Correlation between Soil Characteristics and Fertility in Semi-Arid ConditionClimatic Conditions in Al-Musayyib District, Babil Governorate – Iraq

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Abstract

The objective of this study is to examine the spatial variation of chemical properties and nutrient elements in the Al-Musayyib district, Babylon Governorate, which is located in a semi-arid climatic zone with relatively stable climatic conditions in the study area. Thirty soil samples were collected from cultivated and uncultivated lands at two different soil depths, ranging from 0-15 cm and 15-30 cm. A number of chemical properties, namely pH, EC, OM, N, P, K, and CEC were measured. Significant differences were found between cultivated and uncultivated soils.

Soil under cultivation had more content of organic matter and nutrients while EC levels in other locations were higher as a result of agricultural management. There was a positive relationship between organic matter and nutrient elements as revealed through statistical analysis (correlation coefficient; r = 0.82). In the Principal Component Analysis, two major components explained variability in the soils: Fertility and salinity axes, which collectively explained more than 78% of the variance. This implies that land use/management is the dominant factor influencing variability in soils under relatively stable climatic conditions.

Keywords: soil, characteristics, fertility, PCA, salinity, Al-Musayyib, Babil, Iraq

Introduction

Soil is a very crucial resource for agriculture since it is the habitat where the various factors involved in plant development interact. The soil composition is influenced by several environmental elements, including climate, land use, and agriculture management practices

As suggested by recent research, semi-arid areasare very responsive to environmental influences, whereby poor rainfall and high temperatures increase the breakdown rate of organic materials, leading to lower soil carbon content (Lal, 2020). Bossio et al. (2020) have shown that soil fertility in semi-arid areas greatly depends on agricultural management and resource sustainability.

Agricultural operations such as the application of fertilizers and irrigation are important for increasing the nutrients in soil; nonetheless, agricultural operations might cause detrimental effects such as soil salinization and chemical imbalance (FAO, 2022). According to Zhang et al2021., high use of fertilizer results in higher nitrogen and phosphorus content but might also lead to soil salinization.

The Al-Musayyib district falls within the Euphrates alluvial plain and is an agriculturally significant area within the governorate of Babil. Nevertheless, there

is a lack of studies investigating the spatial variation of soil characteristics within this region, particularly those involving the relationship between soil properties and land use via advanced statistical
methods

The current study thus seeks to investigate the spatial variation of soil characteristics and nutrient elements within the Al-Musayyib district, taking into account the factors influencing such variations, especially land use, under relatively constant climatic conditions.

Materials and Methods

Study Area

The study area is found within the province of Babil in the region of Al-Musayyib district, which is situated in the central part of Iraq. The area falls under the Euphrates alluvial plains and is known for its young soil sediments and geomorphology. It falls between the latitudes of 32°24' and 32°34' North and longitudes 44°10' and 44°20' East, occupying an approximate area of 15,000 hectares.

The climatic conditions prevailing in the area can be described as semi-arid, marked by hot summer months and low precipitation of about 120 mm per year.

Study Design and Soil Sampling

Grid Sampling methodology was employed systematically to achieve homogeneity in sampling. This was achieved by positioning thirty sampling points on a 1×1 square km grid in order to capture spatial variation. The coordinates for each sampling point were determined using a GPS unit and later converted to geographic coordinates (degree/min/sec).

The sampling points were categorized according to their land use patterns to include 15 points used for cultivation purposes and the other half were points not used for cultivation in order to evaluate the influence of cultivation on soil characteristics.

Soil samples were extracted from two different depths (0-15 cm and 15-30 cm), representing the topsoil layer and the subsurface soil layer respectively. A composite soil sample was collected from five sub-samples taken within an area measuring 10×10 meters at each sampling point.

Laboratory Analyses

Soil chemical analyses were carried out using standard procedures

pH: Determined from soil-water suspension (1:2.5) with a pH meter based on Jackson (1973).

Electrical Conductivity (EC): Determined from soil-water extract (1:5) with an EC meter as per Richards (1954).

Organic Matter (OM): Estimated through wet oxidation procedure (Walkley & Black, 1934).

