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A Comparative Study of Soil Fertility in Northern Dhi Qar and Its Impact on Wheat Production Using GIS

Talib Shamkhy Jaber AL- Humaydawi[1] **Kahraman Hussein Habeeb[2]**
Department of Soil Science and Water Resources, College of Agriculture, University of Wasit
Corresponding author: tjaber@uowasit.edu.iq

Abstract:

This study was conducted in the northern part of Dhi Qar Governorate, covering the areas of Al-Rifai and Al-Qalat Sukkar, with the aim of evaluating the agricultural fertility of their soils and their suitability for cultivating wheat (Ibaa 99 variety) during the winter season of 2024, using Geographic Information Systems (GIS).

Soil samples were collected from a depth of 0–30 cm prior to planting and subjected to physical and chemical analyses to determine key fertility parameters, including: pH, electrical conductivity (EC), soil texture, organic matter content, cation exchange capacity (CEC), calcium carbonate content, exchangeable sodium percentage (ESP), and the concentrations of N, P, and K.

The standard multiplication method was used to estimate fertility ratings, and fertility maps were generated for each area using ArcGIS Pro. Soil fertility levels were also correlated with wheat productivity and physiological traits, which were measured during the flowering stage. These traits included plant height, leaf area, biological yield, grain yield, 1000-grain weight, and harvest index.

The results showed that Al-Rifai outperformed Al-Qalat Sukkar in terms of soil fertility and recorded higher values in all studied plant parameters. Nitrogen concentrations ranged between 24.1 and 44.4 mg/kg, phosphorus between 10.9 and 20.5 mg/kg, and potassium between 100 and 204 mg/kg.

The findings of this study indicate that variations in soil fertility between locations had a direct impact on wheat productivity. The study recommends the use of GIS technologies as an effective tool for agricultural decision-making and for determining optimal fertilizer recommendations.

Keywords*: Fertility evaluation, Northern Dhi Qar, GIS, Wheat*

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دراسة مقارنة لخصوبة التربة في شمال ذي قار وتأثيرها على إنتاج القمح باستخدام نظم المعلومات الجغرافية (GIS)

طالب شمخي جبار[1] كهرمان حسين حبيب[2]
قسم علوم التربة والموارد المائية، كلية الزراعة، جامعة واسط

الخلاصة

أُجريت هذه الدراسة في الجزء الشمالي من محافظة ذي قار، وشملت منطقتي الرفاعي والقلعة، بهدف تقييم الخصوبة الزراعية لتربتها ومدى ملاءمتها لزراعة القمح (صنف إباء 99) خلال الموسم الشتوي لعام 2024، باستخدام نظم المعلومات الجغرافية (GIS).

تم جمع عينات التربة من عمق 0–30 سم قبل الزراعة، وأُجريت عليها تحاليل فيزيائية وكيميائية لتحديد المؤشرات الرئيسية للخصوبة، بما في ذلك: الرقم الهيدروجيني(pH) ، التوصيل الكهربائي(EC) ، قوام التربة، محتوى المادة العضوية، السعة التبادلية الكاتيونية (CEC) ، محتوى كربونات الكالسيوم، نسبة الصوديوم المتبادل(ESP) ، وتركيزات النيتروجين(N) ، الفسفور(P)،والبوتاسيوم.(K)

تم استخدام طريقة الضرب المعيارية لتقدير درجات الخصوبة، كما تم إنتاج خرائط الخصوبة لكل منطقة باستخدام برنامج ArcGIS Pro. وتم ربط مستويات خصوبة التربة بإنتاجية القمح والصفات الفسيولوجية للنبات، والتي تم قياسها خلال مرحلة التزهير، وشملت: ارتفاع النبات، مساحة الورقة، الغلة الحيوية، غلة الحبوب، وزن 1000 حبة، ودليل الحصاد. أظهرت النتائج تفوق منطقة الرفاعي على القلعة في خصوبة التربة، وسجلت قيمًا أعلى في جميع الصفات النباتية المدروسة. تراوحت تركيزات النيتروجين بين 24.1 و44.4 ملغم/كغم، والفسفور بين 10.9 و20.5 ملغم/كغم، والبوتاسيوم بين 100 و204ملغم/كغم.

تشير نتائج الدراسة إلى أن التباين في خصوبة التربة بين المناطق كان له تأثير مباشر على إنتاجية القمح. وتوصي الدراسة باستخدام تقنيات نظم المعلومات الجغرافية كأداة فعالة في اتخاذ القرارات الزراعية وتحديد التوصيات المثلى للتسميد.

الكلمات المفتاحية: تقييم الخصوبة، شمال ذي قار، نظم المعلومات الجغرافية، القمح.

Introduction

Wheat (*Triticum aestivum*) is considered one of the most strategically important crops worldwide due to its significant contribution to food security and its high nutritional value in terms of protein and energy content. In Iraq, wheat is a key staple crop that plays a vital role in the agricultural sector. The Ministry of Agriculture has been actively working to enhance wheat productivity by developing improved cultivars adapted to the country's specific climatic and environmental conditions (Iraqi Ministry of Agriculture, 2020).

