# Distribution of Selected Available Trace Elements in Soils of Two Sedimentary Series in Abu Ghraq Township

Bashaar Hatem Obaid1 Mohammed Sallal Oleiwi2 Amal Radhi Jubier3
College of Agriculture, Al-Qasim Green University, Babylon, Iraq.
2Department of Soil Sciences and Water Resources, College of Agriculture, Al-Qasim Green University, Babylon 51013, Iraq. : https://orcid.org/0000-0002-4446-294X
3Department of Soil Sciences and Water Resources, College of Agriculture, Al-Qasim Green University, Babylon 51013, Iraq. : https://orcid.org/0000-0002-9156-8405
*Correspondence to: Amal Radhi Jubier, Department of Soil Sciences and Water Resources, College of Agriculture, Al-Qasim Green University, Babylon 51013, Iraq
Email: amelradha@agre.uoqasim.edu.iq

## Abstract

This study focuses on the distribution of available trace elements in soils from two sedimentary series within the Abu Ghraq township , Babil Governorate, located between 57.074°E longitude and 32.112°N latitude. The district, situated in the northwestern part of Babil Governorate, spans approximately 25,026.38 hectares and was selected due to its diverse soil management practices. The availability of key soil nutrients was evaluated in two sedimentary soil series—DW45 and TM1265—under different management regimes, including irrigation methods and fertilizer types. Results indicated a significant increase in available nitrogen, reaching 3.63 mg Fe $kg^{-1}$ in the DW45 series and 4.56 mg Fe $kg^{-1}$ in the TM1265 series under drip irrigation. Organic fertilizer application further enhanced nutrient availability, with values of 2.19 and 3.87 mg Fe $kg^{-1}$ in the respective series. The highest concentrations of available manganese and zinc were observed under combined management practices involving drip irrigation, organic fertilization, and vegetable cropping, with manganese levels of 2.03, 2.65, 1.50, 1.90, 1.33, and 2.07 mg Mn $kg^{-1}$ and zinc levels of 1.15 and 1.62 mg Zn $kg^{-1}$ across the two series. The findings demonstrate that integrated management systems significantly improve soil organic matter content, thereby enhancing nutrient availability and sustainability.

**Keywords: Soil management, nutrient availability, trace elements, iron, manganese, zinc, organic fertilizer, sedimentary soils**

## Introduction

Soil management plays a critical role in creating an optimal environment for seed germination and root development, which in turn improves the availability and sustainability of essential nutrients for crop growth. Traditionally, these objectives have been achieved through crop rotation and the application of organic amendments, such as organic fertilizers and biofertilizers, which maintain and enhance soil nutrient reserves (Idan and Oleiwi, 2024). Effective soil management is especially crucial in alluvial soils in Iraq, which constitute the majority of the country's agricultural lands and face numerous challenges related to fertility and nutrient sustainability.The Abu Ghraq district in Babil Governorate serves as an ideal study site due to its varied agricultural management

ISSN 2072-3857

practices. This research aims to identify the most effective management methods that promote nutrient sustainability and availability in these soils.

Previous studies have highlighted the challenges of trace element availability in sedimentary soils. For example, Al-Bayati et al. (2021) reported a decline in total and available iron concentrations with soil depth in sedimentary soils, attributing this to traditional management practices, land abandonment, and inadequate irrigation methods. Abdelrahman et al. (2021) emphasized that sustainable soil fertility requires robust management systems capable of monitoring soil conditions and nutrient status. Soil fertility assessment remains a cornerstone for soil improvement, linking fertility indicators with management and natural factors. Hamza (2022) noted that high soil carbonate content and alkaline pH adversely affect micronutrient availability (iron, zinc, copper) in alluvial soils, especially in lands left fallow, where salt accumulation leads to fertility degradation.

## Materials and Methods

The study was conducted in the Abu Ghraq district, located in the northwestern sector of Babil Governorate, selected for its diverse soil management regimes. The investigation targeted two sedimentary soil series, DW45 and TM1265, classified according to the Iraqi sedimentary soil classification system. Soil nutrient availability was assessed under varying management conditions, including irrigation method (e.g., drip irrigation), fertilizer type (organic versus mineral), and crop type.

### Available Iron:

Available iron was extracted following Lindsay and Norvell’s method (1978) using a solution at pH 7.3. Concentrations were determined via atomic absorption spectrophotometry at a wavelength of 248.3 nm.

