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RESEARCH ARTICLE
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Evaluation of Active CaCO3 Effect on Zn Availability in Soil and Plant at Erbil State-Iraq, Kurdistan Region

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ABSTRACT

The study was conducted during May 2023 in some locations in the Erbil plain and Bardarash sub-district of the Kurdistan Region of Iraq to examine the relationships between zinc (Zn) availability and several key soil parameters - total CaCO3, active CaCO3, phosphorus, and bicarbonate ions (HCO_3^-) - in calcareous soils. Zinc is an essential micronutrient required for optimal plant growth and physiological functioning, playing vital roles in enzyme activation, protein synthesis, regulation of growth hormones, and numerous metabolic pathways. However, Zn availability in soil is highly variable and strongly affected by multiple interacting chemical and physical properties, particularly in calcareous soils, where high carbonate content often limits micronutrient mobility and uptake. Thirteen paired soil and plant samples were collected to assess both soil Zn concentrations and corresponding plant uptake. The results revealed considerable spatial variation in soil Zn levels. Sample S6 contained the lowest Zn concentration (0.13 $mg.g^{-1}$), while sample S7 exhibited the highest value (0.65 $mg.g^{-1}$). Notably, S7 also recorded the lowest total $CaCO_3$ content (10.9%) and active $CaCO_3$ content (5.0%), whereas S6 recorded among the highest total $CaCO_3$ content (35.8%), consistent with an inverse relationship between carbonate content and Zn availability. Statistical analyses identified significant negative correlations between Zn concentration and active $CaCO_3$ ($r = –0.52$ in soil, $r = –0.578$ in plant, $p < 0.05$) and total $CaCO_3$ ($r = –0.565$ in soil, $r = –0.613$ in plant, $p < 0.05$) across both soil and plant datasets, suggesting that elevated $CaCO_3$ levels markedly reduce Zn bioavailability, likely by enhancing Zn adsorption or precipitation within the soil matrix. Additionally, a highly significant positive correlation ($r = 0.952$, $p < 0.01$) was found between soil Zn and plant Zn content, indicating that plant uptake is closely governed by the soil's Zn status. Overall, these findings underscore the complex interactions among soil chemistry, micronutrient behavior, and plant nutrition, and highlight $CaCO_3$ fractions as a critical factor controlling Zn availability, offering valuable insights for managing Zn nutrition and improving crop productivity in calcareous agricultural systems.

***Keywords*:** Active CaCO3; Zinc; Wheat; Calcareous Soil, soil-plant relationship.

INTRODUCTION

Lime is a pedogenic material in the semi-arid and arid soil. Illuviation of $CaCO_3$ creates the calcitic horizon in the subsoil horizon **[1, 2]**.Calcareous soils cover more than 30% of the surface of the earth, and the $CaCO_3$ content in the soils can range from a few percent to 90% **[3]**. The natural development of calcareous soils happens in semi-arid and arid areas because of low leaching with the soil having a higher pH, plants are more able to absorb Zn. There has been significant work to assess the agricultural value of Erbil to support the country's growing population. Low Zn availability vegetation's would be a problem more severe than their deficiencies in high pH and $CaCO_3$-dominated calcareous soils **[4].**

This occurs most commonly in arid regions with low rainfall. $CaCO_3$ has been identified in horizons in other soils after leaching of the overlying layers. Lower concentrations of $CaCO_3$ are brought to the surface after extended soil cultivation **[5]**. High $CaCO_3$ content could affect soil properties that play a key role in the development of plants, including soil water behavior and the availability of plant nutrients, like Zn, Ca, and P **[6].**