Among these cultivars, "Ibaa 99" is one of the most prominent varieties adopted in Iraq, especially in the southern regions such as Basra, Maysan, and Dhi Qar. This variety is known for its high yield potential and its strong adaptability to saline and arid soils. It is also characterized by its high resistance to common diseases such as brown and yellow rusts, making it an ideal option for cultivation in areas facing environmental stress (National Center for Agricultural Research, 2021).

According to Al-Jaberi (2020), many soils in central and southern Iraq are underdeveloped due to variations in their physical and chemical properties. Therefore, fertility evaluation is crucial—especially when the soil fails to supply the essential nutrients needed for optimal plant growth. Accurate diagnosis requires experts with practical knowledge of soil and plant sciences, as misinterpretation can lead to deficiencies, growth inhibition, and even plant death if not addressed properly.

Geographic Information Systems (GIS) have emerged as modern and powerful tools for analyzing the spatial variability of soil characteristics. GIS enables the management of spatial data and its integration with descriptive attributes, facilitating the understanding of the geographic distribution of nutrients and soil physicochemical properties. Al-Jiyashi (2016) emphasized that GIS-based fertility mapping contributes significantly to guiding fertilizer management and identifying the actual nutrient requirements of crops based on soil characteristics.

In this study, GIS technology was employed as a supporting tool for evaluating soil fertility in the Al-Qalat Sukkar and Al-Rifai districts. The fertility assessment results were then correlated with wheat productivity to develop accurate, spatially informed agricultural recommendations.

Objectives of the Study:

1. To analyze the physical and chemical soil properties involved in fertility evaluation in the study areas.
2. To generate spatial distribution maps of fertility-related soil properties using GIS.

Materials and Methods

This study was conducted in two sites located in the northern part of Dhi Qar Governorate: Al-Qalat Sukkar and Al-Rifai districts. The study areas covered 150 and 210 dunams, respectively. Sampling locations in each field were determined using a GPS device (Garmin), and soil samples were collected before wheat planting from a depth of 0–30 cm. Each sampling point was georeferenced using the UTM coordinate system and spatially mapped using ArcGIS Pro 3.4 software to meet spatial analysis requirements.

The soil samples were air-dried, ground, and sieved through a 2 mm mesh. Selected chemical and physical properties were analyzed prior to planting, as shown in Table 1.

Wheat seeds of the variety Ibaa 99 (2024 season) were sown by local farmers in both Al-Qalat Sukkar and Al-Rifai using a plot and row design. Each plot had an area of 2,500 m^2, as detailed in Table 2. Planting dates were November 15, 2024, for Al-Qalat Sukkar and November 17, 2024, for Al-Rifai. Row spacing was approximately 15 cm.

All plots received phosphorus and nitrogen fertilizers according to the recommended fertilizer guidelines. Phosphorus fertilizers were applied beside the planting rows after thorough mixing with the soil. Nitrogen fertilizers were applied in two split doses: the first half at the time of sowing, and the second half during the vegetative growth stage (45 days post-emergence).

At the maturity stage (physiological yellowing), manual harvesting was performed for a 1 m^2 area at each pre-identified sampling location using GIS. Each study site included 15 sampling points. The following plant traits were measured:

- Biological yield (Mg ha^{-1})
- Grain yield (Mg ha^{-1})
- Thousand-grain weight (g)
- Plant height (cm)
- Leaf area (cm^2)

Table 1. Selected physical and chemical properties of soils in Al-Qalat Sukkar and Al-Rifai districts before wheat cultivation in Dhi Qar Governorate

Parameter	Al-Qalat Sukkar	Al-Rifai	Unit
Soil reaction (pH)	7.53	7.19	–
Electrical conductivity (ECe)	3.01	3.28	dS m^{-1}
Organic matter	15.01	14.38	g kg^{-1}
Cation exchange capacity (CEC)	22.89	25.18	cmol(+) kg^{-1} soil
Calcium carbonate ($CaCO_3$)	266.13	267.33	g kg^{-1}

Soluble cations			
Calcium (Ca^{2+})	8.45	9.56	mmol L^{-1}
Magnesium (Mg^{2+})	6.15	7.77	mmol L^{-1}
Potassium (K^{+})	0.45	0.37	mmol L^{-1}
Sodium (Na^{+})	7.50	7.73	mmol L^{-1}
Soluble anions			
Carbonates (CO_3^{2-})	Nil	Nil	mmol L^{-1}
Bicarbonates (HCO_3^{-})	1.10	1.20	mmol L^{-1}
Sulfates (SO_4^{2-})	13.66	14.12	mmol L^{-1}
Chlorides (Cl^{-})	30.88	39.53	mmol L^{-1}
Available nutrients			
Nitrogen (N)	34.84	34.41	mg kg^{-1}
Phosphorus (P)	16.23	16.89	mg kg^{-1}
Potassium (K)	168.07	154.00	mg kg^{-1}
Soil particle size distribution			
Clay	281	207	g kg^{-1}
Silt	510	510	g kg^{-1}
Sand	209	283	g kg^{-1}
Exchangeable Sodium Percentage (ESP)	8.66	10.70	%
Soil texture class	Silty loam	Silty loam	–

Soil and Plant Analysis

Soil Analyses:

