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Spatial Distribution of Some Soil Elements in the Al-Kawtha Project in Iraq

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ABSTRACT

This study was conducted in the Al-Kawtha Agricultural Project, Babil Governorate, Iraq (874 km²), with the aim of evaluating the spatial distribution of major soil nutrients. Four land-use types were considered: wheat, maize, eggplant, and uncultivated land. Soil samples were collected from two depths (0–30 cm and 30–60 cm) and analyzed to determine nitrogen, phosphorus, potassium, iron, and zinc.as well as key physical and chemical properties.The results showed substantial variation in nutrient levels among the different land uses, while soil pH remained relatively stable. Nitrogen concentrations ranged from 18.90 to 38.9 mg kg^{-1}, phosphorus from 4.30 to 11.27 mg kg^{-1}, potassium from 97.60 to 145.3 mg kg^{-1}, iron from 3.58 to 7.58 mg kg^{-1}, and zinc from 0.31 to 0.46 mg kg^{-1}. The highest nutrient concentrations were observed in uncultivated areas, reflecting minimal nutrient removal, whereas cultivated fields—especially maize—showed lower nitrogen and organic matter content. Phosphorus was more abundant in deeper layers, while other nutrients were concentrated in the topsoil .Statistical analysis ($p \leq 0.05$) confirmed that Findings revealed that soil nutrient distribution was significantly influenced by both land-use type and soil depth. These findings emphasize the long-term impact of cultivation on soil nutrient depletion and highlight the necessity of sustainable management strategies, including organic fertilization and crop rotation, to preserve soil fertility and productivity.

KEY WORDS: Soil fertility, Spatial variability, Geostatistics, Land use

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I. INTRODUCTION

The productivity of agricultural systems is closely linked to soil fertility, which determines The abundance of essential nutrients is vital for healthy plant growth, especially in arid and semi-arid regions such as southern Iraq, extended periods of intensive cultivation have substantially reduced nutrient reserves and deteriorated soil quality, raising concerns about long-term land degradation and declining crop yields. Soil nutrient distribution is affected by several interrelated factors, including crop type, soil texture, management practices, and soil depth. Yet, studies examining the spatial variability of nutrients across different land uses in Iraq remain scarce (Yu et al., 2020). Understanding the patterns of nutrient abundance or deficiency is essential for interpreting soil productivity (Liu et al., 2018).Recent advancements in spatial analysis techniques, particularly Geographic Information Systems (GIS) and remote sensing (RS), have greatly improved the capacity to map and quantify nutrient variability. These tools support better decision-making in land management and targeted fertilizer application. However, few investigations in Babil Governorate have combined high-resolution spatial analysis with field-based soil measurements to assess how land-use systems influence nutrient distribution. The current study addresses this knowledge gap by assessing how various cropping Land-use patterns significantly affect the availability of macro- and micronutrients in the soils of the Al-Kawtha Agricultural Project. Specifically, the study compares nutrient concentrations in soils cultivated with wheat, maize, and vegetables to those in uncultivated plots, across two distinct soil depths, to evaluate the impact of land-use practices on soil fertility.

II. MATERIALS AND METHODS

Study Area

This study was conducted at the Al-Kawtha Agricultural Project in Al-Mahawil District, Babil Governorate, Iraq (44°36′37″ E, 32°45′02″ N). The area falls within the semi-arid climate of central Iraq and is characterized by fertile alluvial soils rich in nutrients deposited over time by the Euphrates River. The geographic location of Babil Governorate, along with the specific site of the Al-Kawtha Project selected for this study, is illustrated in Figure 1

