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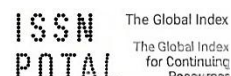
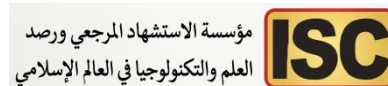
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Characterization and Classification of Soils in Al-Muwafaqiyah and Al-Dujaili Areas within Al-Kut District, Wasit Governorate, and Evaluation of Their Agricultural Suitability

A research manuscript prepared in the field of Soil
Characterization and Classification
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Abstract

The aim of this study was to characterize and taxonomically classify two agricultural soil sites, Al-Muwafaqiyah (K1) and Al-Dujaili (K2), of the Tigris alluvial plain of Wasit Governorate in central Iraq, each represented by three field replicates, and to evaluate their agricultural suitability. This site-level characterization is intended as a preliminary contribution rather than a comprehensive regional soil survey. Both locations are predominantly irrigated by surface water from the Tigris River and associated irrigation canals, not by groundwater wells. The surface soil samples (0-30 cm) were tested for soil reaction, electrical conductivity, Cation Exchange Capacity, organic matter, calcium carbonate, soluble ions, available N, P, and K,

particle-size distribution, sodium adsorption ratio, exchangeable sodium percentage, and suitability indicators. Soils were slightly alkaline (pH 7.29) and moderately calcareous (CaCO₃ 21.49%), and lower than the monitoring threshold for salinity (mean EC_e 3.65 dS m⁻¹) but not severely saline, and low in organic matter (mean 6.38 g kg⁻¹). The ESP averaged 17.30%, which is regarded as the main management constraint, with sodicity being the predominant issue. Texture varied in local deposits within the alluvial plain, becoming silt-dominated in K1 and a clay-loam in K2. The soils at both Al-Muwafaqiyah and Al-Dujaili were classified as Typic Torrifluvents (USDA Soil Taxonomy: order Entisols, suborder Fluvents) based on representative pedons at each site through morphological observations and laboratory analyses. The field morphology, recent alluvial parent material of the Tigris, and the physicochemical features of both representative soil profiles support this classification. Data from descriptive statistical analysis indicated low to moderate differences between sites for most of the soil properties used for this study, and high variability within the sites for available N. Agricultural suitability was determined as moderately suitable (S2), which was primarily limited by sodicity, low organic matter, and moderate nutrient-retention capacity. As a preliminary, site-level characterization, the results of this study indicate that combining soil chemistry, pedon morphology, texture classification, descriptive statistics, and taxonomic interpretation provides a more informative basis for the management of alluvial

agricultural soils in the Al-Kut District than any single indicator alone, while broader, more intensively replicated survey work is still needed to support a comprehensive regional management framework.

Keywords: soil survey; Soil Taxonomy; *Typic Torrifluvents*; Tigris alluvial plain; Al-Kut; sodicity; agricultural suitability.

Abbreviations: CEC, cation exchange capacity; CV, coefficient of variation; E_{ce}, electrical conductivity of the saturation extract; ESP, exchangeable sodium percentage; GIS, Geographic Information System; K1, Al-Muwafaqiyah site; K2, Al-Dujaili site; OM, organic matter; PSD, particle-size distribution; SAR, sodium adsorption ratio; SD, standard deviation; TSA, total soluble anions; TSC, total soluble cations; USDA, United States Department of Agriculture.

1. Introduction

Soil survey and soil classification are important tools for transforming the scattered analytical data into information that can be used for land management, irrigation planning, fertility improvement, agricultural suitability assessment, etc. A soil survey is not just a description of soil properties; it attempts to correlate the landscape position, parent material, physical behavior, and chemical status of the soil into interpretable soil units. A strategy of this kind is particularly necessary in alluvial situations where small-scale changes in sediment loads can result in significant changes in texture, salinity, sodicity, and nutrient availability (Soil Science Division Staff, 2017; Soil Survey Staff, 2022).

Soils are natural bodies that result from the interaction of parent material, climate, organisms, relief, and time. Soil development and function are also influenced by human management and water quality in irrigated dry and semi-dry conditions. Hence, soil reaction, calcium carbonate, electrical conductivity, exchangeable sodium percentage, cation exchange capacity, and organic matter should be evaluated as an expression of the soil-forming environment and current constraints imposed by soil management and not as independent properties (Brady & Weil, 2017; Buol et al., 2011; Jenny, 1941; Wilding et al., 1983; Yaalon, 1971).

One of the most historically important agricultural regions in the world is the Mesopotamian alluvial plain. Its soil types are mostly fluvial accumulations of sediments from the Tigris and Euphrates rivers and their associated irrigation systems. In central and southern Iraq, these soils often have a high calcium content, a slight alkaline reaction, and are prone to salinity and sodicity issues when irrigation and drainage are not managed properly (Awadh et al., 2011; Brady & Weil, 2017; Qureshi & Al-Falahi, 2015; Richards, 1954).

The Wasit Governorate is located in an important part of the Tigris alluvial system. Al-Kut and the associated irrigation canals are important agricultural areas that are heavily reliant on surface water from the Tigris River. This is a logical basis for comparison of agricultural soils within the district, and recognizes that variations due to micro-relief, drainage efficiency, cultivation history, and salt accumulation are present on each site (Richards, 1954; Soil Science Division Staff, 2017).

These soil properties are also shaped by the region's evolving climatic and hydrological conditions. A water-balance study for the Al-Kut station over 2000-2019 documented rising

temperature and evaporation together with declining annual rainfall and relative humidity, producing a clear water deficit in the area (Muhammad & Al-Dabbas, 2022). Under these arid conditions, elevated evaporation increases surface water loss while reduced rainfall limits the natural leaching of salts; where drainage is inefficient and the water table is shallow, capillary rise can move water and dissolved salts toward the surface, promoting salinization. A study of the nearby Batar area in Al-Kut District linked this combination of flat topography, shallow groundwater, high temperature, and evaporation to increased capillary rise, soil salinization, and the appearance of sabkha and salt-efflorescence features (Al-Kaabi, 2025). Consistent with this, a hydrochemical study of groundwater in eastern Wasit Governorate identified evaporation as a major control on groundwater chemistry, with higher evaporation associated with increased sodium and chloride concentrations and, consequently, higher groundwater salinity (Ghalib, 2017). These regional climatic and hydrological trends provide context for the moderate salinity, sodicity, and carbonate accumulation observed in the present study, although site-specific meteorological and groundwater-table data were not collected as part of this work (Section 5).

In this regard, the two representative agricultural areas of the study are Al-Muwafaqiyah and Al-Dujaili within the general agricultural area of Wasit Governorate, influenced by the Tigris River. The research is based on the Soil Survey and Soil Classifications. It seeks to transcend descriptive chemistry and establish a relationship between the measured properties, alluvial soil genesis, soil taxonomy, and agricultural usefulness.

The research problem is that many alluvial agricultural soils in the Al-Kut area are managed mainly on the basis of routine fertility indicators, while their survey interpretation, taxonomic tendency, sodicity status, and suitability limitations are not always presented in an integrated form. Evaluating pH or salinity alone is insufficient because agricultural performance depends on the combined effect of texture, organic matter, carbonate content, CEC, soluble ions, SAR, ESP, and available nutrients (FAO, 1976; Richards, 1954; Sys et al., 1991).

The objectives were to: (1) characterize selected physicochemical properties of two agricultural soils, Al-Muwafaqiyah (K1) and Al-Dujaili (K2), each represented by three field replicates; (2) interpret salinity, sodicity, carbonate status, texture, and nutrient availability from a site-characterization perspective; (3) compare the two sites using both descriptive statistics and an independent-samples t-test; (4) provide a taxonomic interpretation according to USDA Soil Taxonomy, supported by a detailed pedon morphological description; and (5) evaluate the major agricultural suitability limitations.