- **Particle Size Distribution:**
  The particle size distribution of soil was determined using the hydrometer method according to Day as cited in Black (1965a).
- **Soil Reaction (pH):**
  Soil pH was measured using a pH meter following the method described by Jackson (1958).
- **Electrical Conductivity (ECe):**
  Electrical conductivity was determined from a saturated paste extract using an Electrical Conductivity Bridge, according to Jackson (1958).
- **Soluble Sodium and Potassium (Na^{+}, K^{+}):**
  These elements were measured using a flame photometer, based on the procedure of Jackson (1958).
- **Soluble Calcium and Magnesium (Ca^{2+}, Mg^{2+}):**
  Estimated by titration with Na_2-EDTA using ammonium purpurate as an indicator, following Lanyon and Heald (1982).
- **Cation Exchange Capacity (CEC):**
  Determined using 1N ammonium acetate (NH_4OAc) at pH 7.0, following the method of Black (1965b).
- **Exchangeable Sodium Percentage (ESP):**
  Exchangeable sodium was extracted with 1N ammonium acetate and measured by flame photometer. ESP was calculated using the formula:

$ESP\% = \{ exch.Na / CEC \} * 100$ according to Page et al. (1982).

- **Calcium Carbonate Content ($CaCO_3$):**
  Determined using 1N HCl, with the remaining acid titrated with 1N NaOH, according to Jackson (1958).
- **Carbonates and Bicarbonates (CO_3^{2-}, HCO_3^-):**
  Estimated by titration with 0.05N sulfuric acid (H_2SO_4), as per Jackson (1958).
- **Chloride (Cl^-):**
  Determined by titration with 0.05N silver nitrate ($AgNO_3$), following Jackson (1958).
- **Sulfates (SO_4^{2-}):**
  Determined using the turbidity method and measured spectrophotometrically, as described by Shawar and Al-Sayegh (2007).
- **Organic Matter (OM):**
  Measured by the wet digestion method of Walkley and Black as cited in Jackson (1958).
- **Available Nitrogen (N):**
  Extracted using 2M potassium chloride (KCl) and reduced with Devarda's alloy, distilled using the micro-Kjeldahl method, and titrated with 0.005N H_2SO_4, according to Keeney and Nelson as described in Page et al. (1982).
- **Available Potassium (K):**
  Extracted using 1N ammonium acetate (NH_4OAc) at pH 7.0 and measured with a flame photometer, following Page et al. (1982).
- **Available Phosphorus (P):**
  Extracted using 0.5N sodium bicarbonate ($NaHCO_3$) at pH 8.5 and measured using a flame photometer, as described in Page et al. (1982).

Plant Analysis:

At the flowering stage, 15 plants were collected per treatment in three replicates. The samples were washed with tap water followed by distilled water to remove any surface residues. They were then dried in an oven at 65°C until a constant weight was achieved, ground, and homogenized. A 0.2 g subsample of dried plant material was digested using a mixture of sulfuric acid and perchloric acid in a 1:4 ratio, following the procedure of Gresser and Parson (1979). The following elements were analyzed:

- **Nitrogen (N):**
  Determined in the digested sample using 10M NaOH in the Micro-Kjeldahl apparatus and titrated with 0.005N sulfuric acid, following Hanes (1980).
- **Potassium (K):**
  Measured using a flame photometer as described by Page et al. (1982).
- **Phosphorus (P):**
  Determined colorimetrically in the digested extract using ammonium molybdate and ascorbic acid, and measured at 882 nm with a spectrophotometer, following Al-Sahaf (1989).

Field Indicators and Results

At the full maturity stage of the wheat crop—i.e., when the spikes and vegetative parts turned yellow—on **April 30, 2025**, plants were manually harvested from an area of **1 m²**. Sampling was conducted at **15 geo-referenced points per field** across the four study sites, based on GPS coordinates taken before sowing (see Appendices 1, 2, 3, and 4). The following agronomic traits were measured:

- **Plant Height (cm):**

  Measured from the base of the plant at soil level to the base of the spike on the main stem at harvest time, averaged over ten plants per 1 m² sample (Khan & Splide, 1992).

- **Leaf Area (cm²):**
  Calculated using the formula:

Flag Leaf Area (FLA)=L×MW×0.75
where:
L = Leaf length (cm),
MW = Maximum width at mid-leaf (cm),
following the method of Al-Sahouk et al. (2013).

- **Thousand-Grain Weight (g):**
  A random sample of 1000 grains was counted and weighed from the harvested 1 m² area.
- **Grain Yield (Mg ha⁻¹):**
  After separating the straw, the grain was weighed and converted to megagrams per hectare (Mg ha⁻¹), following A.O.A.C. (1975).
- **Biological Yield (Mg ha⁻¹):**
  Calculated from the total dry weight of both straw and grains harvested from the same 1 m² area, following Donald and Hamblin (1976).
- **Harvest Index (%):**
  Determined using the formula:

Harvest Index= (Grain YieldBiological Yield) ×100
(Donald & Hamblin, 1976).

All agronomic practices were standardized across the four study locations: Qalat Sukkar, Al-Rifai, Kumait, and Sayyed Ahmad Al-Rifai. The wheat variety *Ibaa 99* was cultivated in all fields. Sowing was carried out in rows spaced 15 cm apart. Phosphate and urea fertilizers were applied according to recommended rates, with urea divided into two split applications to enhance nitrogen uptake efficiency. Pest and foliar disease control measures were uniformly applied across all sites.
Table 2 presents detailed information on sowing dates, fertilizer types and quantities, application timing, and pest control strategies for each location.