Zn is an important plant nutrient, and its deficiency has been identified as the most widespread in agricultural soils under wheat, with a reduction in crop quantity and nutritional value **[7, 8]**. $CaCO_3$ affects the bioavailability of Zn in soils **[9].** The primary processes of Zn acquisition in soils include P interaction, high pH precipitation, and inner sphere

complexation that can reduce the availability of Zn for plant uptake **[10].**
Zn deficiency was recorded in most regions of Erbil State in the Kurdistan Region. Electrical conductivity had a significant effect on the availability of Zn in Erbil soils **[4]**. Whereas Zn and P availability were adversely affected by total and $CaCO_3$ **[11, 7, 2]**. As there are few or no data on active $CaCO_3$ influences on zinc availability in soil and plants in the Kurdistan region, the objective of this study was to investigate active $CaCO_3$ influences on Zn availability in calcareous soil and plants of selected locations in Erbil plain and Bardarash Sub District, Kurdistan Region.

Materials And Method

This study was conducted from May 2023 at the Department of Soil and Water, College of Agricultural Engineering Sciences, University of Salahaddin, Kurdistan Region, Erbil, Iraq. Thirteen fertile soil sites of agricultural importance were carefully selected within the Bardarash sub-district and the Erbil Plain in the Kurdistan Region. The sampling locations included Baghamra, Qaranaz, Nzrawa, Fiqa, Abu Maria, Pirdawd, Dugrdkan, Amian, Bardarash 1, Bardarash 2, Daratoo, Sharaih, and Ayn Al-Hisan, as listed in Table 1. The geographical coordinates of these sites are illustrated in Figure 1. Soil samples were collected from wheat fields at a depth of 0–30 cm in May 2023 from the selected. The samples were labeled sequentially from S1 to S13. Concurrently, wheat plant samples were collected from the same sites for subsequent analysis.

Table (1). Coordinates of Soil and Plant Sampling Sites in Erbil Region.

Soil No.	Location	Latitude	Longitude
S1	Baghamra	36.124168	44.09367
S2	Qaranaz	36.56123	43.642868
S3	Nzrawa	36.560442	43.61753
S4	Fiqa	36.46781	42.546734
S5	Abu Maria	36.425821	42.597009
S6	Pirdawd	36.023607	43.929388
S7	Dugrdkan	36.02326	43.936772
S8	Amian	36.534156	43.597819
S9	Big Bardarash	36.499011	43.583225
S10	Small Bardarash	36.506229	43.572432
S11	Daratoo	36.126607	44.065067
S12	Sharaih	36.083646	43.570798
S13	Ayn al Hisan	36.31316	42.229761