2. Materials and Methods

3.1 Study area and site coordinates

The study was conducted in two agricultural areas, Al-Muwafaqiyah (K1) and Al-Dujaili (K2), within the Tigris alluvial agricultural setting of Wasit Governorate, central Iraq. Both sites are associated with the alluvial plain influenced by Tigris River sediments and are irrigated mainly by surface water from the Tigris River and its connected irrigation canals, rather than groundwater wells. Representative coordinates were used for mapping and spatial presentation of the sampling sites. Al-Muwafaqiyah is close to 32.2660 degrees N and 45.9239 degrees E, while the representative Al-Dujaili site is close to 32.1830 degrees N and 46.0677 degrees E.

Representative coordinates are not intended to replace detailed GPS logging in future field surveys, but are a tool to help with the location map.

Code	Site	Latitude (N)	Longitude (E)	Irrigation source	General setting
K1	Al-Muwafaqiyah	32.2660	45.9239	Tigris River surface irrigation and associated canals	Alluvial agricultural soil
K2	Al-Dujaili	32.1830	46.0677	Tigris River surface irrigation and associated canals	Alluvial agricultural soil

Figure 1. Representative sampling sites within the Tigris alluvial plain, Wasit Governorate

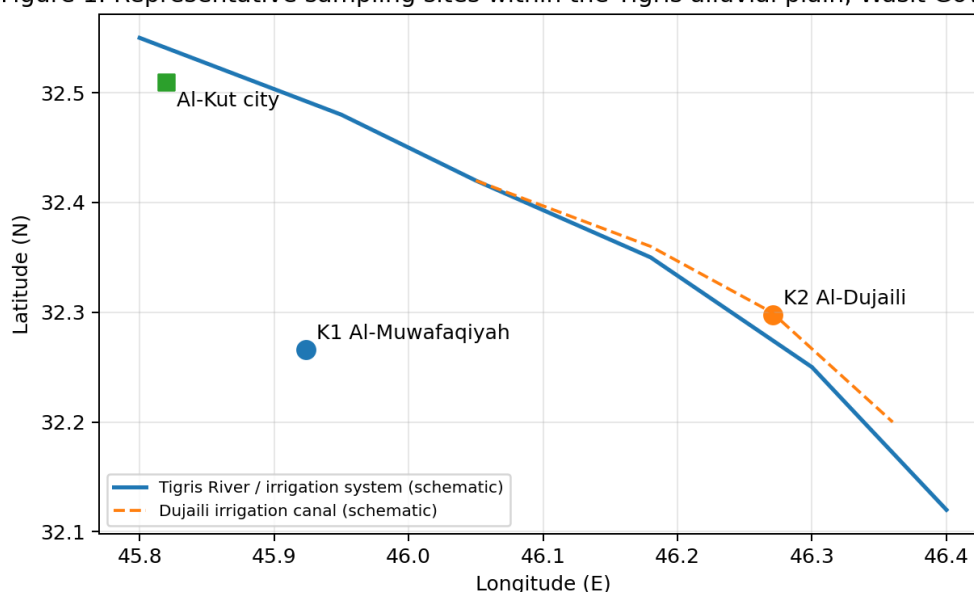


Figure 1. Schematic location map of the representative sampling sites within the Tigris alluvial agricultural setting.

3.2 Sampling and sample preparation

Surface soil samples (0-30 cm) were collected from each site before cultivation. This depth is the most intensely managed area that is impacted by tillage, irrigation, fertilizer application, organic residues, and salt build-up. Soil samples were collected from open, general-purpose agricultural fields within the Al-Muwafaqiyah (K1) and Al-Dujaila (K2) areas of Wasit Governorate. Three field replicates were selected in each area (K1-1, K1-2, K1-3 in Al-Muwafaqiyah; K2-1, K2-2, K2-3 in Al-Dujaila), each representing an approximately 20 × 20 m area. Within each represented area, five sub-samples were collected from spatially scattered points using a zig-zag sampling pattern. The location and coordinates of each field replicate were recorded with a GPS unit (K1-1: 32.2558° N, 45.8958° E; K1-2: 32.2610° N, 45.9020° E; K1-3: 32.2680° N, 45.8980° E; K2-1: 32.1800° N, 46.0620° E; K2-2: 32.1860° N, 46.0680° E; K2-3: 32.1830° N, 46.0730° E). The five sub-samples belonging to the same field replicate were then thoroughly and homogeneously mixed to form one composite soil sample. Accordingly, each area comprised three field replicates, and each composite sample was formed from five sub-samples. Samples were dried in the air, lightly broken, free of plant debris and large particles, and sieved through a 2 mm sieve prior to laboratory analysis. This preparation procedure is similar to that used for soil analysis and

will ensure comparability between chemical and physical measurements (Hesse, 1971; Page et al., 1982; Rowell, 1994; Soil Science Division Staff, 2017).

Detailed Map of Soil Sampling Locations in Al-Muwafaqiyah District and Al-Dujailah Subdistrict, Wasit Governorate, Iraq

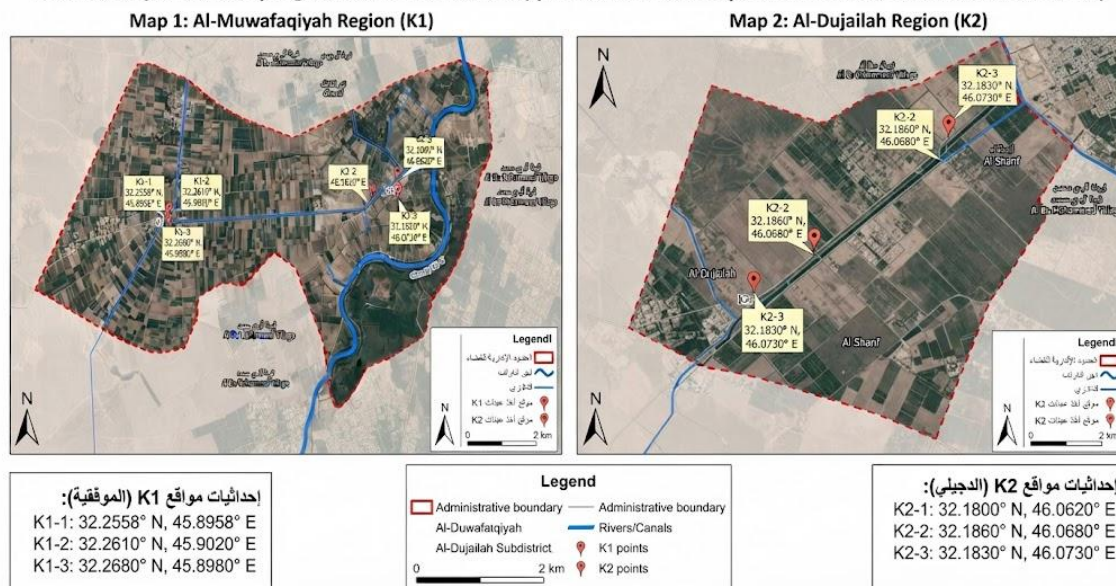


Figure 2. Detailed satellite location map of soil sampling replicates in Al-Muwafaqiyah (K1-1, K1-2, K1-3) and Al-Dujailah (K2-1, K2-2, K2-3), Wasit Governorate, Iraq.

3.3 Laboratory analyses

Soil pH was measured in a 1:1 soil-water suspension using a calibrated pH meter. Two electrical conductivity (EC) measurements were made using a calibrated conductivity meter: EC in a 1:1 soil-water suspension (used as a rapid general indicator) and EC in the saturated paste extract, expressed as dS m⁻¹. Because it is the standard basis to interpret soil salinity in relation to plant response (Richards, 1954), the saturated paste extract was used. The ammonium acetate exchangeable method was used to calculate cation exchange capacity (CEC) and was expressed in cmolc kg⁻¹ (Page et al., 1982).