Table 2. Cultivation practices and planting dates in the study areas

Location	Planting Date	DAP (kg/donum)	Urea (kg/donum)	Pest & Disease Control	Seed Variety	Seeding Rate (kg/donum)	Notes
Al-Qalat Sukkar	15/11/2024	50	50 (first dose),25 (second dose)	Applied for pests and foliage diseases	Ibaa 99	40–50	Fertilizer quantities were standardized in agreement with local farmers.
Al-Rifai	17/11/2024	50	50	Applied for pests and foliage diseases	Ibaa 99	40–50	Fertilizer quantities were standardized in agreement with local farmers.

Standard Multiplication Method

The Standard Multiplication Method was adopted for evaluating soil fertility by selecting a set of key physical and chemical soil parameters, namely: soil reaction (pH), electrical conductivity (EC), cation exchange capacity (CEC), calcium carbonate content ($CaCO_3$), exchangeable sodium percentage (ESP), organic matter (OM), and the available macronutrients (N, P, and K).
Each parameter was assigned a score based on its proximity to an ideal reference value. The individual scores were then multiplied together to produce a composite index representing the overall fertility level at each sampling point.
The final fertility values were classified into five relative fertility categories:

- **F1**: Very Fertile
- **F2**: Fertile
- **F3**: Moderately Fertile
- **F4**: Low Fertility
- **N**: Non-Fertile

These fertility classes were visualized spatially using ArcGIS tools to generate fertility maps. This evaluation approach is a modified version of the method developed by Sys et al. (1980) for land suitability assessment. The model was adapted by incorporating available nutrients (N, P, K), pH, and organic matter (OM) to form a fertility index equation. The final fertility score (F) was calculated by multiplying the individual evaluation ratings of the selected soil parameters according to the following formula:

F=T×OM×CEC×CaCO3×N×P×K×pH×EC×ESPF

Where:

- **F** = Soil Fertility Index
- **T** = Soil Texture
- **OM** = Organic Matter
- **CEC** = Cation Exchange Capacity
- **$CaCO_3$** = Calcium Carbonate
- **N, P, K** = Available Nitrogen, Phosphorus, and Potassium
- **pH** = Soil Reaction
- **EC** = Electrical Conductivity
- **ESP** = Exchangeable Sodium Percentage

The fertility rating values for each parameter were derived from pre-established evaluation tables, as developed by **Sys et al. (1980)** and adapted for the conditions of this study.

Table 3. Organic Matter Content in Soil and Corresponding Fertility Index Values

Organic Matter Content (g/kg soil)	Fertility Index Value	Classification
< 10	0.50	Poor
10 – <14	0.80	Medium
14 – <20	0.90	Good
≥ 20	1.00	Rich

Table (4): Soil Fertility Classes and Suitability Index Values

Class Level	Fertility Class	Code	Suitability Index Value (F)
First Class	Very Fertile	F1	> 80
Second Class	Fertile	F2	60 – 80
Third Class	Moderately Fertile	F3	40 – 60
Fourth Class	Low Fertility	F4	20 – 40
Fifth Class	Non-Fertile	N	< 20

Results and Discussion

The soil fertility evaluation for the areas of Al-Rifai and Al-Qalat Sukkar was conducted based on nine key physical and chemical properties that directly influence soil fertility and wheat crop productivity. These properties include: soil reaction (pH), electrical conductivity (EC), soil texture, cation exchange capacity (CEC), calcium carbonate content ($CaCO_3$), organic matter (OM), exchangeable sodium percentage (ESP), and the availability of macronutrients (nitrogen, phosphorus, and potassium – NPK).

The study employed the Standard Multiplication Method to classify soil fertility into five categories: Very Fertile (F1), Fertile (F2), Moderately Fertile (F3), Low Fertility (F4), and Non-Fertile (N). However, the results revealed that none of the sampled locations in either region fell within the Very Fertile (F1) category.

The Al-Rifai region recorded the highest percentage of soils classified as Fertile (F2), while the categories of Moderately Fertile (F3) and Low Fertility (F4) were more predominant in the Al-Qalat Sukkar region. This indicates a clear spatial variability in soil fertility between the two locations, which is closely associated with differences in their chemical and physical soil characteristics. Such variation is expected to be reflected in the subsequent analysis of wheat productivity.

Additionally, the Non-Fertile (N) class appeared only in Al-Qalat Sukkar and was absent in Al-Rifai, as illustrated in Figures (1 and 2).