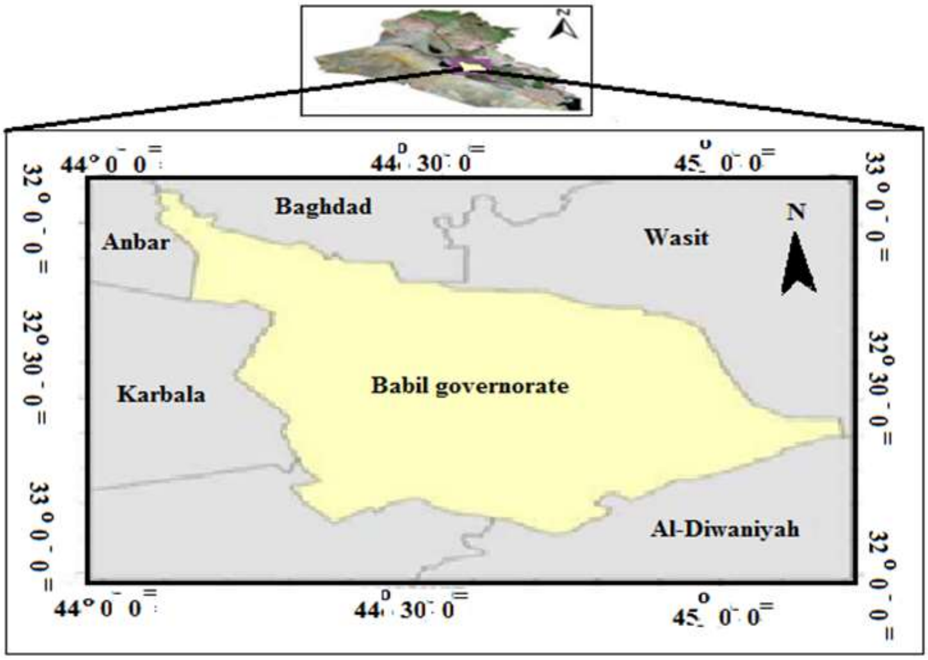

Figure 1: Map of the study area

Climate Description

Climatic data for the study area indicate that the average annual rainfall ranges between 100–150 mm, concentrated mainly between November and March during the wet season, and from May to September, with summer temperatures exceeding 45°C. These conditions lead to high evaporation rates, which increase the likelihood of nutrient movement in the soil through the leaching process, particularly in the upper soil layers. This negatively affects the availability of essential elements such as nitrogen and potassium. It has been observed that leaching rates significantly increase during periods of concentrated winter rainfall, resulting in the loss of nutrients from the root zone

Cropping History and Agricultural Practices

A crop rotation system with diversification has been practiced in the project for over ten years to maintain soil fertility and minimize the spread of pests and diseases. The main crops cultivated over the past three years include:

• Wheat as a winter crop
• Yellow maize as a summer crop
• Eggplant, planted in late spring and early summer

The following table shows the fertilizer requirements for the main crops in the area.:

Crop	N (kg/ha)	P_2O_5 (kg/ha)	K_2O (kg/ha)	Notes
Wheat	120	60	40	Applied in two splits
Yellow maize	180	90	60	Requires high nitrogen levels
Eggplant	150	80	100	Fertilized throughout the growing season

Irrigation System and Water Quality

The study area relies primarily on surface irrigation from the Euphrates River and its network of irrigation canals, in addition to some groundwater wells in the southern regions. The quality of irrigation water has a direct impact on soil fertility, as the continuous use of moderately saline water may It may result in the accumulation of salts in the topsoil, which limits the uptake of nutrients and negatively affects agricultural productivity. Moreover, irregular irrigation practices or over-irrigation accelerate the leaching process, causing the loss of soluble nutrients, particularly nitrates and sulfates

The irrigation water requirements vary by crop, as follows:
- Wheat: 450–500 mm/season
- Yellow maize: 600–650 mm/season
- Eggplant: 700–800 mm/season (due to the longer growing period and high summer temperatures)

Land Use and Sampling Design

The study was conducted in the Al-Kawtha Agricultural Project, which covers an area of 150 hectares, of which about 120 hectares are currently cultivated with wheat, yellow maize, and eggplant, in addition Uncultivated lands were used as a control. Composite soil samples were collected from two depths (0–30 cm and 30–60 cm) using a manual auger, and the geographic coordinates of each sampling site were recorded with a GPS device Laboratory analyses were conducted in three replications, and a factorial design within a randomized complete block design (RCBD) was applied to assess the effects of both land-use type and soil depth. Figure 2 illustrates the patterns of land use

Figure 2 Land-use patterns distribution in the study area

Laboratory Analysis

Samples were taken at both surface and subsurface depths for all study sites for chemical and physical analyses. The particle size distribution of soil separates (sand, silt, and clay) was determined using the hydrometer method as described by Black (1965). Soil pH was measured in a 1:1 soil-to-water suspension by Ryan et al. (2003), and electrical conductivity was determined following Richards (1954). Cation exchange capacity and organic matter were assessed according to Jackson and Black (1958, 1965), while available nitrogen was estimated as described by Black (1965). Available phosphorus and potassium were determined following Page (1928), and available iron and zinc were extracted using the DTPA chelating agent according to Lindsay and Norvell (1978).