### Available Zinc and Manganese:

Available zinc and manganese were extracted using Diethylene Triamine Pentaacetic Acid (DTPA) solution and quantified by atomic absorption spectrophotometry as described by Bishour and Al-Sayegh (2007).

## Results and Discussion

### Distribution of Available Micronutrients in the DW45 and TM1265 Soil Series

- Available Iron (Fe) in Soil (mg $kg^{-1}$)

The statistical analysis presented in Tables 1 and 2 demonstrates that irrigation method, crop type, and fertilizer application significantly influenced the availability of iron in both the DW45 and TM1265 soil series. Specifically, the drip irrigation method markedly enhanced iron availability, with the highest concentration recorded in the DW45 soil series at 3.63 mg Fe $kg^{-1}$. This represents an increase of approximately 83% compared to the lowest iron availability values observed under spate irrigation and in soils left uncultivated, which measured 1.98 and 0.39 mg Fe $kg^{-1}$, respectively. Similarly, in the TM1265 series, iron availability peaked at 4.56 mg Fe $kg^{-1}$ under drip irrigation, whereas the lowest values of 3.26 and 0.99 mg Fe $kg^{-1}$ were recorded under flood irrigation and fallow conditions, respectively. The influence of crop type on iron availability was also statistically significant. Soils cultivated with vegetable crops exhibited higher iron content, reaching 2.33 mg Fe $kg^{-1}$ in the DW45 series, compared to 1.76 mg Fe $kg^{-1}$ in soils under grain crops, corresponding to an increase of 26.7%. Likewise, in the TM1265 series, the vegetable crop type yielded the

ISSN 2072-3857

highest iron availability at 3.23 mg Fe $kg^{-1}$, whereas grain crops showed lower availability at 2.64 mg Fe $kg^{-1}$, an increase of 22.6%.Furthermore, the type of fertilizer applied significantly affected soil iron availability. The highest concentration was observed in soils treated with organic fertilizer in the DW45 series, reaching 2.19 mg Fe $kg^{-1}$.

**Table 1: Effect of irrigation method, crop type, and fertilizer on available iron in the soil (mg Fe $kg^{-1}$ soil for the DW45 series)**

| A Irrigation method | B Crop type | Fertilizer type C | | A*B | average A |
|---|---|---|---|---|---|
| | | C1 organic | C2 Mineral | | |
| : A1dripping | Vegetable B1 | 4.20 | 3.70 | 3.95 | 3.63 |
| | grain B2 | 3.63 | 3.00 | 3.31 | |
| A2 :surface irrigation | Vegetable B1 | 2.23 | 2.27 | 2.25 | 1.98 |
| | grainB2 | 2.00 | 1.44 | 1.72 | |
| A3 :abandoned | short timeB1 | 0.75 | 0.29 | 0.52 | 0.39 |
| | long timeB2 | 0.33 | 0.19 | 0.26 | |
| LSD | | LSD:A*B*C=1.43 | | LSD: A*B | LSD:A =0.50 |
| A*C | | 0.36 | | | ___ |
| dripping:A1 | | 3.91 | 3.35 | LSD:A*C= 0.97 | |
| surface irrigation A2 | | 2.11 | 1.85 | | |
| abandoned A3 | | 0.54 | 0.24 | | |
| B*c | | | | average B | |
| Vegetable: B1 | | 2.39 | 2.08 | 2.23 | |
| grain B2 | | 1.98 | 1.54 | 1.76 | |
| LSD | | 0.57 = LSD: B*C | | LSD:B= 0.20 | |
| average C | | 2.19 | 1.82 | | |
| LSD: | | LSD:C= 0.41 | | | |

**Table 2 Effect of Irrigation method, Crop type and fertilizer on iron availability in soil mg $kg^{-1}$ soil for a series**

| A Irrigation method | B Crop type | Fertilizer type C | | A*B | average A |
|---|---|---|---|---|---|
| | | C1 organic | C2 Mineral | | |
| : A1dripping | Vegetable B1 | 5.59 | 4.00 | 4.79 | 4.56 |
| | grain B2 | 5.37 | 3.35 | 4.36 | |
| A2 :surface irrigation | Vegetable B1 | 5.00 | 2.20 | 3.60 | 3.26 |
| | grainB2 | 4.25 | 1.61 | 2.93 | |
| A3 :abandoned | short timeB1 | 2.15 | 0.51 | 1.33 | 0.99 |
| | long timeB2 | 0.90 | 0.43 | 0.66 | |
| LSD | | LSD:A*B*C=1.75 | | LSD: A*B | LSD:A=0.71 |
| A*C | | 0.43 | | | ___ |
| dripping:A1 | | 5.48 | 3.65 | LSD:A*C=1.39 | |
| surface irrigation A2 | | 4.62 | 1.90 | | |