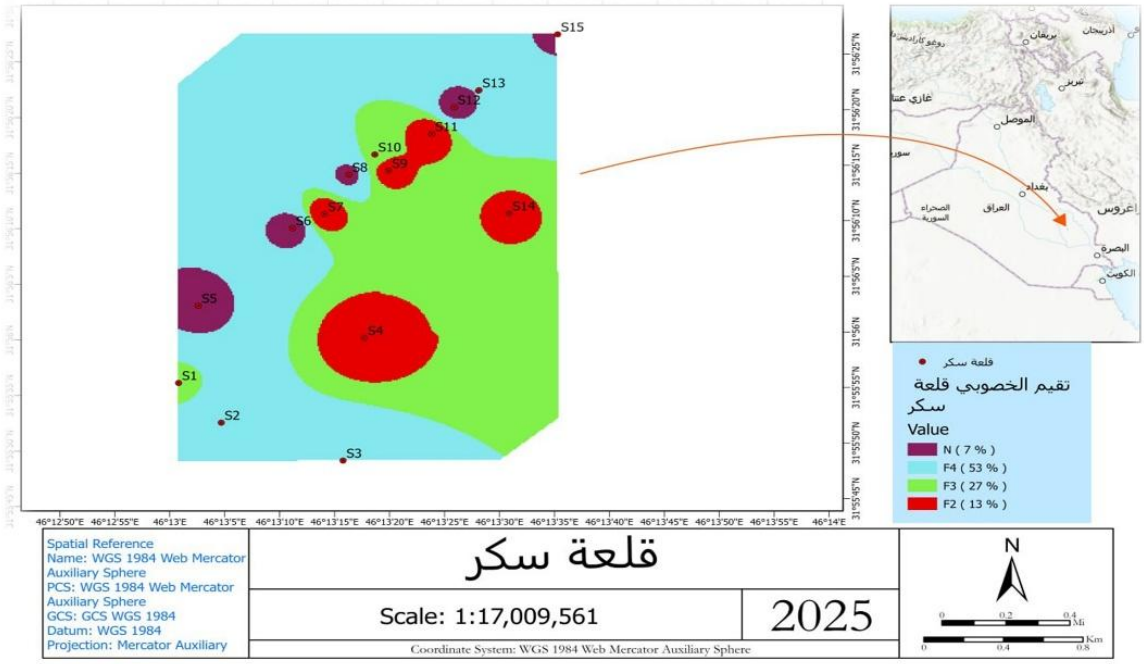

Figure (1): Map of Fertility Evaluation Distribution Rates for the Qalat Sukkar Area

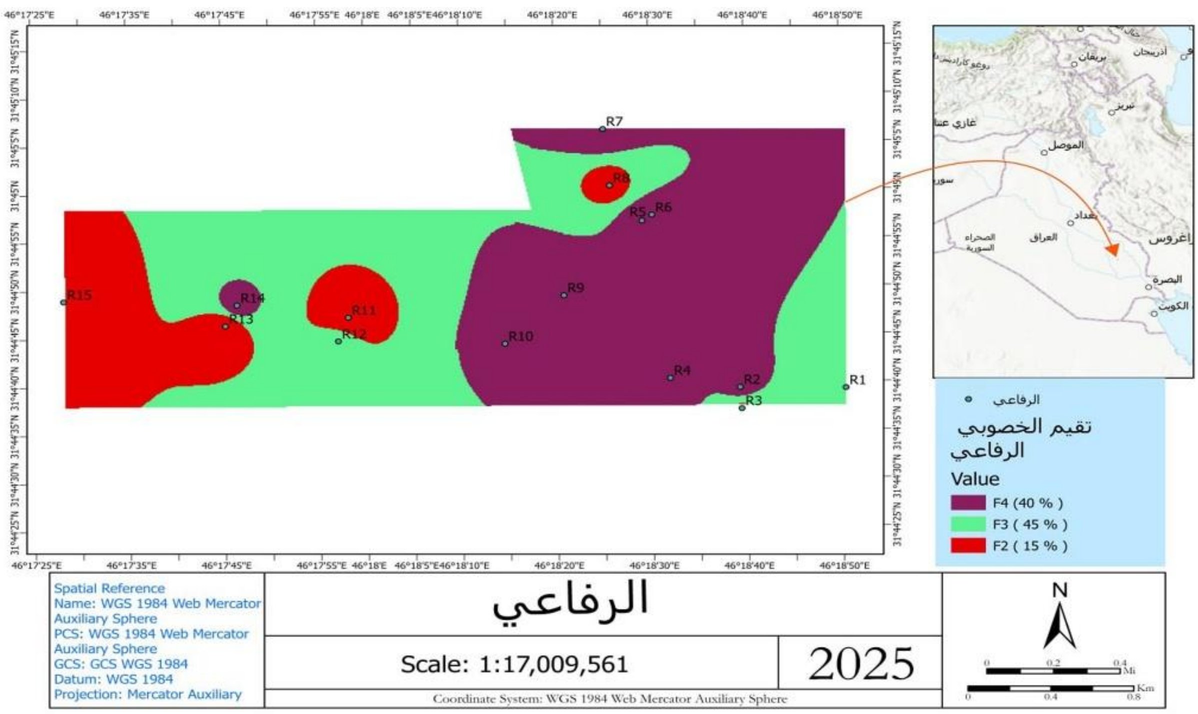

Figure (2): Map of Fertility Evaluation Distribution Rates for the Al-Rifai Area

Table 5. Soil Properties Used in Fertility Evaluation for Qadaa Qal'at Sukkar Area