RESULTS

The physical and chemical characteristics of the soils under study are shown in(Table, 2). In the 0–30 cm soil layer, pH values varied between 7.30 and 7.76, while in the 30–60 cm layer they ranged from 7.47 to 7.82, indicating that the soils are generally neutral to slightly alkaline, which is favorable for most crops. Differences between soil depths were minimal, although some variation was observed across different land-use types. While a moderate pH generally supports nutrient availability, slightly higher pH levels in maize and vegetable fields could limit the accessibility of certain micronutrients, including iron and zinc (Sposito, 2020; Penn and Camberato, 2019).Electrical conductivity in the surface layer ranged from 3.36 to 5.06 dS·m^{-1} and from 3.24 to 4.96 dS·m^{-1} in the subsurface. These elevated values suggest the accumulation of soluble salts, potentially due to the use of moderately saline irrigation water, inadequate drainage, or high temperatures, particularly in clay loam soils where evaporation concentrates salts at the surface (Rengasamy, 2018). Cation exchange capacity (CEC) ranged from 17.26 to 24.58 cmol/kg in the surface layer and 12.31 to 23.40 cmol/kg in the subsurface, reflecting the soils' ability to retain nutrients. CEC is largely influenced by clay content and organic matter, as higher organic matter increases negative charges on soil particles, enhancing the retention and exchange of cations such as Ca^{2+}, K^{+}, and Mg^{2+} (Havlin et al., 2014; Weil, 2016), thereby reducing nutrient losses through leaching (Tahir and Marschner, 2017). The concentration of organic matter ranged between 0.58 and 1.18% in the 0-30 cm layer and between 0.44 and 1.08% in the 30-60 cm layer at all study sites.The highest value was recorded in the eggplant-cultivated lands, followed by the uncultivated lands, while the lowest values were observed in the wheat and maize fields.The higher organic matter content in vegetable-cultivated and uncultivated lands is likely due to reduced frequency of tillage, the presence of organic plant The use of crop residues and organic fertilizers contributes to improving soil fertility, and vegetable cropping systems often enhance soil properties due to intensive management practices (Lal, 2020). Soil chemical properties are highly susceptible to degradation as a result of human activities. (Bhayunagiri and Saifulloh, 2022).

Effect of Soil Depth and Land Use Patterns

Soil depth has a clear influence on its properties, as the surface layer (0–30 cm) exhibited higher levels of Organic content (OM), cation exchange capacity (CEC), and electrical conductivity (EC) compared to the subsurface layer. This is attributed to the concentration of biological activity, accumulation of plant residues, and the application of agricultural practices in the topsoil, while these properties decrease with increasing depth (Blanco-Canqui, 2008). Significant differences were also observed in OM, CEC, EC, and pH among different land use types. Maize fields recorded the highest EC (salinity) and the lowest CEC, indicating poor soil fertility and higher salt accumulation. In contrast, vegetable fields showed the highest OM and CEC and the lowest EC, reflecting more effective agricultural management and better soil fertility (Yan, 2021).

Table 2: Physical and Chemical Characteristics of the Studied Sites

Land use	Soil sample depth (cm)	EC dSm^{-1}	pH	CEC Cmo l(+) kg^{-1} soil	OM gkg^{-1}	Soil texture
Wheat	0-30	3.62	7.30	20.39	0.58	SiC
	30-60	3.67	7.47	19.25	0.54	SiC
Vegetables (eggplant)	0-30	3.36	7.76	23.80	1.41	SiCL
	30-60	3.24	7.82	23.40	1.08	SiCL
Corn	0-30	5.06	7.60	17.26	0.73	CL
	30-60	4.96	7.80	12.31	0.44	CL
Control Uncultiveted	0-30	4.24	7.53	24.58	1.18	Clay
	30-60	3.71	7.64	20.70	0.97	Clay
Mean of depth 0-30		4.07a	7.55a	21.51a	0.98a	
Mean of depth 30-60		3.90b	7.68b	18.92b	0.76b	
$LSD_{0.05}$ for soil depth		0.016	0.012	0.117	0.003	
Mean of Wheat		3.65b	7.39d	19.82c	0.56d	
Mean of Vegetables		3.30c	7.79a	23.60a	1.25a	
Mean of Corn		5.28a	7.70b	14.79d	0.59c	
Mean of Uncultiveted		3.98b	7.59c	22.64b	1.08b	
$LSD_{0.05}$ for land use		0.033	0.025	0.234	0.007	

