EFFECT OF COMMERCIAL SULFURIC ACID, PHOSPHORUS, IRON AND ZINC APPLICATION ON PHOSPHORUS, IRON, ZINC AVAILABILITY IN CALCAREOUS SOIL AND YIELD OF CABBAGE

Firas W. Ahmed — **Researcher**
Ali J. H. AL-Tameemi — **Assist. Prof.**
Dep. Soil Sci. Water Res., Coll. Agric. Engin. Sci., University of Baghdad, Iraq
firas.ahmed@coagri.uobaghdad.edu.iq ali.j@coagri.uobaghdad.edu.iq

ABSTRACT

A field experiment was conducted to evaluate the effect of commercial Sulfuric acid, phosphorous, iron, and zinc application on Phosphorus, Iron, Zinc Availability in Calcareous Soil and Yield of Cabbage (*Brassica oleracea* L.), in an agricultural field at College of Agricultural Engineering Sciences / University of Baghdad / Iraq during the autumn season of 2021, in silty loam soil using Split Plot Design in a randomized complete block design (RCBD) with three replicates. Sulfuric acid H_2SO_4 added with irrigation water at 0 and 2 ml L^{-1}. Phosphorus was added to the soil at (0, 50, 75 and 100%) from the recommended level (65 kg P ha^{-1}) as TSP (20% P), iron was added to the soil at 10 kg Fe ha^{-1} as $FeSO_4.7H_2O$ (20% Fe), and zinc was added to the soil at 5 kg Zn ha^{-1} as $ZnSO_4.7H_2O$ (23 %Zn). Results showed a significant effect of adding commercial sulfuric acid H_2SO_4, Phosphorus and zinc fertilizers to the soil (2 ml L^{-1} + 65 kg P ha^{-1} + 5 kg Zn ha^{-1}) after 30 days of planting and after harvest and achieved available phosphorus of 27.87 and 22.48 mg P kg^{-1} soil and available iron of 7.197 and 7.210 mg Fe kg^{-1} soil and available zinc of 1.907 and 1.883 mg Zn kg^{-1} soil respectively, and plant yield of 70.64 Mg ha^{-1} with an increase of 81.12 % compared to control.

Keywords: Acidified Water; Active lime; Calcareous Soil; Cabbage.

*** Part of Ph.D Dissertation of the 1st author**

مجلة العلوم الزراعية العراقية- 2025 :56 (6):1968-1980 احمد والتميمي

تأثير حامض الكبريتيك التجاري ومستويات اسمدة الفسفور والحديد والزنك في جاهزية الفسفور والحديد والزنك في تربة كلسية وحاصل اللهانة

فراس وعدالله احمد — **باحث علمي**
علي جاسم هادي التميمي — **استاذ مساعد**
قسم علوم التربة والموارد المائية – كلية علوم الهندسة الزراعية – جامعة بغداد

المستخلص

نفذت تجربة حقلية لدراسة تأثير اضافة حامض الكبريتيك ومستويات من اسمدة الفسفور والحديد والزنك في جاهزية الفسفور والحديد والزنك في تربة كلسية وحاصل اللهانة (*Brassica oleracea* L.) في احد الحقول الزراعية التابعة لكلية علوم الهندسة الزراعية / جامعة بغداد خلال الموسم الزراعي الخريفي 2021 في تربة مزيجة غرينية Silty loam ، باستعمال ترتيب الألواح المنشقة Split Plot بتصميم القطاعات الكاملة المعشاة RCBD وبثلاثة مكررات، خصصت الالواح الرئيسة لمستويات المياه المحمضة (حامض الكبريتيك التجاري H_2SO_4) بتركيز 0 و 2 مللتر لتر$^{-1}$ تمت اضافته مع مياه الري، واضيف الفسفور الى التربة بمستوى (0 ، 50 ، 75 و 100 %) من التوصية السمادية (65 كغم P هـ$^{-1}$) على شكل سوبر فوسفات ثلاثي TSP (20% P)، واضيف الحديد والزنك الى التربة بمستوى 10 كغم Fe هـ$^{-1}$ و 5 كغم Zn هـ$^{-1}$ على التتابع. أظهرت النتائج التأثير المعنوي لإضافة حامض الكبريتيك والفوسفور والزنك إلى التربة (2 مللتر لتر$^{-1}$ + 65 كغم P هـ$^{-1}$ + 5 كغم Zn هـ$^{-1}$) بعد 30 يوما من الزراعة وبعد الحصاد واعطت أعلى فسفور جاهز في التربة بلغ 27.87 و 22.48 ملغم P كغم$^{-1}$ تربة وحديد جاهز بلغ 7.197 و7.210 ملغم Fe كغم$^{-1}$ تربة وزنك جاهز بلغ 1.907 و 1.883 ملغم Zn كغم$^{-1}$ تربة على التوالي، وحاصل كلي بلغ 70.64 ميكاغرام هـ$^{-1}$ وبنسبة زيادة بلغت 81.12% مقارنة بمعاملة المقارنة.

الكلمات المفتاحية: المياه المحمضة، الكلس النشط، الترب الكلسية، لهانة.

جزء من اطروحة دكتوراه للباحث الاول.