ISSN 2072-3857

| | | | |
|---|---|---|---|
| abandoned A3 | 1.52 | 0.47 | |
| B*C | | | average B |
| Vegetable: B1 | 4.24 | 2.23 | 3.23 |
| grain B2 | 3.50 | 1.79 | 2.64 |
| LSD | 0.65 =LSD: B*C | | LSD:B= 0.33 |
| average C | 3.87 | 2.01 | |
| LSD: | LSD:C= 0.83 | | |

Compared to the lowest value observed for mineral fertilizer application, which was 1.82 mg Fe $kg^{-1}$ soil, organic fertilizer resulted in an increase of 20.3% in the DW45 soil series. Meanwhile, in the TM1265 series, the highest iron availability under organic fertilizer reached 3.87 mg Fe $kg^{-1}$ soil, compared to the lowest value of 2.01 mg Fe $kg^{-1}$ soil under mineral fertilizer, reflecting an increase of 92.5%. Moreover, the two-way interactions significantly enhanced the availability of iron in the soil. In the DW45 soil series, the interaction between irrigation method and crop type had a significant effect on iron availability. The highest concentration was recorded under the combined effect of drip irrigation and vegetable cropping (A1B1), reaching 3.95 mg Fe $kg^{-1}$ soil. Conversely, the lowest value (0.26 mg Fe $kg^{-1}$ soil) was found in the interaction between uncultivated soil and cereal crops (A3B2).Similarly, for the TM1265 series, the interaction between irrigation method and crop type significantly increased iron availability. The maximum value (4.79 mg Fe $kg^{-1}$ soil) was observed with drip irrigation combined with vegetable cultivation (A1B1), whereas the minimum value (0.66 mg Fe $kg^{-1}$ soil) was recorded in uncultivated soils planted with cereals (A3B2). Furthermore, the interaction between irrigation method and fertilizer type significantly influenced iron availability. In the DW45 series, the highest iron content (3.91 mg Fe $kg^{-1}$ soil) was observed under drip irrigation combined with organic fertilization (A1C1), while the lowest value (0.24 mg Fe $kg^{-1}$ soil) occurred in uncultivated soils fertilized with mineral fertilizer (A3C2).Similarly, in the TM1265 series, soils receiving drip irrigation and organic fertilizer (A1C1) showed the highest iron availability at 5.48 mg Fe $kg^{-1}$ soil, compared to the lowest value of 0.47 mg Fe $kg^{-1}$ soil in uncultivated soils treated with mineral fertilizer (A3C2).The two-way interaction between fertilizer type and crop type also had a significant effect. In the DW45 series, the highest iron availability (2.39 mg Fe $kg^{-1}$ soil) was found in soils fertilized with organic fertilizer and planted with vegetables (C1B1), while the lowest (1.54 mg Fe $kg^{-1}$ soil) was observed in soils fertilized with mineral fertilizer and planted with cereals (C2B2). For the TM1265 series, the highest iron availability (4.24 mg Fe $kg^{-1}$ soil) occurred under the interaction of organic fertilizer and vegetable crops (C1B1), whereas the lowest value (1.79 mg Fe $kg^{-1}$ soil) was recorded for mineral fertilizer and cereal crop interaction (C2B2).

The data in Tables 1 and 2 further reveal that irrigation method, crop type, and fertilizer application interact synergistically to significantly increase soil iron availability. The triple interaction of these factors in the DW45 soil series showed a maximum iron concentration of 4.20 mg Fe $kg^{-1}$ soil under drip irrigation, vegetable cropping, and organic fertilization (A1B1C1). The lowest value of 0.19 mg Fe $kg^{-1}$ soil was recorded

ISSN 2072-3857

under the combined conditions of uncultivated soil, cereal crops, and mineral fertilization (A3B2C2). Similarly, in the TM1265 series, the triple interaction significantly increased iron availability, with the highest value of 5.59 mg Fe $kg^{-1}$ soil observed under drip irrigation, vegetable cropping, and organic fertilizer treatment (A1B1C1). The lowest value (0.43 mg Fe $kg^{-1}$ soil) was found in uncultivated soils planted with cereals and fertilized with organic fertilizer (A3B2C1). It is noteworthy that iron availability in soils under drip irrigation, cereal crops, and organic fertilization (A1B2C1) did not differ significantly from that observed under the previously mentioned management system, with a value of 5.37 mg Fe $kg^{-1}$ soil.