- ***Different letters indicate significant differences.***
- ***SiCL = Silty Clay Loam   SiC = Silty Clay   CL = Clay LoamFigure Captions***

Availability of Macro- and Micronutrients in Soils under Different Land Uses

Table 3 shows the levels of available soil nutrients, with a focus on available nitrogen (N). The study area has a semi-arid climate, with average annual rainfall ranging between 100 to 150 mm, most of which occurs between November and March. The dry season extends from May to September, during which daytime temperatures often exceed 40°C, directly affecting nutrient dynamics in the soil, particularly through leaching and downward movement. Although limited rainfall reduces the natural downward movement of nitrogen, excessive irrigation or flood irrigation can cause soluble nutrients such as nitrate (NO_3^-) to leach into deeper soil layers. The results indicated that nitrogen concentration in maize soils was only 18.9 mg/kg, compared to 38.9 mg/kg in uncultivated soils. The LSD value indicates significant differences between soil depths and land-use types, reflecting nitrogen loss due to leaching or insufficient fertilization. Higher nitrogen levels were recorded in the surface layer (0–30 cm), due to the accumulation of organic matter and increased microbial activity. These results are consistent with those of Havlin et al. (2005) and Pervaiz et al. (2020), who emphasized the role of organic matter in maintaining nitrogen availability. Intensive agricultural practices can also lead to soil degradation and irreversible damage (Kartini et al., 2024). Variations in nitrogen levels are linked to differences in land management practices and farmers' approaches to returning plant residues to the soil (Wang et al., 2020). In addition, Ammonium and nitrate transformations result in nitrogen loss, which contributes to making fertilizer management essential. Excessive nitrogen fertilization can lower soil pH and increase acidity, which may hinder plant growth and reduce the availability of certain nutrients (Daba et al., 2021). Nitrogen is a mobile element in the soil and declines rapidly in cultivated lands unless regularly replenished through fertilization (Fageria, 2019). Loss of organic matter and nutrients in the topsoil reduces the soil's capacity to support plant growth and deteriorates its properties (Alewell et al., 2020; Demir et al., 2023). Organic matter influences soil pH and enhances nitrogen uptake, while deep roots improve nitrogen availability in lower soil layers. Decomposition of organic matter and applied organic fertilizers continues to supply nitrogen to plants consistently.

Available Phosphorus (P)

The results showed that phosphorus concentrations were higher in the uncultivated soils, averaging 11.27 mg kg^{-1}, compared to lower levels in the cultivated soils. Since phosphorus tends to accumulate in the deep layer (30-60 cm), this is attributed to its fixation in calcareous surface soils. The high calcium carbonate content and high pH also reduce phosphorus mobility and solubility, which is consistent with the high concentration of phosphorus in the soils Rafiullah et al. (2020) and Brownrigg et al. (2022).Microbial activity plays an important role in providing nutrients, participating in nitrification, producing organic acids, and releasing carbon dioxide, which can lower soil pH. and increase nutrient accessibility (Msimbira and Smith, 2020). The decrease in available phosphorus is linked to agricultural use, where plant roots absorb phosphorus at specific depths. Interactions between fertilizers and soil can further reduce the amount of plant-available phosphorus and lead to the formation of poorly soluble compounds. At soil pH above 7.2, $H_2PO_4^-$ converts to HPO_4^{2-} with the release of a proton, which increases soil acidity (Fertilizer Technology Research Center, 2020).Phosphorus is characterized by its slow movement. that binds to the surfaces of clay minerals, resulting in lower concentrations in the topsoil and higher concentrations at depth. Root density also affects phosphorus uptake, as deeper roots can access phosphorus that is otherwise unavailable in the upper layers. Studies have shown that soil amendments with compounds such as glucose, sulfuric acid, and oxalic acid enhance phosphorus solubility and mobility. Phosphorus also participates in biological processes Related to energy molecules such as ATP and NADPH.