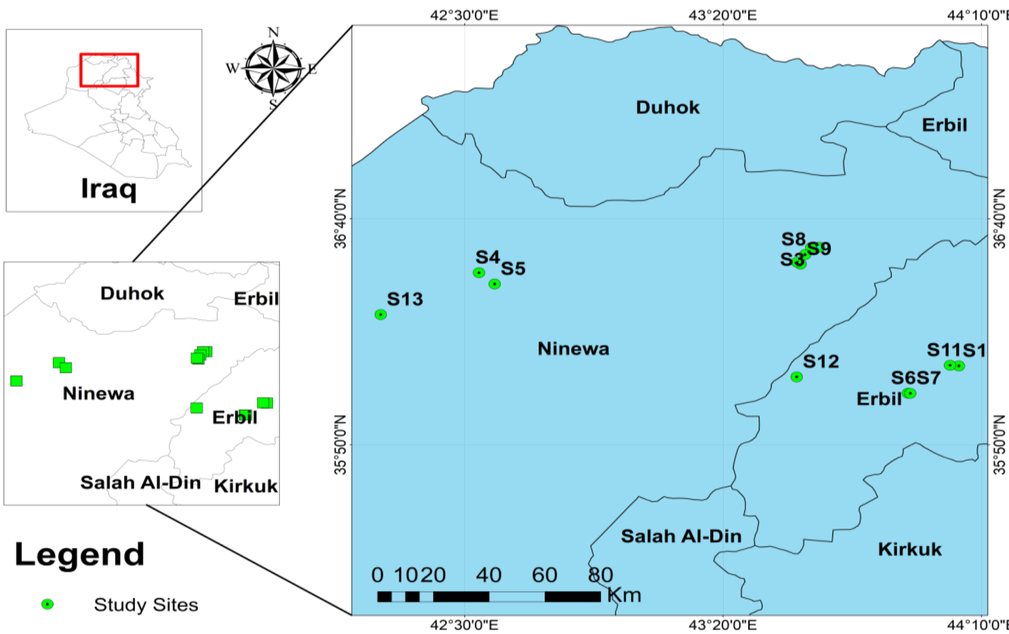

Figure 1**:** The map and coordinates of the Sample study sites.

Statistical Analysis

Statistical analysis was also conducted with the IBM SPSS version 23 computer software. Correlation analyses were specifically conducted for calcium carbonate ($CaCO_3$), zinc, and phosphorus for plant and soil samples. Significance was set at $P \leq 0.05$ to determine the statistical significance of any observed association.

Results

Table 1 presents the concentrations of Zn, P, and $CaCO_3$ in soil and plant samples across sampling locations in the Erbil Plain and Bardarash sub-district. Analysis of the thirteen soil samples (S1–S13) revealed that site S7 (Dugrdkan) contained the highest zinc concentrations in both soil (0.65 mg.g¹) and plant (23.30 mg.g¹) tissue. In contrast, site S6 (Pirdawd) - characterized by active $CaCO_3$ (14.9%), total $CaCO_3$ (35.8%), and HCO_3^- (3 meq L^{-1}) - showed the lowest zinc concentrations in both soil (0.13 mg.g^{-1}) and plant (10.10 mg.g^{-1}) samples. Soil phosphorus showed a moderate, statistically non-significant negative correlation with Zn concentration in both soil and plant samples ($r = –0.50$ and $r = –0.53$, respectively; critical $r = 0.553$ at $p \leq 0.05$, $df = 11$), while plant phosphorus showed weak, non-significant negative correlations with Zn in soil ($r = –0.05$) and Zn in plant ($r = –0.11$), as shown in Table 2.

Table (2): Zinc, phosphorus, and calcium carbonate concentrations in soils and plants by location in Erbil.

Locations	Zn in Soil	Zn in Plant	P in Soil	P in Plant	Active $CaCO_3$	Total $CaCO_3$	HCO_3
	mg g^{-1}	mg g^{-1}	mg g^{-1}	mg g^{-1}	%	%	meq L^{-1}
Baghamra	0.17	10.60	4.60	14.34	14.10	35.70	2.40
Qaranaz	0.18	11.60	4.30	12.23	13.40	33.60	2.20
Nzrawa	0.21	14.50	4.20	15.65	13.70	30.10	2.40
Fiqa	0.23	14.10	4.76	12.39	13.50	31.70	2.20
Abu Maria	0.41	15.20	3.78	16.30	12.70	25.50	2.90
Pirdawd	0.13	10.10	4.76	19.56	14.90	35.80	3.00
Dugrdkan	0.65	23.30	3.50	13.69	5.00	10.90	2.00
Amian	0.23	13.80	2.94	21.19	13.30	27.70	2.40
Bardarash 1	0.58	21.60	2.94	19.56	14.10	29.90	2.40
Bardarash 2	0.35	16.10	3.64	13.69	6.10	11.20	2.40
Daratoo	0.44	17.30	5.04	13.69	7.10	11.70	2.40
Sharaih	0.22	14.20	4.34	13.04	6.20	10.80	2.00
Ayn al Hisan	0.48	21.70	3.78	12.71	6.90	14.20	2.80

Table (2): Output of the Correlation Analysis

Correlation							
	Zn in Soil (mg g^{-1})	Zn in Plant (mg g^{-1})	P in Soil (%)	P in Plant (%)	Active $CaCO_3$ (%)	Total $CaCO_3$ (%)	HCO_3 (meq L^{-1})
Zn in Soil (mg g^{-1})	1						
Zn in Plant (mg g^{-1})	.952**	1					
P in Soil (%)	-0.50	-0.53	1				
P in Plant (%)	-0.05	-0.11	-0.48	1			
Active $CaCO_3$ (%)	-0.52	-.578*	0.06	0.53	1		
Total $CaCO_3$ (%)	-.565*	-.613*	0.14	0.41	.976**	1	
HCO_3 (meq L^{-1})	-0.09	-0.16	0.04	0.42	0.34	0.29	1

Correlation is significant at the 0.01 level (2-tailed) **.