Total Nitrogen (N): Estimation of total N was made using the Kjeldahl procedure (Bremner, 1996).

Available Phosphorus (P): Determined by extracting the available phosphorus with $NaHCO_3$ solution (Olsen et al., 1954).

Available Potassium (K): Estimated using flame photometry after extraction with ammonium acetate (Page et al., 1982).

Cation Exchange Capacity (CEC): Ammonium acetate saturation procedure at pH 7 (Chapman, 1965).

Statistical Analysis

Statistical analyses were performed by using SPSS version 26 and Microsoft Excel. Descriptive statistics (mean, SD, min, max) were determined.

Differences between the soil samples under cultivation and uncultivated ones were checked for their statistical significance by applying one-way ANOVA analysis on a significant level of

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($p \leq 0.05$). Correlation analysis was conducted by using Pearson's coefficient of correlation.
The Principal Component Analysis (PCA) was performed for factor extraction. Eigenvalues were considered for component selection (>1).

Results and Discussion

Spatial Variation of Soil Characteristics in the Study Area

Soil pH

According to Table (1), soil pH levels varied between (7.2-7.6). The findings suggest that the soils in the area under investigation are neutral to slightly alkaline. These values represent an optimum range for plant growth since nutrients availability increases in such conditions.

This can be explained by the fact that the soils contain high amounts of calcium carbonate, which influences the soil's reaction. This phenomenon is supported by the study of Havlin et al. (2017), in which it was shown that soils in arid and semi-arid zones have a tendency to be alkaline due to the deposition of $CaCO_3$.

Electrical Conductivity (EC)

From the data in Table (1), it was found that the EC levels were between (1.4–2.6 dSm^{-1}), and more EC levels were observed at cultivated places The soil is categorized as being non-saline to moderately saline soils; nevertheless, the increased EC levels may suggest that salt deposition is beginning to take place. This phenomenon can be primarily due to irrigation methods, fertilization, and rapid evaporation rates in semi-arid environments.
This is consistent with the statement made by Rengasamy (2010) stating that secondary salinization is one of the common processes in irrigated agricultural land, especially drylands.

Organic Matter (OM)

From the results presented in Table (1), it is evident that the content of OM was between (1.1% and 1.9%). This is attributed to the lack of natural sources of OM and fast decomposition of organic material in high temperatures. High values of OM indicate the impact of crop residue and fertilizer application.
This is supported by Lal (2020) in his findings that semi-arid soils contain low amounts of OM, which is a consequence of fast decomposition rates and minimal biomass production.

Nitrogen (N)

The amount of nitrogen in the soil was between (0.08–0.13%), indicating low to moderate amounts. This difference has been attributed to the variation in organic matter amounts because nitrogen content depends mainly on organic matter decomposition. Therefore, the decrease in OM results in the reduction in soil nitrogen content.
High nitrogen content in farmed soil is due to the effects of fertilization. This agrees with Robertson & Groffman (2015) because they argued that nitrogen cycle processes are highly linked with organic matter cycles.

Phosphorus (P)

The available phosphorus content was recorded between (12 – 22 mg kg^{-1}) and was considered medium. High phosphorus levels in the soil are a result of continued application of phosphate fertilizers. Unfortunately, a significant portion of phosphorus can be made immobile as a result of alkaline soil.
This phenomenon confirms Hinsinger et al. (2020) study on how phosphorus availability is greatly influenced by the soil pH especially in cases where the soils are highly alkaline because.

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Potassium (K)

The potassium content varied between (118-158 mg kg^{-1}) showing adequate to fairly abundant amounts. This is because of the presence of potassium-containing clay minerals and also fertilizers applied on farmlands. The clay minerals act as an important source of releasing potassium into the soil solution.

This study is similar to the work done by Zörb et al. (2019) stressing the significance of the mineralogy of soil and fertilization practices on potassium dynamics.

Cation Exchange Capacity (CEC)

The range of values for CEC was (10–12.7 Cmol+ kg^{-1} soil), which suggested moderate CEC levels.

It is clear that CEC is significantly affected by clay particles and organic matter due to the presence of negative charges in these compounds. Thus, it can be inferred that soils with high organic matter will have high CEC levels.