The organic matter was determined by the wet oxidation procedure according to the Walkley-Black principle, and the calcium carbonate content was determined by the acid reaction and expressed as g kg⁻¹. For interpretive discussion, CaCO₃ was also expressed as a percentage by dividing g kg⁻¹ values by 10; both the original g kg⁻¹ value and the derived percentage are reported together in Table 1. Soluble cations (Ca²⁺, Mg²⁺, Na⁺, and K⁺) and anions (CO₃²⁻, HCO₃⁻, SO₄²⁻, and Cl⁻) were determined in the saturated paste extract and used to evaluate salt composition, ionic balance, and sodium hazard (Jackson, 1958; Page et al., 1982; Richards, 1954).

Available nitrogen, phosphorus, and potassium were determined according to standard soil-testing procedures and expressed as mg kg⁻¹. Their interpretation considered the calcareous nature of the soils, particularly the tendency of phosphorus to become less available in carbonate-rich and slightly alkaline soils (Hazelton & Murphy, 2016; Lindsay, 1979; Page et al., 1982). Particle-size distribution was determined by the standard particle-size analysis procedure, and textural classes were interpreted using the USDA texture triangle (Gee & Bauder, 1986; Klute, 1986; Soil Science Division Staff, 2017).

3.4 SAR, ESP, and ionic balance

Sodium adsorption ratio (SAR) was calculated from soluble Na^+ , Ca^{2+} , and Mg^{2+} according to the equation $\text{SAR} = \text{Na} / \sqrt{(\text{Ca} + \text{Mg}) / 2}$, where concentrations are expressed in mmolc L⁻¹. The sodicity risk was directly estimated by exchangeable sodium percentage (ESP) and interpreted based on the soil structural stability, permeability, and irrigation management. Chemistry of extracts (TSC, TSA) was also compared to test for internal consistency (Richards, 1954).

3.4b Irrigation water quality

Irrigation water samples were collected from the water sources associated with the K1 (Al-Muwafaqiyah) and K2 (Al-Dujaili) sites, with three replicates per site. Electrical conductivity (EC), soluble sodium (Na), soluble chloride (Cl), and the sodium adsorption ratio (SAR) were determined. EC ranged from 1050-1070 $\mu\text{S}/\text{cm}$ in K1 and 1000-1020 $\mu\text{S}/\text{cm}$ in K2; Na ranged from 70-80 mg/L in K1 and 60-70 mg/L in K2; Cl ranged from 125-165 mg/L in K1 and 120-155 mg/L in K2; SAR was uniformly 2 for all replicates at both sites. An independent-samples t-test (Table 2b) indicated that the difference in EC between K1 and K2 was statistically significant ($p < 0.05$), whereas the differences in Na and Cl were not significant at the 0.05 level. According to standard irrigation-water classification (Richards, 1954), EC values in this range (medium salinity, C2) and a low, uniform SAR (S1) indicate water generally suitable for irrigation of moderately salt-tolerant crops with reasonable drainage. These values are broadly consistent with independent regional studies reporting the Dujaila River and its associated channels as fresh to moderately mineralized water generally suitable for irrigation (Al-Dabbas & Maiws, 2016; Kareem et al., 2019), although a direct site-specific comparison was not possible since sampling dates and exact locations differ.

Table 2b. Irrigation water quality indicators for K1 and K2 (mean $\pm$ SD, $n=3$) and independent-samples t-test ($df=4$).

Parameter	K1 mean $\pm$ SD	K2 mean $\pm$ SD	t	p-value	Significant
EC ($\mu\text{S}/\text{cm}$)	1060.0 $\pm$ 10.0	1010.0 $\pm$ 10.0	6.124	0.0036	Yes
Na (mg/L)	75.0 $\pm$ 5.0	65.0 $\pm$ 5.0	2.449	0.0705	No
Cl (mg/L)	144.0 $\pm$ 20.1	137.7 $\pm$ 17.5	0.412	0.7015	No
SAR	2.0 $\pm$ 0.0	2.0 $\pm$ 0.0	-	-	No variation

3.4c Laboratory quality control

Laboratory quality control included routine calibration of analytical instruments, use of blanks and appropriate reference or standard materials where applicable, duplicate checks, and verification of analytical results before interpretation. Consistent analytical procedures and units were used throughout the laboratory measurements, with internal checks performed to identify potential analytical errors.

3.5 Statistical analysis

Each site (K1 and K2) was represented by three independent field replicates (Section 2.2), rather than a single composite sample. This allowed an independent-samples t-test (two-tailed, $\alpha = 0.05$, $df = 4$) to be applied for each property to test whether the mean difference between K1 and K2 was statistically significant, in addition to the descriptive statistics (means, SD, CV%, and relative difference) reported for each site. Table 5b summarizes the t-test results. Differences between K1 and K2 were statistically

significant ($p < 0.05$) for pH, ECe, CEC, OM, CaCO_3 , ESP, SAR, soluble Ca^{2+} , Mg^{2+} , and Na^+ , total soluble cations, sand, silt, clay, and available N, P, and K. Differences were not statistically significant for soluble K^+ , HCO_3^- , SO_4^{2-} , Cl^- , and total soluble anions, indicating that these properties did not differ reliably between the two sites given the available replication.

Two statistical limitations of this comparison should be acknowledged. First, with only three field replicates per site ($df = 4$), the independent-samples t-test has low statistical power; the widespread pattern of significant differences ($p < 0.05$) should therefore be interpreted as indicative of site-level contrasts rather than as a precise or generalizable estimate of population-level differences, and does not by itself account for field-scale spatial heterogeneity beyond the sampled replicates. Second, formal tests of the normality and homogeneity-of-variance assumptions underlying the t-test (e.g., Shapiro-Wilk, Levene's test) were not performed, and with $n=3$ per group such assumptions cannot be reliably verified; the t-test results should accordingly be read as a preliminary, exploratory comparison. A larger, spatially explicit sampling design (minimum $n=5-6$ replicates per site, e.g., a grid or transect layout) together with non-parametric alternatives (e.g., Mann-Whitney U test) or reporting of effect sizes and confidence intervals is recommended for future work to more robustly confirm these site-level differences.

3.6 Soil characterization and taxonomic interpretation

The field morphological observations and lab analyses of two representative pedons, Mwaf 200 at Al-Muwafaqiyah (K1) and Duj 150 at Al-Dujaili (K2), both situated within approximately 30 km of Al-Kut, Wasit Governorate, confirmed the taxonomic interpretation of the soils studied. Both soils developed on the recent calcareous alluvial deposits of the Tigris River under the influence of a semi-arid climate.

Horizon	Depth (cm)	Dry color	Moist color	Texture	Structure	Consistence	Boundary
Ap	0–25	10YR 6/4, light yellowish brown	10YR 5/4, yellowish brown	Silty clay loam	Moderate, medium granular	Soft when dry; friable when moist; root traces present	Clear, smooth
Bw	25–65	10YR 6/5, pale yellowish brown	10YR 5/6, yellowish brown	Silt loam	Moderate, fine subangular blocky	Slightly firm; few fine CaCO_3 crystallizations	Gradual
C	65–100+	2.5Y 7/2, light gray	2.5Y 6/2, light yellowish gray	Silt loam	Massive	Firm; fine quartz and gypsum intrusions	Not recorded

Table 3c. Morphological description of the representative pedon of Al-Dujaili (Duj 150).

Horizon	Depth (cm)	pH	ECe (dS m^{-1})	CEC (cmolc kg^{-1})	ESP (%)	CaCO_3 (%)
Ap	0–25	7.55	18.50	16.80	22.40	23.10
Bw	25–65	7.68	11.20	17.90	15.60	24.80
C	65–100+	7.82	6.80	18.50	11.20	25.60

Table 3d. Laboratory analytical results by horizon for the representative pedon of Al-Dujaili (Duj 150). Texture for all horizons: silt loam (Bw, C) and silty clay loam (Ap), consistent with Table 3c.