Correlation is significant at the 0.05 level (2-tailed) *.

Table 2 presents the SPSS correlation output, revealing several important relationships among the soil and plant variables. The strong positive correlation between soil and plant Zn concentration ($r = 0.952$, $p < 0.01$) highlights the important role of soil Zn availability in determining plant Zn content. In contrast, plant Zn concentration was negatively correlated with active $CaCO_3$ ($r = –0.578$, $p \leq 0.05$) and total $CaCO_3$ ($r = –0.613$, $p \leq 0.05$), suggesting that increasing carbonate content reduces Zn availability and plant uptake. Additionally, active and total $CaCO_3$ were very strongly and positively correlated with each other ($r = 0.976$, $p < 0.01$), reflecting their shared origin as two forms of calcium carbonate in soil. Bicarbonate (HCO_3^-) showed weak and statistically non-significant correlations with all other variables in this study. By contrast, Zn concentration in both soil and plant showed significant correlations with several key parameters, particularly $CaCO_3$ fractions, reinforcing the conclusion that soil Zn availability is a key determinant of Zn content in plants **[20, 21].**

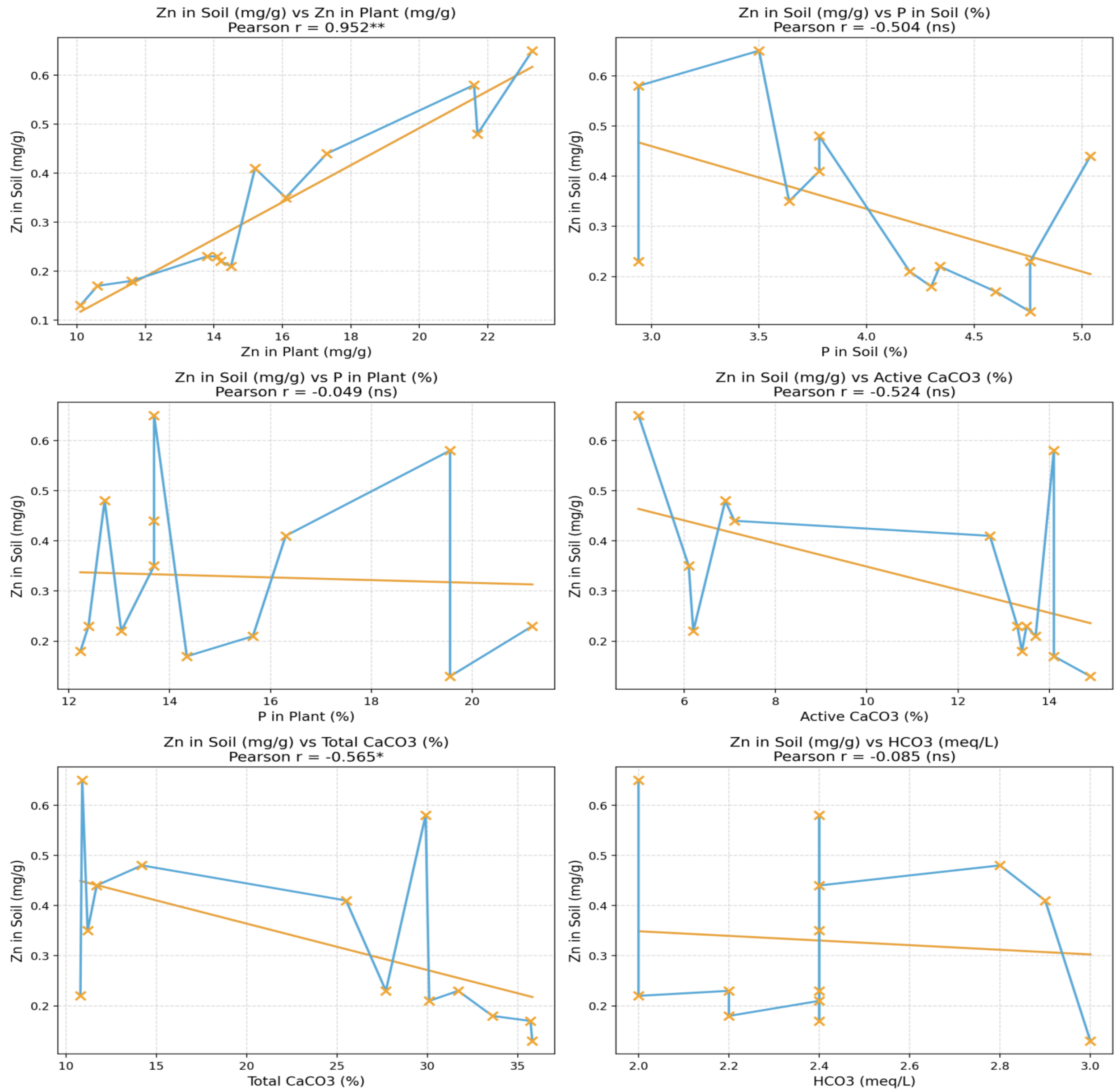

Figure 2: Interaction of Soil Zinc Levels with Various soil and Plant Factors.

Figure 2 diagrams involved relationships in zinc availability in soils and plants in the studied calcareous regions. Soil zinc concentration and plant zinc concentration show extremely strong positive relationships and confirm that soil zinc is the primary determinant of plant micronutrient status. The relationship becomes complicated due to the antagonistic effects of certain chemical constituents of the soil. Active and total calcium carbonate fractions also exhibit extremely strong inverse correlations with soil zinc concentration, which suggest that carbonate-dominated zinc-containing soils geologically depress zinc concentration in soil solutions. In the same way, high soil P concentration is associated with low soil zinc concentration, representing the antagonistic relations between these nutrients. As opposed to that, plant P and soil bicarbonate have low correlations with soil zinc, and this shows that these do not depend on zinc in this