95 | 0.90 | 0.95| 1.0 | 0.92   | 0.35| 0.85 | 1.00  | 1.00  | 1.00| 22.23 | N2          |
| A5   | 100.0 | 1.00  | 0.90 | 1.00 | 0.90| 1.0 | 0.70   | 0.25| 0.7 | 1.00  | 0.70  | 1.00| 7.72  | N2          |
| A6   | 100.0 | 1.00  | 0.95 | 0.90 | 1.00| 1.0 | 0.85   | 0.25| 0.75| 1.00  | 1.00  | 1.00| 13.63 | N2          |
| A7   | 100.0 | 1.00  | 0.95 | 0.90 | 0.95| 1.0 | 0.95   | 0.40| 0.95 | 1.00  | 1.00  | 1.00| 29.32 | N1          |
FAO, (2011) indicated that approximately 60% of the cultivated land in central Iraq has been seriously affected by salinity and 20-30% of the abandoned soils. Many researchers found that salinity and SOC are the most limiting factor for wheat production in central and southern Iraq (Alshafi and Muhaimeed, 2012; Muhaimeed et al., 2015; Muhaimeed et al., 2016). The results shown in Table 4 indicated that soils of the study area are moderately to not suitable for wheat production and the dominant suitability classes found are S2, S3, N1 and N2.

**Prediction of Wheat suitability**

The results of Pearson correlation analysis for computing the best statistical prediction model for wheat suitability using some vegetation indices included EVI, SAVI, and GDVI, indicated very high significant positive correlation ($R^2 = 0.95$) between the actual suitability values (Figure 2) and the predicted suitability values calculated using equation 1. The prediction model was used to developed the map of spatial distribution of wheat suitability in the study area (Figure 3). The results shown in Figure 3 revealed the presence of four suitability classes including S2, S3, N1 and N2. The percentage area for classes S2, S3, N1 and N2 were 12.28, 21.69, 20.36 and 36.26 respectively. Map of the spatial distribution pattern shows that the non-suitable classes (N1 and N2) are located with the area of salt affected soils, while the moderately suitable classes (S2 and S3) are located within the area of non-salt affected soils. The non-suitable classes are dominant and cover more than 56% from the total area of the study area (Figure 3). The domination of non-suitable classes are due to bad management practices as well as low content of SOC and total available nitrogen.
The study area suffering from unsuitable irrigation and drainage systems as well as bad quality of irrigation water. These factors allow to increase the rate of salt accumulation in most of the soils in the study area. Muhaimeed and Ali, 2016 indicated that land degradation which affects crop production in central Iraq is the result of complex interactions between physical, chemical, biological, socio-economical, and political issue of local and national conditions.
Effect of SOC and TAN on Wheat suitability

The results (Table 3 and 4) show that the content of SOC and total available Nitrogen in most soils in the study area are low and have moderate effect on the degree of soil suitability for wheat production. This is reflected by the pattern of spatial distribution for SOC and TAN in the study area. Figure 4 was developed by using geostatistical analysis and ordinary Kriging model to show the relationship between spatial distribution of SOC content and wheat suitability of study area. The results (Figure 5) revealed the presence of high positive correlation between soil suitability for wheat production and the content of SOC with $R^2 = 0.834$. This result is due to the fact which indicated that soil organic matter is a major source of many nutrients including nitrogen used by crops and at any given time, a high portion of the potentially available nitrogen in the soil is in organic forms, either in plant and animal residues, in the relatively stable soil organic matter, or in living soil organisms, mainly microbes such as bacteria (Glass, 2003).

![Spatial Distribution pattern for suitability classes and SOC in the study area.](image)

Available total nitrogen in the studied soils show the same trend of correlation shown by SOC with soil suitability for wheat production. The results (Figure 5) revealed high positive correlation between wheat suitability and TAN with $R^2 = 0.957$. This correlation was used to develop the spatial distribution map for both wheat suitability and TAN in the study area.
Figure 6). The results indicated a good correlation between the location of wheat suitability classes and the soil content from TAN, moderately suitable classes (S2, S3) located within area of moderately content of TAN, while unsuitable classes going parallel with low TAN content in the soil of the study area. This shows the importance of available nitrogen on plant growth. Nitrogen is an important nutrient in soil, a basic resource for maintaining the Earth’s ecosystems, and a primary restrictive factor for crop production (Glass, 2003).

![Fig. 5. The correlation between wheat suitability score and SOC content](image1)

Wheat Suit. = 2.2528e^{0.3769\text{(S.O.C.)}}
R^2 = 0.8343**

![Fig. 6. The correlation between wheat suitability score and TAN content](image2)

Wheat Suit. = 0.6191e^{0.0899\text{(T.A.N)}}
R^2 = 0.9570**
Conclusions

Statistical prediction models used in this study for both SOC, TAN and soil suitability for wheat production are corresponded well with actual measured values of these attributes. Soil organic carbon and available nitrogen content showed high correlation with spatial distribution pattern for wheat suitability classes in the study area. These results revealed the important of SOC and TAN for plant growth and consequently for soil suitability for wheat production.

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