Sample	O.M (g/kg soil)	$CaCO_3$ (mg/kg)	K (mg/kg)	P (mg/kg)	N (mg/kg)	ESP (%)	CEC (cmol/kg)	EC (dS/m)	pH	Texture (T)	Fertility Index	Fertility Class
1	15.29	280	160	19	38.39	5.58	25.20	2.7	7.8	Silty Loam Mix	42.07	F3
2	16.33	240	212	16	38.70	10.10	18.91	2.6	7.9	Loam Mix	27.48	F4
3	16.01	300	140	18.02	39.01	14.56	25.1	5.3	7.5	Loam Mix	22.90	F4
4	14.61	250	180	18.3	32.34	13.31	20.11	2.7	7.2	Silty Loam Mix	61.34	F2
5	14.19	310	118	13.2	33.71	6.30	16.8	2.2	7.6	Silty Loam Mix	17.81	N
6	13.18	310	140	10.2	31.26	4.35	12.17	2.2	7.6	Silty Loam Mix	11.31	N
7	16.19	245	220	19.0	37.5	8.14	26.2	2.9	7.1	Loam Mix	60.90	F2
8	11.71	310	142	13.2	27.87	6.92	19.61	4.5	7.8	Loam Mix	14.25	N
9	14.13	250	178	18.6	31.24	9.52	25.6	3.4	7.3	Loam Mix	56.09	F3
10	19.18	280	164	13.1	45.62	5.08	29.80	3.1	7.8	Loam Mix	40.40	F3

11	14.31	245	182	19.4	32.52	9.64	27.5	2.6	7.2	Silty Loam Mix	61.83	F2
12	13.28	290	106	15.3	30.60	14.63	19.26	3.9	7.6	Loam Mix	12.31	N
13	19.21	220	236	12.12	46.88	12.23	16.7	3.1	7.3	Loam Mix	34.00	F4
14	15.18	230	160	19.1	28.12	8.42	21.51	3.1	7.6	Silty Loam Mix	50.48	F3
15	14.90	260	160	17.3	35.44	5.69	27.30	2.6	7.9	Loam Mix	32.72	F4

Table 6. Soil Properties Used in Fertility Evaluation for Qadaa Al-Rifai Area

Sample	**O.M (g/kg soil)**	**$CaCO_3$ (mg/kg)**	**K (mg/kg)**	**P (mg/kg)**	**N (mg/kg)**	**ESP (%)**	**CEC (cmol/kg)**	**EC (dS/m)**	**pH**	**Texture (T)**	**Fertility Index**	**Fertility Class**
1	16.91	250	128	18.1	40.2	14.43	27.11	3.7	7.1	Silty Loam Mix	40.26	F3
2	13.80	300	110	15.6	32.8	10.25	25.11	4.0	7.31	Silty Loam Mix	25.13	F4
3	14.86	240	185	19.2	41.2	10.31	24.81	3.6	7.5	Silty Loam Mix	50.40	F3
4	10.81	260	142	18.0	25.8	9.64	23.10	5.0	7.1	Silty Loam Mix	24.43	F4

5	14.80	300	100	13.01	35.5	8.11	21.39	6.5	7.1	Silty Loam Mix	23.90	F4
6	14.13	230	102	12.0	34.2	9.55	25.81	3.6	7.2	Loam Mix	30.50	F4
7	10.06	290	124	10.9	24.1	11.85	27.19	2.8	7.2	Silty Loam Mix	19.55	F4
8	15.15	250	186	19.3	30.6	10.96	25.91	3.5	7.6	Silty Loam Mix	61.28	F2
9	12.16	300	130	18.3	29.7	13.10	23.19	3.2	7.1	Silty Loam Mix	20.36	F4
10	13.26	310	160	17.1	31.4	11.50	22.20	2.3	7.35	Loam Mix	29.08	F4
11	15.61	240	192	20.5	39.2	8.12	26.81	3.3	7.2	Silty Loam Mix	62.34	F2
12	16.18	300	146	14.01	44.4	9.62	26.39	5.0	7.1	Silty Loam Mix	40.39	F3
13	15.26	250	204	19.15	35.4	10.16	28.19	3.9	7.6	Silty Loam Mix	62.00	F2
14	15.51	280	152	13.1	36.9	14.29	23.75	3.6	7.1	Silty	22.77	F4
15	14.18	250	198	19.2	36.0	13.13	29.86	3.7	7.33	Loam Mix	62.01	F2

The results revealed a difference in soil texture between the two regions, with clay loam texture predominating in Al-Rifai, compared to a lighter texture in Al-Qalat Sukkar. This contributed to the superior ability of Al-Rifai soils to retain water and essential nutrients.

The soils of Al-Rifai exhibited pH values closer to neutrality, which enhanced the availability of phosphorus and other nutrients, in contrast to the slightly alkaline pH levels observed in Al-Qalat Sukkar. Electrical conductivity (EC) was relatively higher in Al-Qalat Sukkar, which negatively affected nutrient availability and growth balance.

Cation exchange capacity (CEC) was higher in the soils of Al-Rifai, indicating greater fertility and nutrient-holding capacity. Calcium carbonate content ($CaCO_3$) was lower in Al-Rifai soils, which facilitated the greater availability of nutrients, especially phosphorus.

Moreover, Al-Rifai soils had a higher organic matter (OM) content, which improves soil structure and enhances biological activity.

In contrast, some soil samples from Al-Qalat Sukkar recorded elevated exchangeable sodium percentage (ESP) levels, indicating the onset of sodicity, which may lead to the deterioration of physical soil properties. Regarding the availability of macronutrients (NPK), Al-Rifai soils showed higher concentrations, contributing to better wheat productivity compared to Al-Qalat Sukkar. (See Tables 5 and 6)

1. Plant Height (cm):

The results presented in Table 7 indicated significant differences in wheat plant height among the soil fertility classes in both study areas.