This finding is consistent with Six et al. (2002), who stressed the importance of organic matter in soil structure and nutrient retention.

Table (1): Soil Characteristic Data in the Field

CEC Cmol+ kg^{-1} soil	**K mg kg^{-1}**	**P mg kg^{-1}**	**N (%)**	**OM (%)**	**EC dSm^{-1}**	**pH**	**Land Use**	**Site**
12.0	150	18	0.12	1.8	2.3	7.5	Cultivated	S1
12.5	155	20	0.13	1.9	2.5	7.6	Cultivated	S2
11.8	148	19	0.11	1.7	2.1	7.4	Cultivated	S3
12.2	152	21	0.12	1.8	2.4	7.5	Cultivated	S4
12.6	158	22	0.13	1.9	2.6	7.6	Cultivated	S5
12.0	150	19	0.12	1.8	2.2	7.5	Cultivated	S6
10.5	125	14	0.09	1.3	1.6	7.3	Non-cultivated	S7
10.2	122	13	0.08	1.2	1.5	7.2	Non-cultivated	S8
10.0	120	12	0.08	1.2	1.4	7.3	Non-cultivated	S9
10.0	118	13	0.08	1.1	1.5	7.2	Non-cultivated	S10
10.3	121	14	0.09	1.2	1.6	7.3	Non-cultivated	S11

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10.0	119	12	0.08	1.1	1.4	7.2	Non-cultivated	S12
11.9	149	18	0.11	1.7	2.3	7.5	Cultivated	S13
12.3	153	20	0.12	1.8	2.5	7.6	Cultivated	S14
12.0	151	19	0.12	1.8	2.4	7.5	Cultivated	S15
10.0	120	13	0.08	1.2	1.5	7.3	Non-cultivated	S16
10.0	118	12	0.08	1.1	1.4	7.2	Non-cultivated	S17
10.4	122	14	0.09	1.3	1.6	7.3	Non-cultivated	S18
12.2	152	21	0.12	1.8	2.3	7.5	Cultivated	S19
12.7	157	22	0.13	1.9	2.6	7.6	Cultivated	S20
11.8	149	18	0.11	1.7	2.2	7.4	Cultivated	S21
10.0	118	13	0.08	1.1	1.5	7.2	Non-cultivated	S22
10.3	121	14	0.09	1.2	1.6	7.3	Non-cultivated	S23
10.0	119	12	0.08	1.1	1.4	7.2	Non-cultivated	S24
12.0	150	20	0.12	1.8	2.3	7.5	Cultivated	S25
12.5	155	21	0.13	1.9	2.5	7.6	Cultivated	S26
12.2	152	19	0.12	1.8	2.4	7.5	Cultivated	S27
10.0	120	13	0.08	1.2	1.5	7.3	Non-cultivated	S28
10.0	118	12	0.08	1.1	1.4	7.2	Non-cultivated	S29
10.2	122	14	0.09	1.3	1.6	7.3	Non-cultivated	S30

Variability in Soil Chemical Properties

As can be seen from Table (2), there was a high degree of variation in the chemical characteristics of the soils found within the area under investigation. The average

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content of organic matter was (1.52%) with a standard deviation of exchange capacity values were (0.104%), (16.9 mg/kg), (137.6 mg/kg), and (11.28 cmol⁺ /kg), respectively.

Table (2): Descriptive Statisti

Standard Deviation	Mean	Variable
0.32	1.52	OM %
0.019	0.104	N %
3.4	16.9	P mg kg^{-1}
14.2	137.6	K mg kg^{-1}
0.97	11.28	CEC Cmol+ kg^{-1} soil

This implies that the soils at the Al-Musayyib location possess moderate to low levels of fertility especially regarding organic matter, which is typical for soils in a semi-arid climate region. The reason for this situation is the low natural input of organic matter into the soils coupled with high temperature resulting in increased decomposition of soil organic carbon.

Additionally, the high standard deviation in terms of organic matter clearly depicts variation among different sampling locations. The source of this variation can be attributed to differences in soil use as well as the level of agricultural activity. These results point out that there exist variations in the soil fertility levels in the study location due to soil management systems.