system. These in aggregate govern that it is essential for the effective management of zinc in calcareous soils to know the absolute content of zinc and the governing behavior chemical environment. Limitation of carbonate and phosphorus on zinc availability is similar to the fundamental principles of nutrient chemistry of alkaline soils concerning aggregation and competitive micronutrient sorption **[23, 24, 25, and 26]**. The idea forms the foundation of developing sufficient measures for soil amendments that are aimed at improving the zinc nutrition.

Discussion

The higher level of zinc at site S7 (Dugrdkan) may be explained by the fact that it had the lowest active $CaCO_3$ (5.0%) and total $CaCO_3$ (10.9%) content, together with a low HCO_3^-concentration (2 meq L^{-1}), creating more favorable conditions for zinc bioavailability. This observation is consistent with the tendency for higher $CaCO_3$ concentrations in soil to reduce the amount of zinc available for plant growth. The higher concentration of carbonates and bicarbonates in calcareous soils tends to reduce zinc concentration in soil through precipitation and adsorption **[17, 18, 19].** Negative correlations were observed between zinc concentration and both active $CaCO_3$ (r = –0.52, soil; r = –0.578, plant) and total $CaCO_3$ (r = –0.565, soil; r = –0.613, plant), confirming that $CaCO_3$ fractions play the dominant role in restricting zinc uptake into plants **[20, 21]**. By contrast, the correlation between HCO_3^- and zinc concentration was weak and statistically non-significant in both soil (r = –0.09) and plant (r = –0.16) tissue, indicating that bicarbonate exerts only a minor, indirect influence on zinc availability compared with $CaCO_3$. Site S6 (Pirdawd) supports this interpretation, as its elevated calcium carbonate concentration corresponds with the lowest measured soil zinc content, reflecting reduced zinc availability and uptake by plant roots. These findings are in accordance with **[22]**. Zinc deficiency is widespread in calcareous soils. The weak relationship observed between phosphorus and zinc (r = –0.50, soil; r = –0.11, plant) further suggests that phosphorus had a limited and statistically non-significant influence on zinc availability and uptake in this dataset.