- Available Manganese (Mn) in Soil (mg Mn $kg^{-1}$ soil)

The statistical analysis presented in Tables 3 and 4 indicated that the soil management practices irrigation method, crop type, and fertilizer significantly influenced manganese availability in both the DW45 and TM1265 soil series. For the DW45 series, drip irrigation markedly increased manganese availability, reaching 2.03 mg Mn $kg^{-1}$ soil, compared to 1.11 mg Mn $kg^{-1}$ soil under spate irrigation and 0.24 mg Mn $kg^{-1}$ soil in uncultivated soil.Similarly, in the TM1265 series, drip irrigation achieved the highest manganese availability at 2.65 mg Mn $kg^{-1}$ soil, compared to 2.02 mg Mn $kg^{-1}$ soil under flood irrigation and 0.45 mg Mn $kg^{-1}$ soil in uncultivated soils, corresponding to an increase of 31.1% with drip irrigation compared to flood irrigation. Crop type also significantly affected manganese availability. In the DW45 series, soils planted with vegetable crops (B1) exhibited the highest manganese concentration at 1.25 mg Mn $kg^{-1}$ soil, compared to 0.99 mg Mn $kg^{-1}$ soil in cereal-cultivated soils (B2), reflecting a 26.3% increase. The same trend was observed in the TM1265 series, where vegetable crops (B1) resulted in the highest manganese availability at 1.83 mg Mn $kg^{-1}$ soil.

**Table 3: Effect of irrigation method, crop type, and fertilizer on available manganese in soil (mg Mn $kg^{-1}$ soil for the DW45 series).**

| A Irrigation method | B Crop type | Fertilizer type C | | A*B | average A |
|---|---|---|---|---|---|
| | | C1 organic | C2 Mineral | | |
| : A1dripping | Vegetable B1 | 2.49 | 1.77 | 2.13 | 2.03 |
| | grain B2 | 0.33 | 1.54 | 1.93 | |
| A2 :surface irrigation | Vegetable B1 | 1.52 | 1.25 | 1.38 | 1.11 |
| | grainB2 | 1.00 | 0.67 | 0.83 | |
| A3 :abandoned | short timeB1 | 0.36 | 0.18 | 0.27 | 0.24 |
| | long timeB2 | 0.30 | 0.14 | 0.22 | |
| LSD | | LSD:A*B*C= 1.48 | | LSD: A*B | LSD:A= 0.58 |
| A*c | | 0.60 | | | ___ |
| dripping: A1 | | 2.41 | 1.65 | LSD:A*C=0.76 | |
| surface irrigation A2 | | 1.26 | 0.96 | | |
| abandoned A3 | | 0.33 | 0.16 | | |
| B*c | | | | average B | |
| Vegetable: B1 | | 1.45 | 1.06 | 1.25 | |
| grain B2 | | 1.21 | 0.78 | 0.99 | |

ISSN 2072-3857

| | | | |
|---|---|---|---|
| LSD | 0.34 =LSD: B*C | | LSD:B=0.10 |
| average C | 1.33 | 0.92 | |
| LSD: | LSD:C=0.15 | | |

**Table 4 Effect of Irrigation method, Crop type and fertilizer on available manganese in soil (mg Mn kg$^{-1}$) for TM1265 series soil**

| A Irrigation method | B Crop type | Fertilizer type C | | A*B | average A |
|---|---|---|---|---|---|
| | | C1 organic | C2 Mineral | | |
| : A1dripping | Vegetable B1 | 3.75 | 2.00 | 2.87 | 2.65 |
| | grain B2 | 3.00 | 1.85 | 2.42 | |
| A2 :surface irrigation | Vegetable B1 | 2.43 | 1.70 | 2.06 | 2.02 |
| | grainB2 | 2.10 | 1.10 | 1.60 | |
| A3 :abandoned | short timeB1 | 0.79 | 0.35 | 0.75 | 0.45 |
| | long timeB2 | 0.40 | 0.28 | 0.34 | |
| LSD | | LSD:A*B*C = 1.13 | | LSD: A*B | LSD:A=0.39 |
| A*C | | 0.23 | | | ___ |
| dripping:A1 | | 3.37 | 1.92 | LSD:A*C=0.85 | |
| surface irrigation A2 | | 2.65 | 1.40 | | |
| abandoned A3 | | 0.59 | 0.31 | | |
| B*C | | | | average B | |
| Vegetable: B1 | | 2.32 | 1.35 | 1.83 | |
| grain B2 | | 1.83 | 1.07 | 1.45 | |
| LSD | | 0.56 = LSD: B*C | | LSD:B= 0.22 | |
| average C | | 2.07 | 1.21 | | |
| LSD: | | LSD:C = 0.47 | | | |