The Duj 150 pedon at Al-Dujaili shows a similarly weak Ap–Bw–C horizon differentiation, dominantly silty textures, and moderate calcium carbonate accumulation (23.1–25.6%) that decreases only slightly with depth, together with a slightly alkaline reaction (pH 7.55–7.82) and a fine, weakly developed subangular blocky structure in the Bw horizon that does not meet the

criteria for an argillic or cambic diagnostic horizon. ESP declines with depth (22.4% in Ap to 11.2% in C), broadly paralleling the surface-to-depth pattern observed at K1. On this basis, and consistent with the criteria applied to Mwaf 200 (Section 2.6), the Duj 150 pedon is likewise classified as Typic Torrifluvents. For both pedons, the correct taxonomic hierarchy under USDA Soil Taxonomy (Soil Survey Staff, 2022) is order Entisols, suborder Fluvents, great group Torrifluvents, subgroup Typic Torrifluvents; the classification reflects the very weak pedogenic development and fluvial origin of these soils rather than an aridic soil moisture regime association implied by the Aridisols order, and this hierarchy is stated explicitly here to avoid ambiguity. With representative pedons now described and classified at both sites, the taxonomic interpretation of Al-Muwafaqiyah and Al-Dujaili is placed on comparable morphological and analytical footing.

The representative profile of Mwaf 200 (K1) consists of an Ap horizon (0–15 cm) overlying Ck1 (15–52 cm), Ck2 (52–92 cm), Ck3 (92–104 cm), and C4 (>104 cm) horizons. A profile is described as having poor horizon differentiation, lots of calcium carbonate accumulations, a slightly alkaline reaction, and good drainage on almost flat topography, based on the field-observed absence of redoximorphic mottling or gleying in the profile; a quantitative drainage class assessment (e.g., water table depth monitoring) was not performed. The properties suggest that they are young alluvial soils that have not been highly pedogenic. Table 3b presents the detailed morphological description of the profile.

Horizon	Depth (cm)	Dry color	Moist color	Texture	Structure	Consistence	Boundary
Ap	0–15	10YR 5/4, yellowish brown	10YR 4/3, brown	Silt loam	Medium granular to subangular blocky	Slightly hard when dry; friable when moist	Clear, smooth
Ck1	15–52	10YR 6/4, light yellowish brown	10YR 5/4, yellowish brown	Silt loam to silty clay loam	Weak coarse subangular blocky	Friable; slightly sticky	Gradual, smooth
Ck2	52–92	10YR 6/3, pale brown	10YR 5/3, brown	Silty clay	Strong fine subangular blocky	Firm when moist; sticky and plastic when wet	Clear, wavy
Ck3	92–104	2.5Y 6/3, pale olive	2.5Y 5/3, olive brown	Silt loam	Strong fine subangular blocky	Friable	Clear, smooth
C4	>104 cm	2.5Y 6/4, light yellowish brown	2.5Y 5/4, yellowish brown	Not recorded	Not recorded	Not recorded	Not recorded

Table 3b. Morphological description of the representative pedon (Mwaf 200).

The field morphology has confirmed the laboratory findings of moderately calcareous, slightly alkaline pH, moderate salinity, and moderate sodicity. The very recent fluvial sediments are dominant, showing weak Ap–Ck–C horizon differentiation, a succession of stratified C-type horizons, dominantly silty to silty clay textures, and features associated with carbonate accumulation. No field evidence of an argillic or cambic horizon was recorded in the described part of the profile. These properties are broadly consistent with weakly developed alluvial soils in the Wasit region. However, the assignment of the pedon to the Typic Torrifluvents subgroup was based on the integration of field morphological description, laboratory results, and soil moisture regime criteria, rather than on the absence of a single diagnostic horizon alone, consistent with the USDA Soil Taxonomy (Soil Survey Staff, 2022) framework. The morphological features of the representative pedon are in agreement with the young alluvial soils

formed under recent fluvial deposition, and the observed physicochemical properties of the studied sites.

With both the Al-Muwafaqiyah (K1, Mwaf 200) and Al-Dujaili (K2, Duj 150) sites now described through representative pedons and classified as Typic Torrifluvents (Section 2.6), the taxonomic interpretation of both study sites rests on comparable field-morphological and laboratory evidence rather than on surface samples or inference from one site to the other. The regional interpretation is also consistent with published studies from Wasit Governorate. A study in Al-Muwafaqiyah reported predominantly silty-loamy soil textures, relatively low salinity, and elevated calcium carbonate-related properties (Al-Zamili, 2020). A study of Dujaila sediments reported relatively weak chemical weathering in the investigated sediments (Al-Dabbas et al., 2017). In addition, Typic Torrifluvents has been reported among the soil classifications identified in another Wasit study area (Al-Jubouri et al., 2023). These studies provide regional support, whereas the classification of Mwaf 200 is based on the specific field and laboratory data of the present study.

This taxonomic interpretation is more scientifically valid for assessing suitability for crop production as it considers field characteristics as well as laboratory analysis of the soil, which is not possible for surface soil characteristics alone.

3.7 Agricultural suitability evaluation

Integrated interpretive index of texture, organic matter, CEC, CaCO_3 , N, P, K, pH, ECe, and ESP were used for assessing the agricultural suitability of the soil. A score of 0 to 1 was assigned to each indicator, with the higher score signifying less limitation. Final suitability was determined by applying qualitative land-evaluation principles: S1-high, S2-moderate, S3-marginal, and N-non suitable (FAO, 1976; Sys et al., 1991). All ten indicators were assigned equal weight in the composite index (i.e., the overall suitability index is the simple arithmetic mean of the individual indicator scores), and the resulting index was assigned to a suitability class using the following thresholds: S1 (highly suitable) ≥ 0.80 ; S2 (moderately suitable) 0.60-0.79; S3 (marginally suitable) 0.40-0.59; N (not suitable) < 0.40 . This equal-weighting scheme is a simplifying assumption adopted for this preliminary characterization; it does not differentiate indicators that may be more agronomically limiting (e.g., ESP) from less limiting ones, and refining the weights for local cropping systems is recommended for future suitability assessments.

3. Results and Discussion

4.1 General physicochemical properties

The soils studied were slightly alkaline with a pH of 7.25 for K1 soil, 7.34 for K2 soil, and an average value of 7.29. They are fairly common in calcareous alluvial soils found in arid and semi-arid regions and do not constitute restrictions for most crops. However, some nutrients, such as phosphorus and some micronutrients, might be less available if carbonate content is high, in slightly alkaline conditions (Bohn et al., 2001; Brady & Weil, 2017; Lindsay, 1979).

The values of electrical conductivity were 3.55 dS m^{-1} and 3.74 dS m^{-1} in K1 and K2, respectively. The mean ECe of 3.65 dS m^{-1} suggests non-severe salinity, but is close to the

salinity at which salt-sensitive crops will start to suffer reduced performance. So, salinity should not be considered as an acute and serious constraint, but as a monitoring problem (Richards, 1954).

The organic matter content was low in both sites (5.62 and 7.15 g kg⁻¹). This is one of the most significant limitations since organic matter enhances the stability of aggregates, water holding capacity, nutrient supply, microbial activity, and CEC. The low OM status also makes the soil more susceptible to structural degradation with high ESP (Brady & Weil, 2017; Hazelton & Murphy, 2016). The calcium carbonate content in the soils varied between 20.53% and 22.45%, indicating a moderately calcareous soil, which affects the buffering and availability of soil phosphorus (Bohn et al., 2001; Lindsay, 1979).

Table 1. Main physicochemical properties of the studied soils.