Conclusion

The chemical composition of Erbil soils plays a critical role in regulating micronutrient balance in plants. A strong, highly significant positive correlation was observed between soil and plant zinc concentrations (r = 0.952, $p < 0.01$), confirming that plant zinc uptake is closely governed by soil zinc status. Zinc availability was significantly and negatively affected by both active $CaCO_3$ (r = –0.578, $p < 0.05$) and total $CaCO_3$ (r = –0.613, $p < 0.05$), identifying carbonate fractions as the principal soil constituents limiting zinc bioavailability in the calcareous soils of the Erbil region. In contrast, phosphorus and bicarbonate (HCO_3^-) exhibited only weak and statistically non-significant inverse relationships with zinc in both soil and plant systems, indicating that these parameters play a comparatively minor role in controlling zinc availability under the conditions of this study.

Supplementary Materials:

No Supplementary Materials.

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Institutional Review Board Statement:

The study was conducted following the protocol authorized by the Head of the Ethics Committee, University of Salahaddin, Erbil, Iraq Republic.

Informed Consent Statement:

Not applicable.

Data Availability Statement:

Data available upon request.

Conflicts of Interest:

The authors declare no conflict of interest.

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Conflict Of Interest

The authors declare no conflicts of interest associated with this manuscript.

References

[1]. Umer, M. I., Rajab, S. M., & Ismail, H. K. (2020). Effect of CaCO3 form on soil inherent quality properties of calcareous soils. In Materials Science Forum (Vol. 1002, pp. 459-467). Trans Tech Publications Ltd.

[2]. Azeez, H. H., Mansour, H. H., & Ahmad, S. T. (2020). Effect of Using Chemical Fertilizers on Natural Radioactivity Levels in Agricultural Soil in the Iraqi Kurdistan Region. Polish Journal of Environmental