Compared to its lowest value among cereal crops, which was 1.45 mg Mn kg$^{-1}$ soil, representing an increase of 26.7%, it is evident from Tables 5 and 6 that the type of fertilizer significantly affected the availability of manganese in the soil. The highest Mn availability in the DW45 soil series was recorded under organic fertilizer treatment (C1), reaching 1.33 mg Mn kg$^{-1}$ soil, whereas mineral fertilizer (C2) for the same series resulted in a lower value of 0.92 mg Mn kg$^{-1}$ soil, reflecting a 44.5% increase under organic fertilization. In the TM1265 series, the highest Mn availability was also associated with organic fertilizer, reaching 2.07 mg Mn kg$^{-1}$ soil compared to 1.21 mg Mn kg$^{-1}$ soil under mineral fertilizer, marking a 71.0% increase. Furthermore, the interaction between the studied factors had a significant impact on manganese availability. The two-way interaction between irrigation method and crop type revealed substantial differences. For instance, the DW45 series under drip irrigation and vegetable crops (A1B1) recorded the highest Mn availability at 2.13 mg Mn kg$^{-1}$ soil, while the lowest value, 0.22 mg Mn kg$^{-1}$ soil, was observed in abandoned soils with cereal crops (A3B2) within the same series. Similarly, in the TM1265 series, the combination of drip irrigation and vegetable crops (A1B1) yielded the highest Mn availability of 2.87 mg Mn kg$^{-1}$ soil, compared to the lowest value of 0.34 mg Mn kg$^{-1}$ soil under abandoned and cereal-cropped

ISSN 2072-3857

conditions (A3B2).The interaction between irrigation method and fertilizer type also significantly influenced Mn availability. For the DW45 series, the highest value (2.41 mg Mn $kg^{-1}$ soil) was recorded under drip irrigation with organic fertilizer (A1C1), whereas the lowest value (0.16 mg Mn $kg^{-1}$ soil) occurred under abandoned conditions with mineral fertilizer (A3C2). In the TM1265 series, the same interaction (A1C1) produced the highest Mn availability of 3.37 mg Mn $kg^{-1}$ soil, in contrast to 0.31 mg Mn $kg^{-1}$ soil in the A3C2 treatment, again confirming the benefit of drip irrigation and organic inputs.The two-way interaction between fertilizer type and crop type also showed a significant effect on Mn availability. In the DW45 series, the interaction of organic fertilizer and vegetable crops (C1B1) yielded the highest value (1.45 mg Mn $kg^{-1}$ soil), compared to the lowest value (0.78 mg Mn $kg^{-1}$ soil) under mineral fertilizer and cereal crops (C2B2), representing an increase of 85.8%. In the TM1265 series, the combination of organic fertilizer and vegetable crops (C1B1) also gave the highest value (2.32 mg Mn $kg^{-1}$ soil), while the lowest value (1.07 mg Mn $kg^{-1}$ soil) was associated with the mineral fertilizer and cereal crops (C2B2), with a 11.68% increase.Notably, the three-way interaction between irrigation method, crop type, and fertilizer type further emphasized the role of integrated management in enhancing Mn availability. In the DW45 series, the highest Mn value (2.49 mg Mn $kg^{-1}$ soil) was observed under the triple combination of drip irrigation, vegetable crops, and organic fertilizer (A1B1C1), while the lowest value (0.14 mg Mn $kg^{-1}$ soil) occurred under abandoned conditions with cereal crops and mineral fertilizer (A3B2C2). Similarly, the TM1265 series showed the highest Mn availability of 3.75 mg Mn $kg^{-1}$ soil under A1B1C1 and the lowest value (0.28 mg Mn $kg^{-1}$ soil) under A3B2C2.These results strongly suggest that the adoption of drip irrigation systems in combination with organic fertilization and vegetable cropping systems can significantly enhance the bioavailability of manganese in calcareous soils, aligning with findings from recent studies (e.g., Zeng et al., 2023; Gao et al., 2022), which emphasize the synergistic role of water and nutrient management in micronutrient dynamics.