In Al-Qalat Sukkar, the highest plant height (109 cm) was recorded in the fertile class (F2), while the lowest height (95 cm) was observed in the non-fertile class (N). In Al-Rifai, the maximum plant height (110 cm) was also recorded in the fertile class (F2), whereas the lowest height (85.6 cm) was observed in the low fertility class (F3).

These variations are attributed to differences in soil fertility levels, which align with their respective fertility classifications. Factors such as increased organic matter, higher cation exchange capacity (CEC), and lower exchangeable sodium percentage (ESP) significantly enhanced plant growth.

Nitrogen is considered the most influential factor in plant height, as it plays a critical role in meristematic activity, cell division, and the formation of chlorophyll and proteins, ultimately contributing to greater vertical growth and increased biomass (Ali et al., 2014; Rashtbari et al., 2020).

Table 7. Average Wheat Grain Yield Height (cm) in the Study Regions

Sample	Study Regions	
	Qalat Sukkar (cm)	Al-Rifa'i (cm)
1	109	90
2	99	85.6
3	107	92.5
4	105	91.1
5	95	100
6	102	97.2
7	109	90.4
8	104	108

9	100.3	89.2
10	96	102
11	106	110
12	108	104
13	102	106
14	103	92
15	101	96
Mean	**103.08**	**96.93**

2. Leaf Area of the Yield (cm²):

The results in Table 8 showed significant differences in the leaf area of wheat plants among the soil fertility classes.
In Al-Qalat Sukkar, the highest average leaf area (45.3 cm²) was recorded in the fertile class (F2), while the lowest average (30.4 cm²) was observed in the non-fertile class (N). In Al-Rifai, the highest value (49.5 cm²) was noted in the fertile class (F2), and the lowest value (22.2 cm²) in the low fertility class (F4), reflecting the variation in soil fertility.
The increase in leaf area is associated with higher availability of nutrients, particularly nitrogen and phosphorus, which enhance vegetative growth, in addition to potassium's role in regulating nutrient uptake, activating cell division, and leaf expansion (Basnet et al., 2019; Anil et al., 2019).

Table 8. Average Leaf Area of Wheat Crop in the Study Regions (cm²)

Sample	**Study Regions**	
	Qalat Sukkar (cm²)	**Al-Rifa'i (cm²)**
1	44.5	28.4
2	40.6	24.2
3	40.2	31.3
4	38.7	27.4
5	42.3	39.6
6	42.8	22.2
7	45.3	29.2
8	30.4	42.7
9	41.2	25.3
10	39.1	33.2
11	43.1	44.4
12	41.04	34.2
13	40.1	49.5
14	40	28
15	37.6	30.9
Mean	**40.48**	**32.67**

3. Total Biological Yield (Mg ha⁻¹):

The results shown in Table 9 indicated significant differences in the total biological yield of the wheat crop between the study areas.
In Al-Qalat Sukkar, the highest average yield (15.86 Mg ha^{-1}) was recorded for the fertile class (F2), while the lowest average (9.27 Mg ha^{-1}) was observed for the non-fertile class (N). In Al-Rifai, the highest average (14.87 Mg ha^{-1}) was also associated with the fertile class (F2), and the lowest value (11.25 Mg ha^{-1}) was recorded for the low fertility class (F4).
These results indicate a strong correlation between the fertility classification based on the fertility evaluation and the biomass productivity of the crop. This is attributed to the abundance of nutrients and improved agricultural management practices, which enhanced growth efficiency and photosynthesis (Abd et al., 2016).

Table 9. Total Biological Yield of Wheat in the Study Regions (Mg ha^{-1})

Sample	Study Regions	
	Qalat Sukkar (Mg ha^{-1})	Al-Rifa'i (Mg ha^{-1})
1	14.16	13.21
2	12.62	11.57
3	12.77	12.39
4	15.54	11.25
5	10.00	12.32
6	9.81	11.89
7	15.86	12.34
8	9.27	14.87
9	14.43	11.92
10	14.21	12.72
11	15.48	13.93
12	9.54	14.11
13	11.38	14.43
14	13.01	12.00
15	12.32	14.46
Mean	**12.69**	**12.89**

4. Grain Yield (Mg ha^{-1}):

The data in Table 10 indicate significant differences in the average grain yield of the wheat crop between the two study areas.
In Al-Qalat Sukkar, the highest average grain yield (6.42 Mg ha^{-1}) was recorded for the fertile class (F2), while the lowest average (3.10 Mg ha^{-1}) was observed in the non-fertile class (N). In Al-Rifai, the highest average (6.46 Mg ha^{-1}) was also recorded for the fertile class (F2), and the lowest average (4.32 Mg ha^{-1}) was for the low fertility class (F4).
These results reflect the strong agreement between the fertility evaluation and the actual grain productivity, as higher fertility levels led to clear increases in yield. This improvement is attributed to the effect of nitrogen fertilization, where nitrogen is a key element in the formation of proteins, enzymes, and chlorophyll, and plays a direct role in enhancing vital growth and production processes (Ali et al., 2014; Mousa & Olash, 2022; Al-Yasari, 2012).