Clay minerals of the 1:1 type have a higher phosphorus-fixing capacity than 2:1 minerals, due to their higher content of iron and aluminum oxides and hydroxides. The presence of two layers of alumina in their composition also significantly enhances their effectiveness. which increases phosphorus retention with depth. Calcareous soils and high pH further reduce nutrient availability. Finally, variations in available phosphorus reflect the effects of NPK fertilizer application and intensive agricultural management practices (Finalis et al., 2021)

Available Potassium (K)

The study showed that the concentration of potassium in soil varies according to the type of land use, with the highest potassium levels observed in uncultivated lands., at 145.3 mg•kg^{-1}, while the lowest was recorded in maize fields, at 97.60 mg•kg^{-1}. The higher availability in the surface layer is mainly due to potassium's low mobility and its strong adsorption to clay minerals. The observed decrease in cultivated soils reflects continuous removal by crops without adequate replenishment through fertilization. These findings align with Das et al. (2022), who reported Potassium depletion in intensive agricultural systems occurred significantly at the exchange sites (CEC).

Available Iron (Fe)

Iron values ranged from 3.58 to 7.58 mg·kg^{-1}. The values were the lowest observed in wheat fields, while the highest were recorded in uncultivated lands and vegetable-cultivated soils. This is attributed to the fact that iron mobility is very limited and is highly influenced by soil pH; since the study soils are alkaline, this reduces iron solubility.Wheat crops have high iron requirements, which may lead to reduced availability over time Microbial activity in uncultivated soils may contribute to increasing the amount of plant-available iron.(Fernández & Brown, 2013). Organic acids produced from the decomposition of organic matter help reduce iron fixation in the soil. These results are consistent with their findings Msimbira and Smith (2020), which demonstrated that root exudates and microbial metabolites significantly contribute to increasing iron availability in calcareous soils

Available Zinc (Zn)

The results showed that zinc levels were higher in the uncultivated soil, at 0.46 mg•kg^{-1}, compared to the soil used for growing vegetables, which recorded a level of 0.42 mg·kg^{-1} The lowest concentration of zinc was 0.31 mg·kg^{-1} in maize fields .The statistical differences were significant ($LSD_{0.05}$ = 0.006 for depth, 0.013 for land use).Zinc is a micronutrient, and its solubility decreases in alkaline soils (pH > 7.5).Soils with high organic matter content enhance zinc uptake, which explains the higher levels observed in eggplant sites. As for maize, it depleted more zinc than other crops due to its deep root system and dense growth. (Alloway, 2008)

Table 3: Values of available Nitrogen, Phosphorus, Potassium, Iron, and Zinc in studied soils.

Land use type	Soil sample depth cm	N_{ava}	P_{ava}	K_{ava}	Fe_{ava}	Zn_{ava}
						$mgkg^{-1}$ soil
Wheat						
	0-30	31.23	5.30	128.06	6.20	0.40
	30-60	26.70	7.20	114.67	5.10	0.35
Corn						
	0-30	23.40	4.30	118.30	4.72	0.33
	30-60	18.90	6.70	97.60	3.58	0.31
Vegetables						
Eggplant	0-30	30.80	6.10	130.46	6.07	0.42
	30-60	26.45	8.21	122.18	6.04	0.40
Control						
Uncultiveted	0-30	38.9	11.27	145.30	7.58	0.46
	30-60	33.3	9.22	142.60	7.04	0.44
Mean of depth 0-30		31.08a	6.74a	130.50a	6.14a	0.40a
Mean of depth 30-60		26.34b	7.83b	119.26b	5.44b	0.38b
$LSD_{0.05}$ for soil depth		0.146	0.045	1.248	0.072	0.006
Mean of Wheat		28.97b	6.25c	121.37c	5.65c	0.38c
Mean of Vegetables		21.15d	5.50d	107.95d	4.15d	0.32d
Mean of Corn		28.63c	7,11b	126.39b	6.06b	0.41b
Mean of Uncultiveted		36.10a	10.24a	143.95a	7.31a	0.45a
$LSD_{0.05}$ for land use		0.293	0.094	2.496	0.146	0.013

Different letters indicate significant differences.