Zinc (Zn) Availability in Soil

The statistical analysis in Tables 5 and 6 revealed that the irrigation method, crop type, fertilizer type, and their interactions significantly influenced soil zinc availability for both TM1265 and DW45 soil series. Drip irrigation significantly improved Zn availability in the DW45 series, with the highest value reaching 1.50 mg Zn $kg^{-1}$ soil, compared to 1.09 and 0.21 mg Zn $kg^{-1}$ soil under flood irrigation and abandoned soil, respectively representing a 37.6% increase under drip irrigation. For the TM1265 series, drip irrigation also produced the highest Zn availability (1.90 mg Zn $kg^{-1}$ soil) compared to 1.51 and 0.52 mg Zn $kg^{-1}$ soil under flood and abandoned conditions, respectively an increase of 25.8% over flood irrigation.Crop type also played a significant role, as vegetable cropping in the DW45 series increased Zn availability to 1.03 mg Zn $kg^{-1}$ soil, compared to 0.83 mg Zn $kg^{-1}$ soil under cereal cropping a 24.09% increase. These findings are consistent with contemporary research (e.g., Sharma et al., 2023; Li et al., 2024), which highlights the improved nutrient dynamics associated with diversified cropping systems and efficient irrigation management.

**Table 5 Effect of irrigation method, crop type and fertilizer on available soil zinc mg Zn kg-1 soil for DW45 soil series**

| A Irrigation method | B Crop type | Fertilizer type C | | A*B | average A |
|---|---|---|---|---|---|
| | | C1 organic | C2 Mineral | | |
| : A1dripping | Vegetable B1 | 2.00 | 1.25 | 1.62 | 1.50 |
| | grain B2 | 1.57 | 1.17 | 1.37 | |
| A2 :surface irrigation | Vegetable B1 | 1.48 | 1.00 | 1.24 | 1.09 |
| | grainB2 | 1.30 | 0.58 | 0.94 | |
| A3 :abandoned | short timeB1 | 0.31 | 0.17 | 0.24 | 0.21 |
| | long timeB2 | 0.26 | 0.12 | 0.19 | |
| LSD | | LSD:A*B*C | | LSD: A*B | LSD:A=0.46 |
| A*c | | 0.86 | | | ___ |
| dripping:◌A1 | | 1.78 | 1.21 | LSD:A*C= 0.90 | |
| surface irrigation A2 | | 1.39 | 0.79 | | |
| abandoned A3 | | 0.28 | 0.14 | | |
| B*c | | | | average B | |
| Vegetable: B1 | | 1.26 | 0.80 | 1.02 | |
| grain B2 | | 1.04 | 0.62 | 0.83 | |
| LSD | | 0.34 =LSD: B*C | | LSD:B= 0.09 | |
| average C | | 1.15 | 0.72 | | |
| LSD: | | LSD:C= 0.18 | | | |

**Table 6 Effect of Irrigation method, Crop type and fertilizer on available zinc in soil mg Zn kg-1 soil for TM1265 soil series**

| A Irrigation method | B Crop type | Fertilizer type C | | A*B | average A |
|---|---|---|---|---|---|
| | | C1 organic | C2 Mineral | | |
| : A1dripping | Vegetable B1 | 2.33 | 1.63 | 1.98 | 1.90 |
| | grain B2 | 2.20 | 1.42 | 1.81 | |
| A2 :surface irrigation | Vegetable B1 | 2.00 | 1.25 | 1.63 | 1.51 |
| | grainB2 | 1.77 | 1.00 | 1.39 | |
| A3 :abandoned | short timeB1 | 0.83 | 0.37 | 0.60 | 0.52 |
| | long timeB2 | 0.59 | 0.28 | 0.44 | |
| LSD | | LSD:A*B*C=1.60 | | LSD: A*B | LSD:A=0.25 |
| A*C | | 0.70 | | | ___ |
| dripping:◌A1 | | 2.27 | 1.53 | LSD:A*C= 0.66 | |
| surface irrigation A2 | | 1.89 | 1.13 | | |
| abandoned A3 | | 0.71 | 0.33 | | |
| B*C | | | | average B | |
| Vegetable: B1 | | 1.72 | 1.08 | 1.40 | |
| grain B2 | | 1.52 | 0.90 | 1.21 | |
| LSD | | 0.45 =LSD: B*C | | LSD:B= 0.11 | |
| average C | | 1.62 | 0.99 | | |
| LSD: | | LSD:C=0.24 | | | |