Property	Unit	K1 Al-Muwafaqiyah	K2 Al-Dujaili	Mean	Interpretation
pH	-	7.25	7.34	7.29	slightly alkaline
ECe	dS m ⁻¹	3.55	3.74	3.65	non-severe salinity
CEC	cmol kg ⁻¹	14.65	16.52	15.59	moderate to low
OM	g kg ⁻¹	5.62	7.15	6.38	low
CaCO ₃	g kg ⁻¹ (%)	205.3 (20.53)	224.5 (22.45)	214.9 (21.49)	moderately calcareous
ESP	%	16.38	18.22	17.30	sodicity limitation
SAR	-	2.65	3.63	3.14	low to moderate sodium adsorption

Figure 3. Main physicochemical indicators of the studied soils (error bars = SD, n=3)

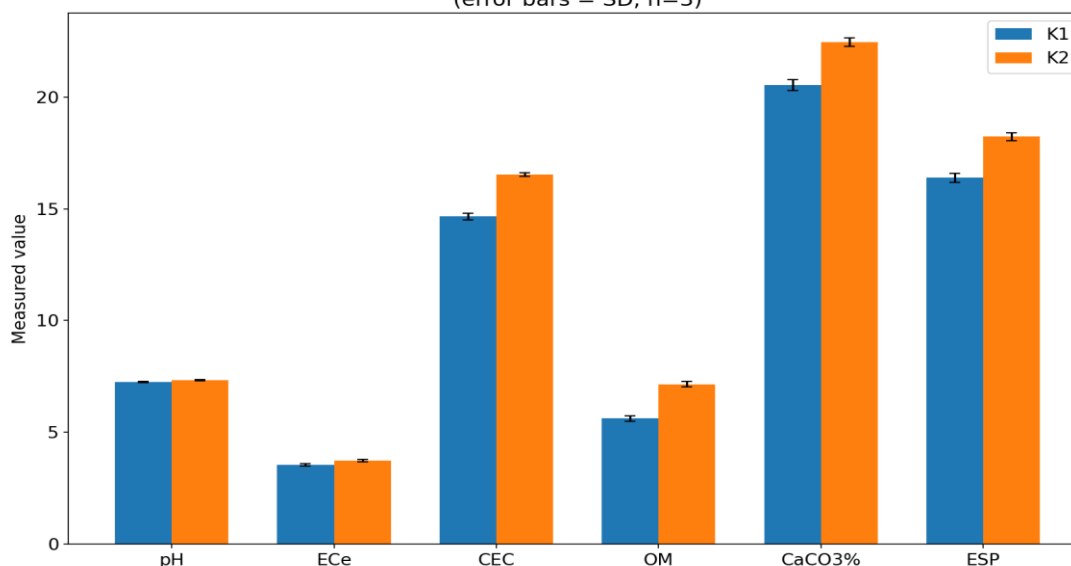


Figure 3. Main physicochemical indicators of the studied soils.

4.2 Soluble ions, SAR, and sodicity risk

The soluble-ion composition indicated that Ca²⁺ and Na⁺ ions were most abundant in the cations, and SO₄²⁻ and Cl⁻ ions were the most abundant in the anions. Occurrence is similar to irrigated alluvial soils with a dry climate and fluctuating drainage, in which soluble salts become

concentrated in the soil. The total soluble cations and anions were similar, which showed good consistency in the extract data (Richards, 1954).

SAR values were 2.65 in K1 and 3.63 in K2. The value of the sodium adsorption ratio (SAR) did not show a very high sodium adsorption risk, but the values of ESP was 16.38% and 18.22%, and the mean was 17.30%. ESP is closely related to the percentage of exchangeable sodium on the exchange complex, so it is more directly correlated with clay dispersion, structural weakening, and decreased permeability. This finding shows that sodicity is the most significant soil constraint in the soils examined (Richards, 1954).

It is worth noting that the low, uniform SAR of the irrigation water (SAR = 2.0; Section 2.4b) contrasts with the considerably higher soil ESP (16.38-18.22%). This apparent discrepancy is not unusual in surface-water-irrigated alluvial soils and is most plausibly explained by evapoconcentration of sodium at the soil surface under the prevailing arid conditions, together with the cumulative effect of long-term irrigation with even moderately sodic water on the exchange complex, rather than by any single irrigation event. Because a shallow groundwater table and its chemistry were not monitored as part of this study (Section 5), a contribution from capillary rise of more saline/sodic groundwater cannot be ruled out and is proposed as a priority for future seasonal monitoring. This observation reinforces that irrigation-water SAR alone should not be used to infer soil sodicity status at these sites, and that periodic ESP measurement remains necessary for management decisions.

Table 2. Soluble ions and ionic-balance indicators.

Ion/indicator	Unit	K1	K2	Mean
Ca ²⁺	mmolc L ⁻¹	12.18	15.20	13.69
Mg ²⁺	mmolc L ⁻¹	6.15	4.18	5.17
K ⁺	mmolc L ⁻¹	1.05	1.02	1.04
Na ⁺	mmolc L ⁻¹	8.02	11.30	9.66
CO ₃ ²⁻	mmolc L ⁻¹	0.00	0.00	0.00
HCO ₃ ⁻	mmolc L ⁻¹	3.22	3.35	3.29
SO ₄ ²⁻	mmolc L ⁻¹	13.75	14.10	13.93
Cl ⁻	mmolc L ⁻¹	11.95	12.32	12.13
Total cations	mmolc L ⁻¹	27.40	31.70	29.55
Total anions	mmolc L ⁻¹	28.92	29.77	29.34
SAR	-	2.65	3.63	3.14
ESP	%	16.38	18.22	17.30

Figure 4. Soluble cation and anion concentrations in K1 and K2
(error bars = SD, n=3)

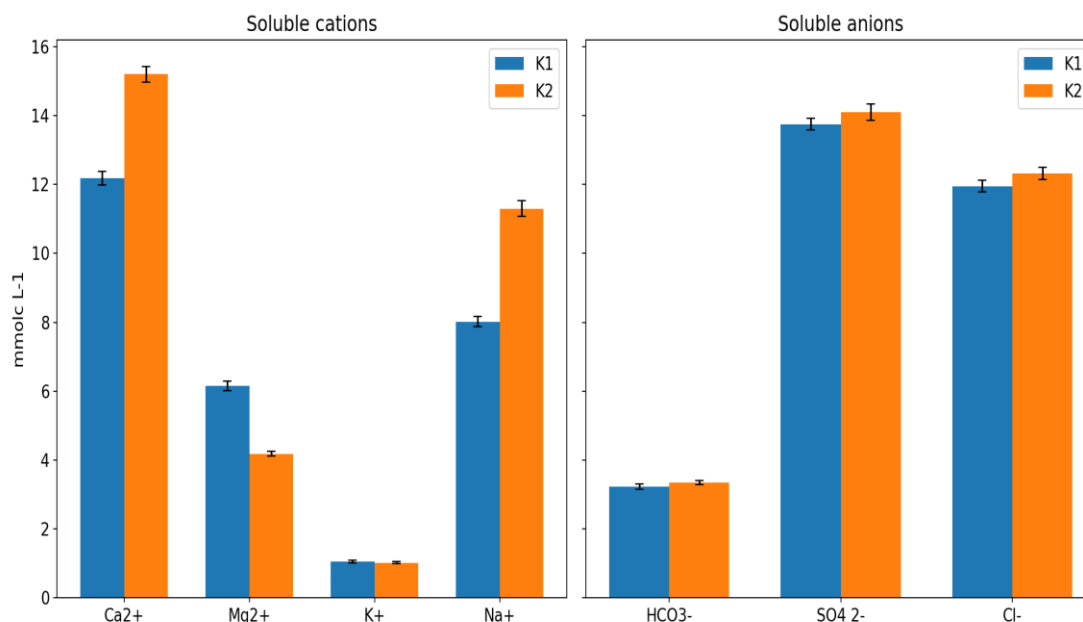


Figure 4. Soluble cation and anion concentrations in K1 and K2 (error bars = SD, n=3).

4.3 Texture and alluvial depositional interpretation

The PSD affirmed a silt/clay-rich alluvial nature. K1 contained 260 g kg⁻¹ sand, 505 g kg⁻¹ silt, and 235 g kg⁻¹ clay, whereas K2 contained 240 g kg⁻¹ sand, 445 g kg⁻¹ silt, and 315 g kg⁻¹ clay. K1 was interpreted as silt-loam, reflecting a silty alluvial texture trend, whereas K2 was clay-loam. It is a common feature in fluvial environments where there is gradation in the texture of the sediment with changes in water energy, distance from the channel, and micro-relief (Gee & Bauder, 1986; Soil Science Division Staff, 2017).