Studies, 29(2).
[3]. Jafari, S. (2021). The study of particle size distribution of calcium carbonate and its effects on some soil properties in khuzestan province. Iran Agricultural Research, 36(2), 71-80.
[4]. Sheikh-Abdullah, S. M. (2019). Availability of Fe, Zn, Cu, and Mn in Soils of Sulaimani Governorate, Kurdistan Region, Iraq. Soil Science, 184(3), 87-94.
[5]. Mitran, T., Sreenivas, K., Janakirama Suresh, K. G., Sujatha, G., & Ravisankar, T. (2021). Spatial prediction of calcium carbonate and clay content in soils using airborne hyperspectral data. Journal of the Indian Society of Remote Sensing, 49(11), 2611-2622.
[6]. Ramadhan, P. I., & Mehmedany, L. A. M. (2020). Zinc Adsorption in Different Calcareous Soils. Journal of Duhok University, 23(2), 118-130.
[7]. Sacristán, D., González–Guzmán, A., Barrón, V., Torrent, J., & Del Campillo, M. C. (2019). Phosphorus-induced zinc deficiency in wheat pot-grown on noncalcareous and calcareous soils of different properties. Archives of Agronomy and Soil Science, 65(2), 208-223.
[8]. Thiébaut, N., & Hanikenne, M. (2022). Zinc deficiency responses: bridging the gap between Arabidopsis and dicotyledonous crops. Journal of Experimental Botany, 73(6), 1699-1716.
[9]. Ilyas, F., Ali, M. A., Modhish, A., Ahmed, N., Hussain, S., Bilal, M., ... & Solaiman, Z. (2022). Synchronisation of zinc application rates with arbuscular mycorrhizal fungi and phosphorus to maximise wheat growth and yield in zinc-deficient soil. Crop and Pasture Science.
[10]. Liao, F., Lilay, G. H., Castro, P. H., Azevedo, H., & Assunção, A. G. (2022). Regulation of the Zinc Deficiency Response in the Legume Model Medicago truncatula. Frontiers in Plant Science, 13.
[11]. Tamir, G., Shenker, M., Heller, H., Bloom, P. R., Fine, P., & Bar-Tal, A. (2012). Dissolution and recrystallization processes of active calcium carbonate in soil developed on tufa. Soil Science Society of America Journal, 76(5), 1606–1613.
[12]. Cakmak, I., Kalayci, M., & Kaya, Y. (2020). Influence of soil carbonate and bicarbonate on zinc uptake by cereals. Communications in Soil Science and Plant Analysis, 51(16), 2089–2102. https://doi.org/10.1080/00103624.2020.1820030
[13]. Pamuk, S., Kaya, C., & Sade, B. (2024). Zinc availability in calcareous soils and its relation to soil carbonate fractions. Environmental Geochemistry and Health, 46(2), 511–525. https://doi.org/10.1007/s10653-025-02544-3
[14]. Rengel, Z. (2015). Availability of zinc in soils and its uptake by plants. Plants, 4(4), 587–595. https://doi.org/10.3390/plants4040587
[15]. Alloway, B. J. (2009). Soil factors are associated with zinc deficiency in crops and humans. Environmental Geochemistry and Health, 31(5), 537–548. https://doi.org/10.1007/s10653-009-9255-4
[16]. Lajayer, B., Vaněk, A., & Astori, M. (2024). Zinc dynamics in soils and its bioavailability to plants: A review of controlling factors with a focus on calcareous soils. International Journal of Environmental Science and Technology, 21(10), 6789–6804. https://doi.org/10.1007/s42729-024-01908-5
[17]. González-Caballo, P., Barrón, V., Torrent, J., del Campillo, M. C., & Sánchez-Rodríguez, A. R. (2022). Wheat and Maize Grown on Two Contrasting Zinc-deficient Calcareous Soils Respond Differently to Soil and Foliar Application of Zinc. Journal of Soil Science and Plant Nutrition, 1–14.
[18]. Aljumaily, M. M., Al-Lami, A. A., & Al-Taai, R. A. (2022). The effect of calcium carbonate content on the zinc quantity in some Iraqi calcareous soils. Revista Facultad Nacional de Agronomía Medellín, 75(1), 9913–9921. https://doi.org/10.15446/rfnam.v75n1.95768.
[19]. Jalal, A., Rehman, A., Ahmad, W., Shahzad, A. N., Abbas, T., Mehmood, F., … Bashir, K. (2024). Zinc fertilization strategies for sustainable crop production: Mechanisms, benefits, and challenges. Plants, 13(5), 571. https://doi.org/10.3390/plants13050571.
[20]. Nadeem, F., Farooq, M., Hussain, M., & Zhang, X. (2024). Phosphorus and zinc nutrition constraints in crop plants: Interactions, mechanisms, and management strategies. Advances in Agronomy, 180, 129–178. https://doi.org/10.1016/bs.agron.2023.12.004.
[21]. Taşpınar, B., Çimrin, K. M., & Yilmaz, K. (2025). Zinc bioavailability in semiarid agricultural regions: A soil property–based assessment. Environmental Science and Technology, 21(10), 6789–6804. https://doi.org/10.1007/s42729-024-01908-5.