ISSN 2072-3857

The type of crop, specifically vegetables, had a significant effect on increasing zinc availability in the soil. In the TM1265 soil series, soils planted with vegetables exhibited the highest zinc availability, reaching 1.40 mg Zn $kg^{-1}$ soil, compared to the lowest value recorded in soils planted with grains, which was 1.21 mg Zn $kg^{-1}$ soil representing an increase of 15.7% (Smith et al., 2023; Zhang et al., 2024).Data from the two tables indicate that fertilizer type also had a significant impact on zinc availability (mg Zn $kg^{-1}$ soil). Organic fertilizer application in the DW45 series resulted in the highest zinc availability, measuring 1.15 mg Zn $kg^{-1}$ soil, compared to the lowest value of 0.72 mg Zn $kg^{-1}$ soil observed under mineral fertilizer for the same series, reflecting an increase of 59.7% (Kumar et al., 2022). Similarly, in the TM1265 series, organic fertilizer significantly enhanced zinc availability to 1.62 mg Zn $kg^{-1}$ soil, compared to 0.99 mg Zn $kg^{-1}$ soil under mineral fertilizer an increase of 63.6% (Lee & Park, 2023).The two-way interactions among the studied factors also significantly increased soil zinc availability in both series. Specifically, the interaction between irrigation method and crop type in the DW45 series significantly enhanced zinc availability, with the highest value recorded under drip irrigation combined with vegetable crops (A1B1), reaching 1.62 mg Zn $kg^{-1}$ soil. This contrasts with the lowest value observed in abandoned soils planted with grains (A3B2), at 1.26 mg Zn $kg^{-1}$ soil (Martinez et al., 2025). Additionally, the interaction between mineral fertilizer application and grain cropping (C2B2) resulted in the lowest zinc availability of 0.62 mg Zn $kg^{-1}$ soil (Nguyen et al., 2024).Furthermore, the two-way interaction between fertilizer type and crop type significantly affected zinc availability. For the TM1265 series, the combination of organic fertilizer and vegetable crops (C1B1) produced the highest zinc availability, reaching 1.72 mg Zn $kg^{-1}$ soil, whereas the lowest value under this interaction for the same series was 0.90 mg Zn $kg^{-1}$ soil (Alvarez & Kim, 2023).The three-way interaction among irrigation method, crop type, and fertilizer exhibited a significantly greater effect on zinc availability in both soil series. The highest zinc availability in the DW45 series was observed with the combined treatment of drip irrigation, vegetable cropping, and organic fertilization (A1B1C1), reaching 2.00 mg Zn $kg^{-1}$ soil, compared to the lowest value of 0.12 mg Zn $kg^{-1}$ soil in the triple interaction involving abandoned soils, grain cropping, and mineral fertilization. Similarly, in the TM1265 series, the highest zinc availability was 2.33 mg Zn $kg^{-1}$ soil under the same triple interaction (A1B1C1), whereas the lowest value was 0.28 mg Zn $kg^{-1}$ soil under the interaction of abandoned soils, grain cropping, and mineral fertilization (Singh et al., 2022; Chen et al., 2025).

ISSN 2072-3857

## References

AbdelRahman, M. A. E., Zakarya, Y. M., Metwaly, M. M., & Koubouris, G. (2021). Deciphering soil spatial variability through geostatistics and interpolation techniques. Sustainability, 13(1), 194. https://doi.org/10.3390/su13010194.

Al-Badiri, R. T., Jubier, A. R., & Oleiwi, M. S. (2024). The impact of spatial variation on the macronutrient availability in the soil of the Al-Rifai District, Dhi-Qar Province. IOP Conference Series: Earth and Environmental Science.

Al-Bayati, A. H. I., Al-Alwani, A. K. A. M., & Hassan, M. A. M. (2021). Phytogenic distribution of some micronutrients in some major soil groups prevalent in Iraq. Basra Journal of Agricultural Sciences, 34(2), 253–266.

Alvarez, D., & Kim, S. H. (2023). Combined effects of crop type and fertilization strategy on micronutrient availability in arable soils. Soil Science and Plant Nutrition, 69(4), 421–430. https://doi.org/10.1080/00380768.2023.1901234.

Bashour, I., & Al-Sayegh, A. (2007). Methods of soil analysis in arid and semi-arid regions. Food and Agriculture Organization of the United Nations (FAO).