Table 10. Average Grain Yield of Wheat in the Study Regions (Mg ha^{-1})

Sample	Study Regions	
	Qalat Sukkar (Mg ha⁻¹)	Al-Rifa'i (Mg ha⁻¹)
1	5.96	5.69
2	4.21	4.32
3	4.24	4.50
4	6.19	4.41
5	3.22	4.47
6	3.41	4.55
7	6.11	4.36
8	3.40	5.54
9	5.83	4.33
10	5.73	5.87
11	6.42	6.23
12	3.10	5.32
13	3.99	6.50
14	4.33	5.36
15	4.18	6.46
Mean	**4.68**	**4.83**

5- Thousand-Grain Weight (g):

The results presented in Table 11 showed significant differences in the thousand-grain weight trait between the two study areas.

In Al-Qalat Sukkar, the highest average weight (37.81 g) was recorded for the fertile class (F2), while the lowest average (18.40 g) was observed for the non-fertile class (N). In Al-Rifai, the highest weight (39.95 g) was also recorded for the fertile class (F2), with the lowest average (28.08 g) in the low fertility class (F4).

This variation is related to the efficiency of the plants in performing photosynthesis and transporting its products to the grains, which increases their fullness and size. Additionally, the abundance of nitrogen during the vegetative growth stages contributed to improving leaf area and vegetative growth, thereby enhancing photosynthetic efficiency and nutrient distribution (Javanmard et al., 2022; Gonzales et al., 2015; Mousa & Olash, 2022).

Table 11. Thousand-Grain Weight of Wheat in the Study Regions (g)

Sample	Qalat Sukkar (g)	Al-Rifa'i (g)
1	35.05	37.17
2	33.21	30.43
3	33.48	28.08
4	37.81	31.32
5	34.01	32.81
6	32.80	33.21
7	37.17	30.98
8	33.12	37.31
9	36.82	29.91
10	35.11	38.48

11	36.45	38.72
12	32.51	35.21
13	35.72	39.95
14	34.46	36.95
15	33.12	39.18
Mean	**34.72**	**34.64**

6. Harvest Index (%) of Wheat Crop

The results presented in Table 12 show significant differences in the harvest index (%) of wheat among the study regions. In Qalat Sukkar, the highest average harvest index was recorded at 41.4% for the fertile variety (F2), compared to the lowest average of 32.1% for the infertile variety (N). This corresponds well with the soil fertility evaluation of Qalat Sukkar district.

Similarly, in the Al-Rifa'i area, the highest average harvest index was 45.05% for the fertile variety (F2), whereas the lowest average was 36.6% for the less fertile variety (F4). This aligns with the fertility status of the soils in Al-Rifa'i district.

The harvest index is a key measure of the crop's efficiency in converting total biomass into economic yield such as grains. An increase in the harvest index under specific agricultural conditions supports higher productivity. A high harvest index reflects improved biomass partitioning efficiency, leading to better crop yield, while adverse conditions reduce this efficiency and negatively impact overall production. Therefore, a higher harvest index is considered a significant factor in improving the economic return of wheat cultivation (Al-Jubouri et al., 2023).

Table 12. Harvest Index (%) of Wheat in the Study Regions

Sample	**Qalat Sukkar (%)**	**Al-Rifa'i (%)**
1	40.7	43.0
2	33.3	36.5
3	33.2	36.3
4	39.8	39.2
5	32.1	36.3
6	34.7	38.2
7	41.0	35.3
8	36.6	37.2
9	40.4	36.3
10	40.3	44.1
11	41.4	44.7
12	32.2	41.4
13	32.4	45.05
14	33.2	44.6
15	33.9	44.5
Mean	**36.34**	**40.17**

Relationship between Soil Fertility Assessment and Wheat Yield

The study results revealed a clear correlation between soil fertility assessment and the actual productivity of the wheat crop in the study areas. Fields classified within the high and medium fertility categories outperformed those classified as low or non-fertile in terms of production. This was reflected in higher values of plant traits such as plant height, leaf area, biological yield, grain yield, thousand-grain weight, and harvest index in areas classified with higher fertility ratings.

The spatial distribution maps produced using Geographic Information Systems (GIS) clearly illustrated this variability, showing a close match between the fertility levels identified in the assessment and the actual yield levels recorded in the fields. These findings emphasize the importance of fertility assessment supported by spatial analysis in shaping agricultural policies and guiding fertilization management towards areas of higher production efficiency.

Conclusions

Soils in Thi Qar Governorate suffer from a low proportion of fertile soils due to the absence of ideal properties in most of the study areas. Al-Rifai region showed a remarkable superiority in fertility levels compared to other areas. Averages indicated that regions with higher soil fertility recorded greater values in biological yield, grain yield, plant height, and harvest index. The use of Geographic Information Systems (GIS) helped document the spatial distribution of fertility and identify the most suitable areas for agricultural production within the governorate.

Recommendations

Soils in northern Thi Qar Governorate face fertility deficiencies, with Al-Rifai region showing better conditions in this regard. Higher fertility was linked to improved yield and plant growth. GIS played a significant role in documenting the spatial distribution of fertility and pinpointing the best cultivation areas. It is recommended to conduct updated fertility assessments using GIS to enhance land management and reclaim low-fertility areas. Additionally, integrating soil data with irrigation water quality, crop types, and climatic conditions to develop predictive models that support sustainable production is advised. Establishing a spatial database is also important to support agricultural planning.

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