The texture is aesthetically relevant. Silt and clay have the ability to retain water and nutrients better than sandy soils, but can be structurally unstable under high levels of exchangeable sodium. Hence, the moderate-fine texture along with ESP > 16% is responsible for the importance of sodicity over salinity in the present interpretation (Richards, 1954).

Table 3. Particle-size distribution and textural interpretation.

Fraction/class	Unit	K1	K2	Interpretation
Sand	g kg ⁻¹	260	240	moderate sand
Silt	g kg ⁻¹	505	445	dominant silt
Clay	g kg ⁻¹	235	315	moderate clay
Textural class	-	silt-loam / silty alluvial trend	clay-loam trend	alluvial variation

Figure 5. Textural position of K1 and K2 on a sand-silt-clay ternary diagram (plotted from measured particle-size data, Table 3)

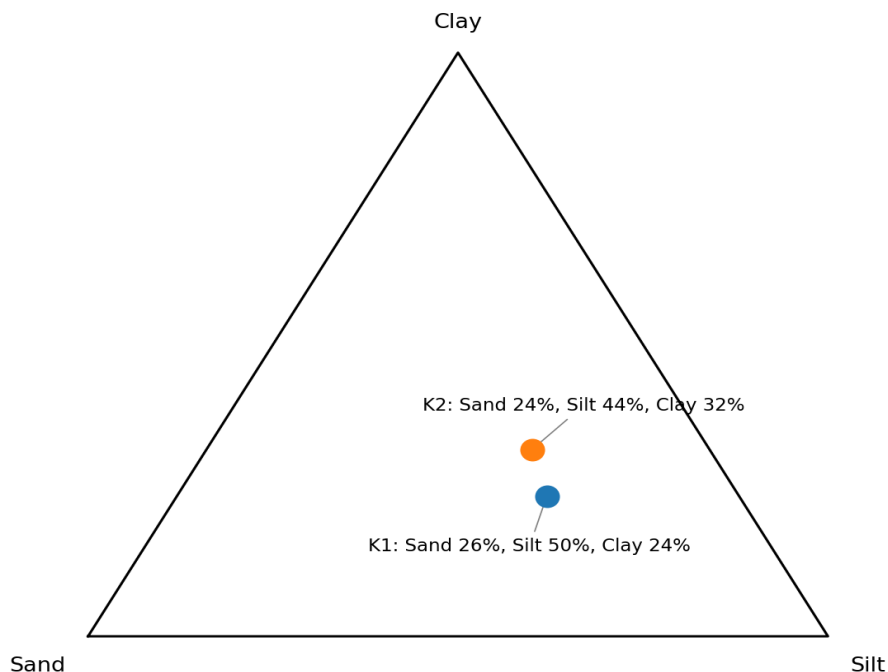


Figure 5. Textural position of K1 and K2 on a sand-silt-clay ternary diagram, plotted from measured particle-size data (Table 3).

4.4 Available macronutrients

The amount of nitrogen available was high, and there was significant site-to-site variation, ranging from 97.2 mg kg⁻¹ in K1 to 25.4 mg kg⁻¹ in K2, and this difference was statistically significant (Table 5b). Management history data (previous cropping, fertilization timing, residue return, or recent moisture conditions) were not recorded for these sites, so the specific cause of this contrast cannot be determined; mineralization and recent fertilization are plausible contributing factors reported for similarly managed alluvial soils (Hazelton & Murphy, 2016; Lindsay, 1979; Page et al., 1982), but this remains an interpretation rather than a confirmed explanation. The available phosphorus content in K1 and K2 was 10.05 and 13.15 mg kg⁻¹, respectively, and that of available potassium was 97.5 and 112.1 mg kg⁻¹ in K1 and K2, respectively. The moderate to low P status is typical for calcareous soils where P can be fixed or precipitated as less soluble calcium forms (Hazelton & Murphy, 2016; Lindsay, 1979; Page et al., 1982).

These nutrient results are not meant to say that the soils are not perfectly suitable for crops, rather that the fertility of the soils must be controlled by using balanced fertilizers according to soil tests. Organic amendments are important in particular as they can increase nutrient retention and decrease structural vulnerability caused by sodicity (Brady & Weil, 2017; Hazelton & Murphy, 2016).

Table 4. Available macronutrients in the studied soils.

Nutrient	Unit	K1	K2	Mean
N	mg kg ⁻¹	97.20	25.40	61.30
P	mg kg ⁻¹	10.05	13.15	11.60
K	mg kg ⁻¹	97.50	112.10	104.80

Figure 6. Available N, P, and K in the studied soils (error bars = SD, n=3)

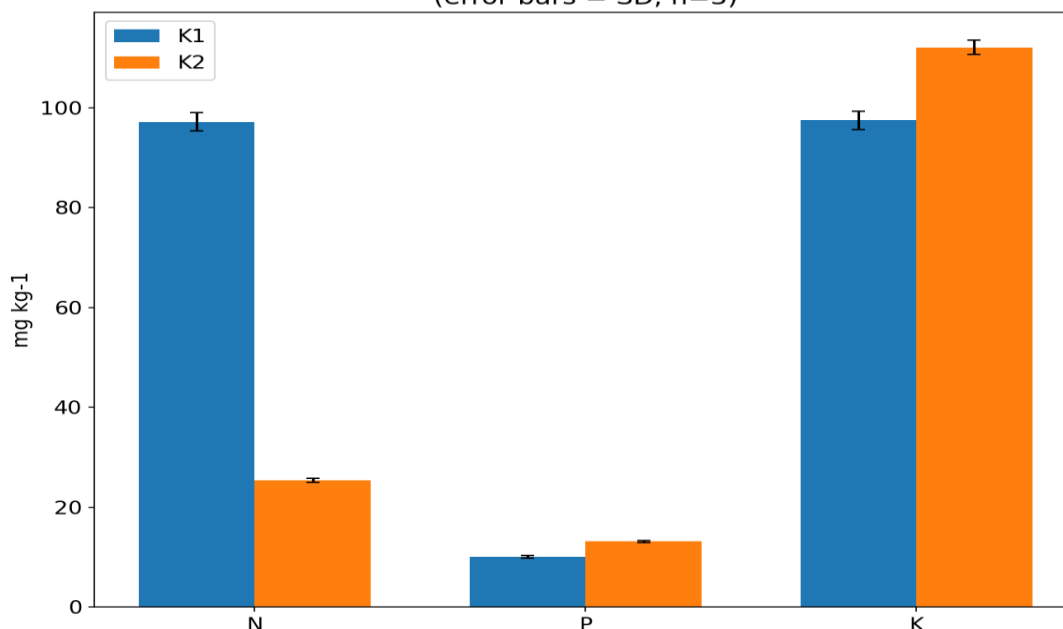


Figure 6. Available N, P, and K in the studied soils.

4.5 Descriptive statistical analysis

Descriptive statistics confirmed that most core properties varied within a low to moderate range between K1 and K2. The lowest variability occurred in pH and ECe, which supports the interpretation that both sites share a similar alluvial and irrigation setting. Moderate variability was recorded for OM, CEC, ESP, clay, and nutrients. Available nitrogen showed the highest CV because it is highly affected by previous management and recent mineralization conditions. This confirms that nutrient indicators are more dynamic than inherent properties such as pH, carbonate content, and texture (Hazelton & Murphy, 2016; Rowell, 1994).

Table 5. Descriptive statistical indicators for selected soil properties.