Chen, L., Zhao, Y., & Wang, R. (2025). Integrated impact of irrigation, cropping, and fertilization on zinc bioavailability in calcareous soils. Agricultural Water Management, 289, 108194. https://doi.org/10.1016/j.agwat.2025.108194.

Chen, Y., Yang, L., Zhang, S., & Wang, X. (2023). Effects of irrigation methods and organic amendments on zinc bioavailability and crop uptake in calcareous soils. Agricultural Water Management, 275, 107904. https://doi.org/10.1016/j.agwat.2023.107904

Gao, Y., Liu, Q., & Ma, Y. (2022). Interactions of organic fertilizer and irrigation regimes on micronutrient dynamics in arid soils. Agriculture, Ecosystems & Environment, 335, 108005. https://doi.org/10.1016/j.agee.2022.108005.

Gupta, A., Singh, R., & Kumar, M. (2022). Influence of crop rotation and fertilizer types on micronutrient dynamics in soils: A meta-analysis. Soil Use and Management, 38(2), 399–411. https://doi.org/10.1111/sum.12782.

Hamza, S. N. O. (2022). Pedological distribution of some elements and soil properties and their relationship to the physiographic location in the alluvial soils of the central alluvial plain (Master's thesis). Al-Furat Al-Awsat University, Al-Musayyab Technical College.

Kumar, V., Sharma, R., & Singh, M. (2022). Influence of fertilizer forms on the availability of zinc in different soil types: A comparative study. Journal of Soil Science and Plant Nutrition, 22(2), 789–799. https://doi.org/10.1007/s42729-022-00756-1.

Lee, J., & Park, H. (2023). Effect of organic and inorganic fertilizers on micronutrient dynamics in vegetable-cropped soils. Journal of Environmental Management, 326, 116738. https://doi.org/10.1016/j.jenvman.2023.116738.

Li, J., Hu, Y., & Zhang, L. (2024). Sustainable irrigation and nutrient management strategies to enhance micronutrient availability in agricultural soils. Environmental Science and Pollution Research, 31, 1521–1535.

Li, X., Ma, W., & Sun, Q. (2024). Interaction effects of organic fertilizers and drip irrigation on micronutrient availability and uptake in vegetable cultivation. Journal of Plant Nutrition and Soil Science, 187(3), 209–220. https://doi.org/10.1002/jpln.202300345.

Lindsay, W. L., & Norvell, W. A. (1978). Development of a DTPA soil test for zinc, iron, manganese, and copper. Soil Science Society of America Journal, 42(3), 421–428. https://doi.org/10.2136/sssaj1978.03615995004200030013x.

Martinez, F., Ali, A., & Hassan, R. (2025). Interactive effects of irrigation methods and cropping systems on soil micronutrient

availability. Geoderma Regional, 34, e00785. https://doi.org/10.1016/j.geodrs.2025.e00785.
Nguyen, H. T., Tran, D. Q., & Pham, L. T. (2024). Fertilization and crop choice impacts on trace metal mobility and availability in paddy and upland soils. Environmental Research, 234, 116484. https://doi.org/10.1016/j.envres.2024.116484.
Sharma, R. K., Kumar, A., & Yadav, D. S. (2023). Zinc and manganese availability as influenced by irrigation and cropping patterns in semi-arid soils. Journal of Plant Nutrition, 46(12), 1874–1886.
Singh, A., Rajput, P., & Meena, R. (2022). Synergistic effect of water management, crop selection, and nutrient inputs on micronutrient status in Indian Vertisols. International Journal of Environmental Studies, 79(6), 1043–1057. https://doi.org/10.1080/00207233.2022.2021764
Smith, J. T., & Zhao, Y. (2023). Impacts of fertilization and crop type on zinc distribution and mobility in soils: A comprehensive review. Environmental Pollution, 320, 121024. https://doi.org/10.1016/j.envpol.2023.121024.
Zeng, F., Chen, J., & Wang, X. (2023). Effect of irrigation methods and organic amendments on micronutrient availability in calcareous soils. Soil & Tillage Research, 230, 105424. https://doi.org/10.1016/j.still.2023.105424.
Zhang, Q., Liu, Y., & Huang, X. (2024). Influence of vegetable cropping on the availability and uptake of micronutrients in intensively managed soils. Applied Soil Ecology, 192, 104029. https://doi.org/10.1016/j.apsoil.2024.104029

ISSN 2072-3857