تقييم تأثير كربونات الكالسيوم النشطة على توافر الزنك في التربة والنبات

اسماعيل طاهر احمد[1] هيوا طاهر مصطفى[1] خوناو عبدالله رحمان[1]

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الخلاصة

أُجريت الدراسة خلال شهر مايو/أيار 2023 في مواقع متفرقة من سهل أربيل وناحية باردارش في إقليم كردستان العراق، لدراسة العلاقة بين توافر الزنك (***Zn***) وعدد من المؤشرات الرئيسية للتربة، وهي: إجمالي كربونات الكالسيوم ($CaCO_3$)، وكربونات الكالسيوم النشطة، والفوسفور، وأيونات البيكربونات ($HCO3^-$)، في التربة الكلسية. يُعدّ الزنك عنصرًا غذائيًا دقيقًا أساسيًا لنمو النبات الأمثل ووظائفه الفسيولوجية، إذ يلعب أدوارًا حيوية في تنشيط الإنزيمات، وتخليق البروتين، وتنظيم هرمونات النمو، والعديد من المسارات الأيضية. مع ذلك، يتفاوت توافر الزنك في التربة بشكل كبير ويتأثر بشدة بخصائص كيميائية وفيزيائية متعددة ومتفاعلة، لا سيما في التربة الكلسية، حيث غالبًا ما يحدّ المحتوى العالي من الكربونات من حركة العناصر الغذائية الدقيقة وامتصاصها. جُمعت ثلاثة عشر عينة مزدوجة من التربة والنباتات لتقييم تركيزات الزنك في التربة وامتصاصه من قِبل النبات. وكشفت النتائج عن تباين مكاني ملحوظ في مستويات الزنك في التربة. احتوت العينة ***S6*** على أدنى تركيز للزنك (0.13 ملغم/غرام)، بينما أظهرت العينة ***S7*** أعلى قيمة (0.65 ملغم/غرام). والجدير بالذكر أن العينة ***S7*** سجلت أيضًا أدنى محتوى إجمالي لكربونات الكالسيوم (10.9%) ومحتوى كربونات الكالسيوم النشط (5.0%)، في حين سجلت العينة ***S6*** من بين أعلى محتوى إجمالي لكربونات الكالسيوم (35.8%)، وهو ما يتوافق مع العلاقة العكسية بين محتوى الكربونات وتوافر الزنك. أظهرت التحليلات الإحصائية وجود ارتباطات سلبية معنوية بين تركيز الزنك وكربونات الكالسيوم النشطة ($r = -0.52$ في التربة، $r = -0.578$ في النبات، $p < 0.05$) وكربونات الكالسيوم الكلية ($r = -0.565$ في التربة، $r = -0.613$ في النبات، $p < 0.05$) في كلتا مجموعتي بيانات التربة والنبات، مما يشير إلى أن ارتفاع مستويات كربونات الكالسيوم يقلل بشكل ملحوظ من التوافر الحيوي للزنك، على الأرجح عن طريق تعزيز امتصاص الزنك أو ترسيبه داخل مصفوفة التربة. بالإضافة إلى ذلك، وُجد ارتباط إيجابي معنوي للغاية ($r = 0.952$، $p < 0.01$) بين محتوى الزنك في التربة والنبات، مما يدل على أن امتصاص النبات للزنك يتأثر بشكل كبير بحالة الزنك في التربة. بشكل عام، تؤكد هذه النتائج على التفاعلات المعقدة بين كيمياء التربة وسلوك العناصر الغذائية الدقيقة وتغذية النبات، وتسلط الضوء على أجزاء $CaCO_3$ كعامل حاسم يتحكم في توافر الزنك، مما يوفر رؤى قيمة لإدارة تغذية الزنك وتحسين إنتاجية المحاصيل في النظم الزراعية الكلسية.

الكلمات المفتاحية: كربونات الكالسيوم النشطة؛ الزنك؛ القمح؛ التربة الكلسية، العلاقة بين التربة والنبات.