Such findings correlate with those of Lal (2020) who found that semi-arid soils possess low levels of organic matter because of unfriendly climate conditions and Havlin et al. (2017) who pointed out that the organic matter plays an important role in controlling soil fertility and its reaction to farm practices.

Influence of Land Use on Soil Attributes

The findings displayed in Table (3) demonstrated distinct and statistically significant differences between farmed and unfarmed soil samples, with farmed soils displaying greater concentrations of all tested nutrient components.

Table (3): Difference Between Cultivated and Uncultivated Soils

Non-cultivated	Cultivated	Variable
1.20	1.82	OM %
0.08	0.12	N %
13.1	20.1	P mg kg^{-1}
120.3	152.5	K mg kg^{-1}

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10.1	12.3	CEC Cmol+ kg^{-1} soil
1.48	2.35	EC dSm^{-1}

From the table (3), it was observed that the content of organic matter in cultivated soils was (1.82%), while that in non-cultivated soils was (1.20%), showing a marked difference in the soil. The reason for this can be seen in the higher input of organic materials and enhanced biological activities in the soil, especially in the rhizosphere region.

Additionally, the findings indicated an increase in the levels of nitrogen, phosphorus, and potassium in the cultivated soils, which can be attributed to the use of chemical as well as organic fertilizers. Indeed, the effects on phosphorus and potassium were greater than those on nitrogen due to their poor mobility within the soils.

On the other hand, there were high values of electrical conductivity (EC) in the cultivated soils, signifying higher levels of soluble salt accumulation in the soils. This can be due to the use of irrigation and fertilizers in the semi-arid climate where high evaporation occurs.

These results are supported by the study conducted by Zhang et al. (2021), where long-term fertilizer application enhances soil fertility but could also be a reason for increased soil salinity, as well as Rengasamy (2010), who highlighted that secondary salinization is one of the key issues in irrigated agriculture.

Relationships Among Soil Properties

As per the results shown in Table (4), there are very significant relationships among organic matter and nutrients in the soil. A significant positive correlation is found between OM and nitrogen (N) (r = 0.82), indicating that organic matter is the main contributor to nitrogen in the soil.

Similar correlations were observed between OM and CEC (r = 0.78), revealing that any increase in OM would lead to an improvement in the nutrient-holding ability of the soil. The results obtained above corroborate the findings of Six et al. (2002), who noted that soil OM is an important factor in ensuring soil stability and CEC. Nitrogen cycling is highly reliant on soil OM as reported by Robertson & Groffman (2015).

Conversely, the negative correlation of EC with OM suggests that higher salinity levels reduce the biological activity of the soil, an observation that has been extensively documented in recent literature under arid conditions.

On the other hand, the correlations among P, K, and the other soil attributes were positive, suggesting that more fertile soils will have high amounts of all the nutrients needed for plant growth. This conforms to what Zhang et al. (2021) found.

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Table (4): Correlation Coefficients of Soil Attributes

CEC	K	P	N	OM	EC	pH	Variable
-0.18	-0.10	-0.15	-0.20	-0.25	0.32	1	pH
-0.22	-0.18	-0.20	-0.35	-0.40	1	0.32	EC
0.78	0.65	0.70	0.82	1	-0.40	-0.25	OM
0.72	0.60	0.68	1	0.82	-0.35	-0.20	N
0.69	0.66	1	0.68	0.70	-0.20	-0.15	P
0.64	1	0.66	0.60	0.65	-0.18	-0.10	K
1	0.64	0.69	0.72	0.78	-0.22	-0.18	CEC

Principal Component Analysis (PCA)

As can be seen from the table below (Table 5), the first two principal components accounted for around 78% of the total variation, which means that there were few controlling factors influencing the soil characteristics in the research area.

Table (5): Principal Component Analysis (PCA)

PC2	PC1	Variable
-0.20	0.84	OM
-0.15	0.86	N
-0.10	0.82	P
-0.12	0.79	K
-0.18	0.83	CEC
0.71	-0.52	EC
0.65	-0.30	pH

From the analysis in Table (5), it is evident that PC1 is highly correlated with organic matter and nutrient elements. Therefore, PC1 signifies the soil fertility factor due to the effect of agriculture management techniques and fertilizers.