Geographic distribution of available nitrogen (N)

The levels of various nutrients—including nitrogen, phosphorus, potassium, iron, zinc, and others—differ across land areas, showing variation both horizontally (among different sites) and vertically (with soil depth) Figure 3 illustrates the spatial distribution of available nitrogen. The highest concentrations (33% of the total area) were recorded in uncultivated lands, while the lowest concentrations (0.17%) appeared in areas under intensive cultivation, such as maize and wheat fields.These patterns reflect the impact of land use on nitrogen availability

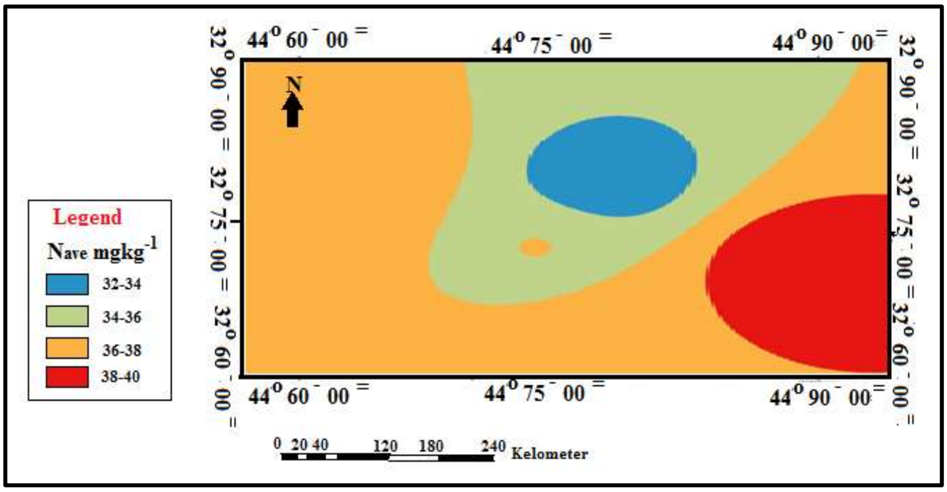

Figure 3. Geographic distribution of available nitrogen (N) in the study area

Geographic distribution of available phosphorus (P)

Figure 4 presents the spatial distribution of available phosphorus, depicting its levels across four regions. The highest phosphorus concentrations were found in uncultivated lands and fields planted with eggplant, whereas the lowest levels occurred in maize-cultivated areas. These results emphasize the issue of phosphorus fixation in calcareous soils and underscore the need for fertilization strategies tailored to specific crop types.

These observations align with the findings of Hammad et al. (2024), who studied the spatial distribution of macronutrients in agricultural areas of Anbar Governorate, Iraq.

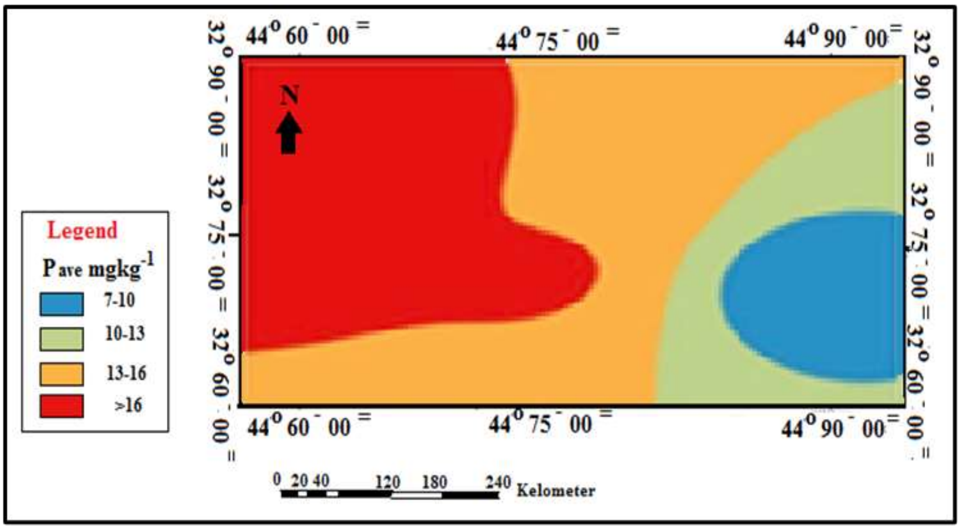

Figure 4. Spatial distribution of available phosphorus (P) and its relation to different agricultural practices.