Property	K1	K2	Mean	SD	CV (%)	Relative difference (%)
pH	7.25	7.34	7.29	0.06	0.87	1.23
ECe (dS m ⁻¹)	3.55	3.74	3.65	0.13	3.69	5.21
CEC (cmolc kg ⁻¹)	14.65	16.52	15.59	1.32	8.48	12.00
OM (g kg ⁻¹)	5.62	7.15	6.38	1.08	16.94	23.96
CaCO ₃ (%)	20.53	22.45	21.49	1.36	6.32	8.93
ESP (%)	16.38	18.22	17.30	1.30	7.52	10.64
SAR	2.65	3.63	3.14	0.69	22.09	31.24
Available N	97.20	25.40	61.30	50.77	82.82	117.13

Property	K1	K2	Mean	SD	CV (%)	Relative difference (%)
(mg kg ⁻¹)						
Available P (mg kg ⁻¹)	10.05	13.15	11.60	2.19	18.90	26.72
Available K (mg kg ⁻¹)	97.50	112.10	104.80	10.32	9.85	13.93
Sand (g kg ⁻¹)	260.00	240.00	250.00	14.14	5.66	8.00
Silt (g kg ⁻¹)	505.00	445.00	475.00	42.43	8.93	12.63
Clay (g kg ⁻¹)	235.00	315.00	275.00	56.57	20.57	29.09

Table 5b. Independent-samples t-test comparing K1 and K2 for each property (two-tailed, df = 4).

Property	t	df	p-value	Significant (p<0.05)
pH	-3.897	4	0.0176	Yes
ECe (dS m ⁻¹)	-4.564	4	0.0103	Yes
CEC (cmolc kg ⁻¹)	-17.939	4	<0.001	Yes
OM (g kg ⁻¹)	-15.403	4	<0.001	Yes
CaCO ₃ (g kg ⁻¹)	-10.893	4	<0.001	Yes
ESP (%)	-11.927	4	<0.001	Yes
SAR	-20.288	4	<0.001	Yes
Soluble Ca ²⁺	-17.321	4	<0.001	Yes
Soluble Mg ²⁺	22.697	4	<0.001	Yes
Soluble K ⁺	0.891	4	0.4232	No
Soluble Na ⁺	-20.703	4	<0.001	Yes
HCO ₃ ⁻	-2.400	4	0.0743	No
SO ₄ ²⁻	-2.138	4	0.0993	No
Cl ⁻	-2.603	4	0.0598	No
Total soluble cations	-9.675	4	<0.001	Yes
Total soluble anions	-2.376	4	0.0764	No
Sand (g kg ⁻¹)	5.457	4	0.0055	Yes
Silt (g kg ⁻¹)	25.525	4	<0.001	Yes
Clay (g kg ⁻¹)	-15.759	4	<0.001	Yes
Available N (mg kg ⁻¹)	66.665	4	<0.001	Yes
Available P (mg kg ⁻¹)	-14.892	4	<0.001	Yes
Available K (mg kg ⁻¹)	-11.026	4	<0.001	Yes

Figure 7. Between-site descriptive variability (K1 vs K2 means, n=2 sites)
 See Table 5b for replicate-based (n=3) inferential t-test results

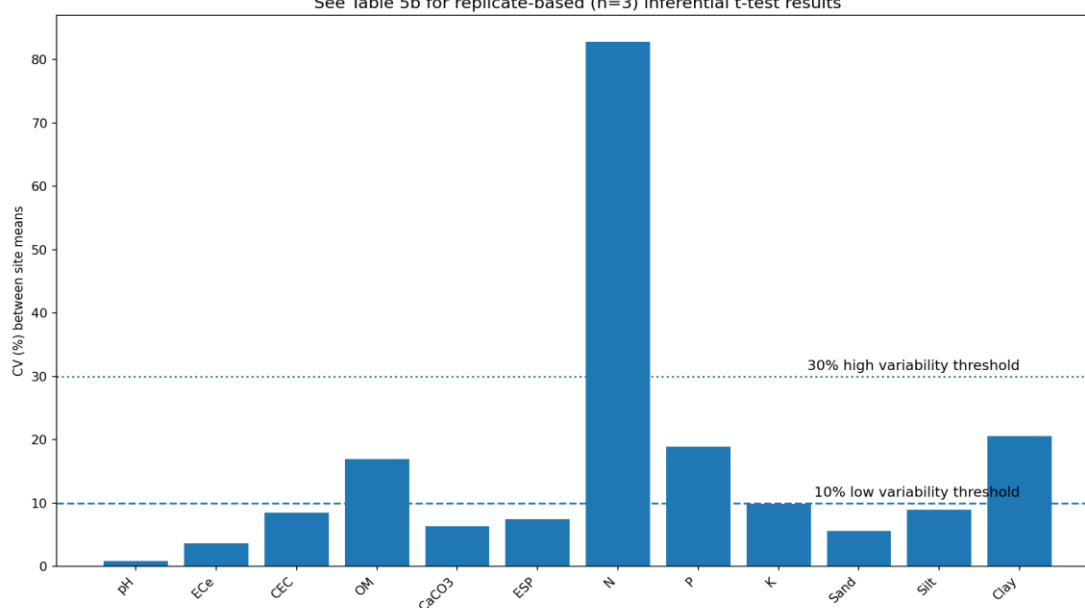


Figure 7. Between-site descriptive variability (K1 vs K2 means, $n=2$ sites); see Table 5b for the replicate-based ($n=3$) inferential t -test.

4.6 Soil Characterization and Taxonomic Interpretation

The studied soils are representative of the recent alluvial deposits of the Tigris River within Al-Muwafaqiyah and Al-Dujaili areas. Their morphological, physical, and chemical characteristics indicate young soils with limited profile development. The representative pedon (Mwaf 200) exhibited an Ap horizon overlying successive Ck horizons with noticeable calcium carbonate accumulations, confirming weak pedogenic development under semi-arid conditions.

Laboratory analyses confirmed the field observations and indicated the soil reaction was slightly alkaline; the calcium carbonate content was moderate; the salinity was moderate; the sodium content, or sodicity, was moderate; and the material in the soil profile was predominantly fine-textured alluvial materials. The characteristics are typical of recently deposited alluvial soils formed under the influence of the Tigris River.

Based on the USDA Soil Taxonomy (Soil Survey Staff, 2022), the representative pedon was determined to be classified as Typic Torrifluvents. As detailed in Section 2.6, this classification is justified by the integration of the field morphological description (Table 3b), the alluvial parent material, laboratory results, and soil moisture regime criteria, rather than by the absence of a single diagnostic horizon alone.

The taxonomic classification is a dependable scientific basis for the interpretations of soil behavior and suitability for agriculture. The findings showed that the real constraints to agricultural production are sodicity, low organic matter content, and the management of irrigation and drainage systems, instead of serious salinity.

4.7 Reference comparison with nearby alluvial soils

The results may be compared to the region with the documented alluvial soils of Wasit Governorate, such as the Al-Ahrar Dalmaj soil. This is presented strictly as a qualitative regional context, since no directly comparable quantitative dataset for the Al-Ahrar Dalmaj soil was available to the authors; no numerical comparison with the present K1/K2 results should be inferred from this paragraph. One should not compare such data with that of the present study, but only as a regional reference. The common characteristics are alluvial origin, fine fractions predominance, calcareous condition, and neutral to slightly alkaline reaction. Variations in salinity may be anticipated due to wetland conditions, flooding-drying cycles, and poor drainage associated with Dalmaj-related soils. So, the comparison helps in the general alluvial interpretation of the Tigris and maintains K1 and K2 as the sites of the current study (Awadh et al., 2011; Soil Science Division Staff, 2017).

4.8 Agricultural suitability evaluation

The integrated suitability score for K1 was 0.78, and for K2 was 0.78, both of which were in the moderately suitable class (S2). The best indicators were pH and E_{Ce}, and the major limitations were low organic matter, ESP values that were too high (above the optimum range), moderate CEC, and variable nutrient availability. Soils are not, however, unsuitable for agriculture, but they do need to be managed sensitively to ensure productivity (FAO, 1976; Richards, 1954; Sys et al., 1991). Although K1 and K2 differed significantly in texture, ESP, and organic matter

(Table 5b), both sites converged on the same overall score (0.78) because the 0-1 scoring framework combines multiple weighted indicators into a single index; moderate differences in individual indicators can therefore offset one another and still yield the same overall suitability class. This indicates that the current scoring resolution is adequate for broad suitability classification but is not sensitive enough to distinguish management priorities between K1 and K2; the individual indicator values (Table 1, Table 5b), rather than the composite score alone, should guide site-specific management decisions. The S2 (moderately suitable) classification represents the general suitability of the studied soils. Crop-specific suitability should be interpreted according to the tolerance of the intended crop to salinity and sodicity and under the prevailing irrigation and drainage conditions.