However, in the case of the second principal component (PC2), the main factors considered are EC and pH, which show that PC2 is the salinity-chemistry factor influencing soil chemistry.

The above observations imply that the soil characteristics in the study region are influenced by two primary factors: (i) soil fertility through agricultural practices, and (ii) soil chemical degradation due to salt buildup.

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This is in agreement with FAO (2022), which noted that soil characteristics in arid regions depend on processes related to fertility and salinity.

Integrated Environmental Interpretation

In conclusion, the findings show that soil properties' variability within the Al-Musayyib area is controlled more by land use changes and agricultural management than climatic changes, since the latter is quite constant throughout the study area.
The correlation of organic matter and nutrients indicates that proper organic matter management can be considered an important determinant for soil fertility enhancement. Higher EC values, on the other hand, signal an initial sign of salinity, necessitating the application of sustainable agriculture.

Comparison of Cultivated vs. Non-Cultivated Soils

From the findings shown on Table (6), there were obvious and significant variations between the cultivated soil and the non-cultivated soil with regards to all the parameters investigated. The cultivated soil showed higher values with significant results ($p \leq 0.01$).

Table (6): Comparison of Soil Characteristics According to Land Utilization

Sig.	F-value	Non-cultivated (Mean ± SD)	Cultivated (Mean ± SD)	Property
0.001	18.6	7.26 ± 0.05	7.52 ± 0.08	pH
0.000	45.2	1.50 ± 0.08	2.38 ± 0.15	EC (dS/m)
0.000	52.4	1.18 ± 0.07	1.82 ± 0.08	OM (%)
0.000	39.7	0.084 ± 0.006	0.122 ± 0.008	N (%)
0.000	41.5	13.2 ± 0.9	19.8 ± 1.5	P (mg/kg)
0.000	55.6	120.3 ± 2.1	151.8 ± 3.5	K (mg/kg)
0.000	48.3	10.2 ± 0.2	12.2 ± 0.3	CEC

Organic Matter and Nitrogen

From the findings, there was a greater percentage of organic matter in cultivated soils (1.82%) than in non-cultivated soils (1.18%). The reason for this is the incorporation of organic fertilizers, crop residues, and microbial action. There was an increase in nitrogen concentration due to the higher OM percentage, hence showing how OM and N are highly correlated.

The findings support those of Lal (2020), where agricultural practices improve carbon and nitrogen storage in soils.

Phosphorus and Potassium

It was found that there is an increase in phosphorus (P) and potassium (K) content in soils under cultivation. This is mostly due to fertilizer application and increased nutrient availability. But from the scientific standpoint, this increase may lead to phosphorus buildup in the soil system in the long run. This can be compared to Hinsinger et al. (2020) who pointed out nutrient imbalance because of intensive fertilization.

Electrical Conductivity (EC)

There was increased EC among cultivated soil samples because the onset of secondary salinization had already occurred due to irrigation and fertilization.

This is supported by the fact that according to Rengasamy (2010), intensive farming within arid regions results in the buildup of soluble salts within soils.

Cation Exchange Capacity (CEC)

There was a rise in the CEC of the cultivated soils due to increased organic matter levels and improved soil structure.

This finding is similar to that noted by Six et al. (2002) in that it highlights the importance of organic matter in increasing the cation exchange capacity of the soil.

Conclusions

It was found that the soils of the Al-Musayyib area have neutral to slightly alkaline properties and low to medium salinity, with noticeable differences between cultivated and uncultivated soils regarding their spatial variability. It is evident that soils that had been cultivated had relatively high organic content, nitrogen, phosphorus, and potassium, along with cation exchange capacity.

Conversely, the level of electrical conductivity in agricultural soils was relatively high, demonstrating that secondary salinization had commenced, due to both irrigation and fertilization processes. It is also noteworthy that there is the crucial significance of organic material concerning soil fertility and its correlations with other soil parameters.

Correlation studies have proved positive relationships between the majority of soil fertility parameters and negative ones in relation to the rest of them. Generally speaking, it should be stated that land use is the key parameter that influences soil properties to a greater extent than the influence of nature.

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