Geographic distribution of available potassium(K)

Figure 5 illustrates the spatial distribution of available potassium. The highest potassium concentrations were recorded in uncultivated lands and wheat-cultivated areas, while a sharp deficiency was observed in maize fields. The results highlight the role of soil texture and organic matter in potassium retention.Vegetable-cultivated lands, especially those planted with eggplant, showed the highest iron concentrations (54%) due to repeated organic fertilization. In contrast, the lowest concentrations were recorded in maize-cultivated areas, indicating iron fixation in calcareous alkaline soils

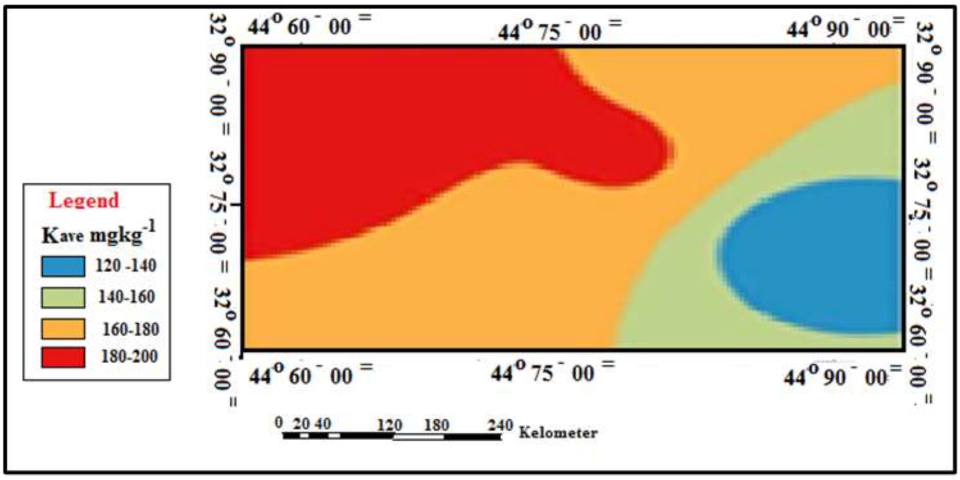

Figure 5. Spatial distribution of available potassium (K) in the study area

Geographic distribution of available iron (Fe).

Figure 6 illustrates the spatial distribution of available iron (Fe). The highest concentrations were recorded in vegetable-cultivated lands, particularly those planted with eggplant (54%), as a result of repeated organic fertilization.In contrast, the lowest concentrations were observed in maize-cultivated lands, indicating iron fixation in calcareous alkaline soils.

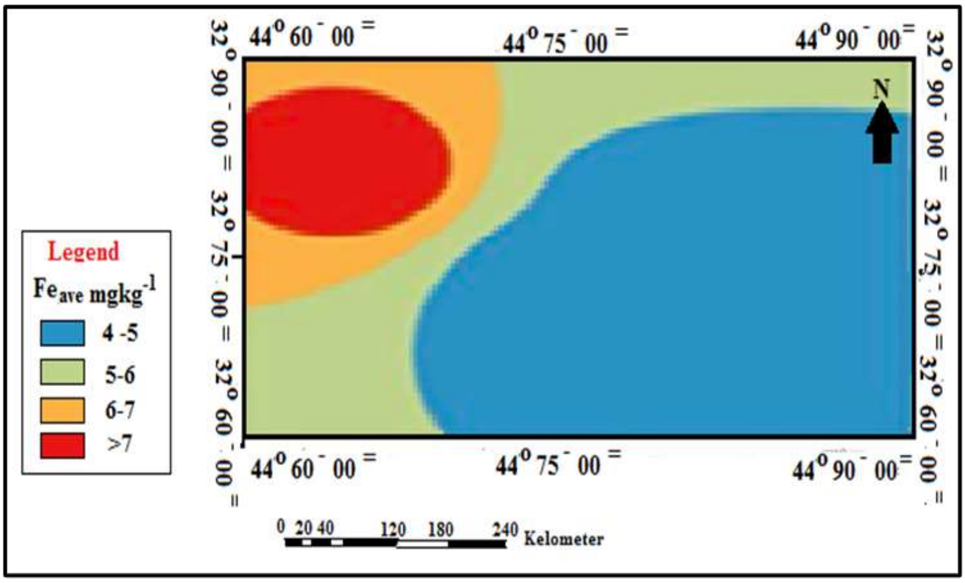

Figure 6. Spatial variation in available iron (Fe) according to land use patterns

Geographic distribution of available zinc (Zn).