Read together with the soil suitability results, the irrigation water quality data (Section 2.4b, Table 2b) reinforce that sodicity, rather than salinity, is the priority management concern at both sites. Although the medium-salinity, low-SAR (C2, S1) classification of the irrigation water indicates that current irrigation practice is not, by itself, actively adding sodicity risk, the already elevated soil ESP (16.38-18.22%) means the sites have limited additional buffering capacity against sodic degradation. This strengthens the case for the sodicity-focused management measures recommended above (organic amendments, leaching fraction, drainage), and for continued monitoring of both irrigation-water and soil sodicity indicators together, rather than treating them as separate datasets.

The key management message is that sodicity needs to be monitored and managed to prevent structural decline. Recommended measures include organic amendments, crop-residue return, correct application of the leaching fraction, maintenance of good drainage, and balanced fertilization. Although the present preliminary irrigation-water sampling (Section 2.4b) indicated water of medium salinity (C2, S1) generally suitable for irrigation, continuous seasonal monitoring of EC, Na, and SAR is recommended at both sites, particularly in dry years, given their dependence on surface water from the Tigris.

Table 6. Agricultural suitability indicator scores.

Indicator	K1 score	K2 score	Interpretation
Texture	0.95	0.85	1.00 = lower limitation
Organic matter	0.50	0.50	1.00 = lower limitation
CEC	0.50	0.70	1.00 = lower limitation
CaCO ₃	0.90	0.90	1.00 = lower limitation
N	1.00	0.70	1.00 = lower limitation
P	0.70	0.70	1.00 = lower limitation
K	0.50	0.70	1.00 = lower limitation
pH	1.00	1.00	1.00 = lower limitation
EC _e	1.00	1.00	1.00 = lower limitation
ESP	0.70	0.70	1.00 = lower limitation
Overall suitability index	0.78	0.78	S2: moderately suitable

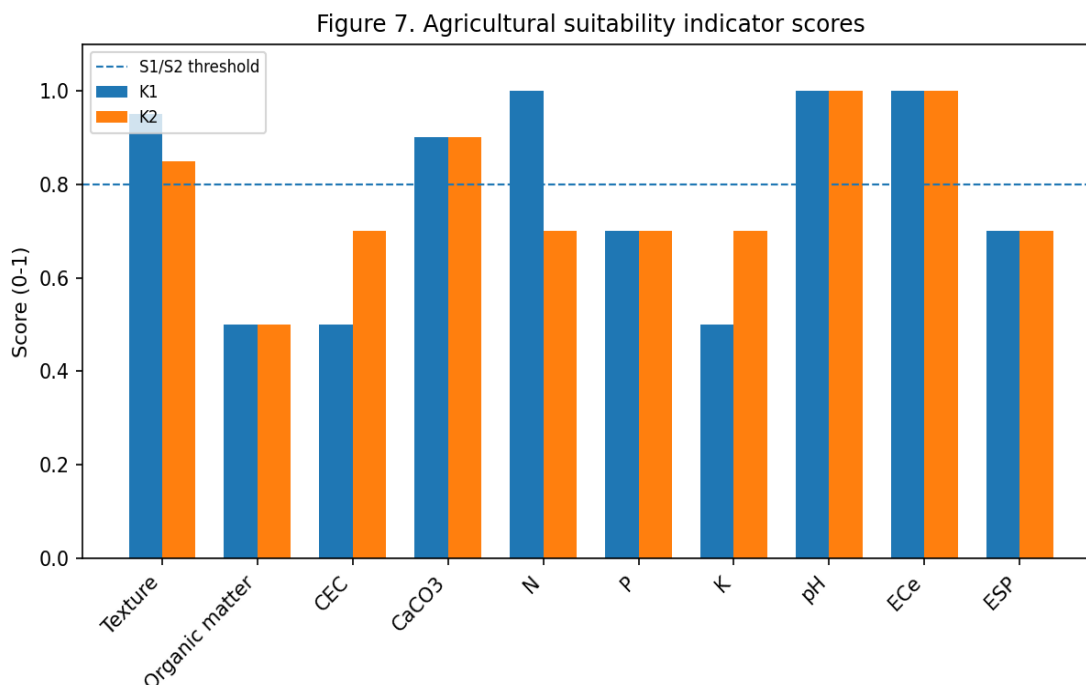


Figure 8. Agricultural suitability indicator scores for K1 and K2.

4. Conclusions

Rather than restating individual measured values, the following points synthesize their combined agronomic and taxonomic implications for land management in the study area.

The studied soils in Al-Muwafaqiyah and Al-Dujaili are alluvial agricultural soils associated with the Tigris River depositional and irrigation system.

The soils are slightly alkaline and moderately calcareous, with non-severe salinity but a need for continuous salinity monitoring.

Low levels of organic matter are a significant fertility and structural constraint at both sites.

If ESP values are greater than 16%, sodicity is the most critical management constraint and can impact soil structure, infiltration, and permeability.

Textural variation between K1 and K2 reflects local alluvial deposition, with silt and clay fractions dominating both sites.

Based on field morphological and laboratory analyses of representative pedons at both sites (Mwaf 200 at K1 and Duj 150 at K2), both Al-Muwafaqiyah and Al-Dujaili were classified as Typic Torrifluvents (order Entisols, suborder Fluvents) using USDA Soil Taxonomy, placing the taxonomic interpretation of the two sites on comparable morphological and analytical footing.

Descriptive statistics showed low variability in pH and ECe, moderate variability in several physical and chemical indicators, and high variability in available N.

Both sites were evaluated as moderately suitable (S2), mainly limited by sodicity, organic matter deficiency, and moderate nutrient-retention capacity.

5. Recommendations

Install a local meteorological record (rainfall, temperature, evaporation) and monitor shallow groundwater table depth at both sites, since regional data indicate these factors directly control salinization risk in the Al-Kut area.

Apply decomposed organic amendments and retain crop residues to improve organic matter, aggregation, CEC, and biological activity.

Monitor E_{Ce}, SAR, and ESP seasonally, especially during intensive irrigation or dryer years; this is proposed as a future monitoring program, since the present study is based on a single sampling event and does not itself include repeated seasonal measurements.

Complete the laboratory characterization of the Mwaf 200 pedon (K1) by analyzing pH, E_{Ce}, CEC, ESP, and CaCO₃ for each individual horizon (A_p, Ck₁, Ck₂, Ck₃, C₄), analogous to the horizon-by-horizon dataset now available for the Duj 150 pedon (K2, Table 3d); this would allow the two representative pedons to be compared on an equal analytical footing in future work.

Drainage and proper leaching to avoid surface salt and sodium buildup.

For K1 (silt loam, lower ESP): prioritize organic matter and nitrogen management, since low OM and the largest N deficit relative to K2 are the main limitations here.

For K2 (clay-loam, higher ESP and SAR): prioritize sodicity management (e.g., gypsum application where warranted by soil testing) and drainage improvement, since its heavier texture and higher ESP increase the risk of structural degradation under continued sodic irrigation.

Follow appropriate fertilization that is balanced for the soil test, particularly in calcareous soils for phosphorus and potassium.

Extend soil survey investigations, providing additional representative soil pedons throughout the study area to enhance soil mapping, assess spatial variability, and facilitate more detailed land capability classification.

Prepare a detailed GIS soil map for agricultural lands around Al-Kut, linking alluvial units with texture, sodicity, and suitability limitations.

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Declaration of Competing Interest

The researcher declares that he has no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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