Figure 7 illustrates the spatial distribution of available zinc. Zinc levels are generally low in the soil, with the highest concentrations recorded in eggplant-cultivated and uncultivated lands, while the lowest concentrations were observed in maize fields. This reflects zinc fixation in calcareous soils and the high nutritional demand of the maize crop

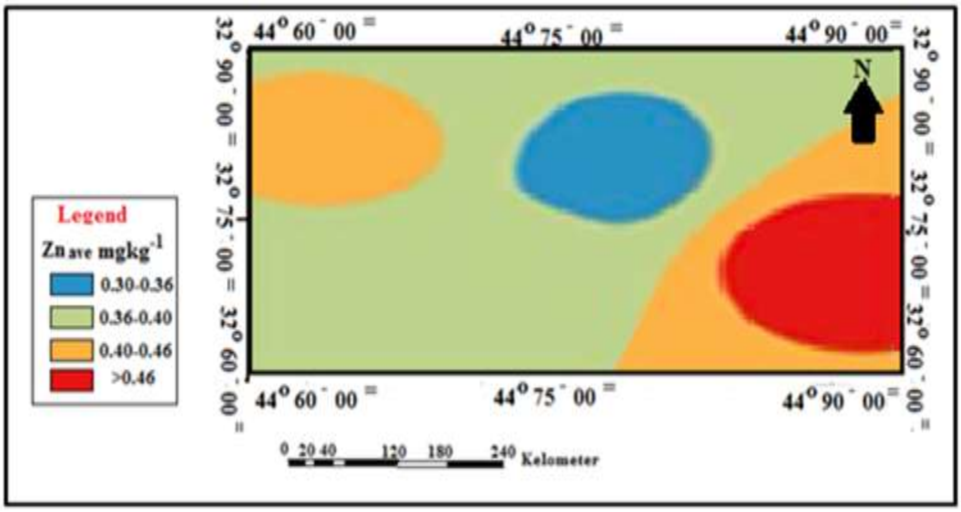

Figure 7. Spatial distribution of available zinc (Zn) and its relationship with agricultural systems

The levels of studied micro nutrients which was recorded for iron and zinc were consistent with what was observed by Hammad et al. (2025) when they studied the spatial distribution of micronutrients in the soils of agricultural areas in Anbar Governorate, Iraq, and with variations in the type of land use.

CONCLUSION

The results of this study clearly indicate the negative impacts of long-term continuous cultivation on soil nutrient dynamics in the Al-Kawtha Agricultural Project. A pronounced depletion of essential macronutrients, such as N,P,K, Addition of micronutrients such as Fe, Zn was observed in cultivated soils, highlighting the vulnerability of surface horizons to intensive agricultural practices. In contrast, uncultivated lands exhibited better nutrient status, demonstrating the protective role of natural vegetation and organic matter accumulation.Phosphorus also showed a distinctive distribution Phosphorus tends to accumulate in the subsurface layers, which is likely due to chemical fixation in the calcareous topsoil reflecting the complex interaction between soil properties, land use, and nutrient mobility in arid ecosystems. Statistical analysis using ANOVA confirmed that both land use type and soil depth significantly influence nutrient availability. These findings emphasis on soil sustainability strategies tailored to dryland agriculture. Recommended measures include adopting crop rotation, increasing the application of organic amendments, and implementing precision fertilization techniques to ensure balanced nutrient supply and long-term restoration of soil fertility.Moving forward, the integration of remote sensing technologies, GIS-based monitoring, and ongoing soil assessments will be essential for informed land management decisions. These combined approaches can help reduce soil degradation, strengthen ecosystem resilience, and promote sustainable agricultural practices, particularly under increasingly challenging climatic conditions.

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