Received:13 /8/2023, Accepted:2/12/2023, Published:December 2025

INTRODUCTION

Iraqi soils, due to its high content of carbonate minerals and high soil pH, due to sorption and micronutrients precipitation, which prompted many researchers to use different methods to increase the availability of these nutrients (7). Therefore, recent studies tended to add soil conditioners with acidic effect in order to reduce the problems of these calcareous soils and increase nutrients availability (19). Sulfuric acid " H_2SO_4 " is one of the commercial materials that used as a soil amendments through its acts to reduce soil pH and increase the availability of phosphorus and most of the micronutrients, as it acts to dissolve some nutrients compounds and convert them into the available to plants (3,4,30,31). Phosphorus is an essential nutrient that is important for plant growth, its direct role in most of the vital processes that take place inside the plant. It also enters with nitrogen in building cellular membranes such as the plasma membrane, vacuole membrane, chloroplast and mitochondria, and acts to increase branching and root proliferation and accelerates maturation and improves the quality of crops. Phosphorus is involved as phospholipids, inositol phosphate, nucleic acids such as NAD and NADP and ATP and this energy is formed as a result of photosynthesis by phosphorylation or as a result of breathing by oxidative phosphorylation and $NADPH_2$ (6,17). Iron is an essential micro-nutrients for plant, as it plays an essential role in the processes of respiration and photosynthesis, and it is involved in the synthesis of the enzymes Catalase, Nitrogenise, Peroxidase, Cytochrome oxidase, NO_3-reductase and dehydrogenase enzymes, as well as contributing significantly to the synthesis, representation of chlorophyll, although it does not enter into its chemical composition. It is important in the nutritional metabolism of the cell, as it oxidizes sugars and reduces nitrates to NH_4^+, and this reduction is related to the formation of amino acids and proteins and to the representation of RNA (6). Zinc is a vital micronutrient that plays a crucial role in plant growth. It has been observed that about 83% of soil in Iraq exhibits zinc shortage due to its susceptibility to adsorption and precipitation within the soil matrix. Carbonate minerals, particularly in arid and semi-arid regions, exhibit a specialized affinity for zinc, which is essential for the functioning of the enzyme Carbonic anhydrase. This enzyme plays a crucial role in chloroplasts by regulating soil pH and safeguarding proteins against denaturation, thereby preserving their structural integrity and biological activity. Zinc is involved in the formation of RNA and DNA and in the formation and representation of protein as well as has an important role in nitrogen transitions (7). Cabbage (*Brassica oleracea* L.) is a prominent leafy vegetable crop cultivated in Iraq throughout the winter season. It is classified under the Brassicaceae family and there is about 300 genders and 3,000 species of this family all over the world, and is cultivated primarily for the purpose of obtaining heads formed by the wrapping of leaves around the larger terminal bud. According to recent data from the Food and Agriculture Organization, there has been a decline in Cabbage productivity per unit area in Iraq when compared to global cabbage productivity. The global cultivated area encompassed a total of 2,412,167 hectares, yielding an average production rate of 28.76 Mg ha^{-1}. In contrast, Iraq's cultivated area amounted to 1121 hectares with an average production of 11.19 Mg ha^{-1} (14). The aim of the study is to study the effect of commercial Sulfuric acid, phosphorous, iron, and zinc applications on Phosphorus, Iron, Zinc availability in calcareous soil and yield of Cabbage.

MATERIALS AND METHODS

A field experiment was carried out in one of the agricultural fields/College of Agricultural Engineering Sciences/ University of Baghdad, during the autumn season 2021, the field located within latitude 33 ^{o} 270" north and longitude 44^o 390" east, to study the effect of Sulfuric Acid, phosphorous, iron, and zinc applications on Phosphorus, Iron, Zinc Availability in Calcareous Soils and Yield of Cabbage using Split Plot Design in a randomized complete block design (RCBD) with three replicates in silty loam soil. One blocks included 24 experimental units with area of 6 m^2. The experimental unit included four lines of 2m in length, and 0.70 m apart, and spacing between each experimental unit was 1m, and spacing between blocks was 2m, and the distance between plants was 40 cm (20 plants in each experimental unit), so the experimental units were 72. Soil samples were taken before planting from the surface layer at (0-30 cm depth). A representative sample was taken to estimate some physical, chemical and fertility analysis (Table 1). All Laboratory analyses were performed in College of Agricultural Engineering Sciences, University of Baghdad, in addition to the laboratories of the Ministry of Science and Technology. Acidified water with commercial Sulfuric acid H_2SO_4 added at concentration of 0 and 2 ml L^{-1} (30) with irrigation water using drip irrigation system (Using two tanks, one for normal water and the other for acidified water) symbolized as A_0 and A_1 respectively, phosphorus TSP (20% P) was added to the soil at four levels (0, 50, 75 and 100%) from the recommended rate (65 kg P ha^{-1}) symbolized by P_0, P_1, P_2 and P_3 respectively, Iron was added to the soil using $FeSO_4.7H_2O$ (20% Fe) at 10 kg Fe ha^{-1} symbolized as S_1. Zinc was added to the soil using $ZnSO_4.7H_2O$ (23 %Zn) at 5 kg Zn ha^{-1} symbolized as S_2, and a control treatment without addition it is symbolized as S_0 (the use of a saline fertilizer source for iron and zinc represent the actual scenario affected by soil pH which is the research problem). Nitrogen fertilizer was added to the soil at 150 kg N ha^{-1} as urea (46% N), while potassium fertilizer was added to the soil at 125 kg K ha^{-1} as K_2SO_4 . Cabbage (Glob Master) was transplanted on 2/10/2021, and the seedlings were transferred to the field on 9/11/2021.

Table 1. Chemical, physical and fertility properties of the Soil

Soil Properties	Value	Unit
EC 1:1	2.03	dS m^{-1}
pH 1:1	7.34	-
Carbonate minerals	287.00	g kg^{-1} soil
Active lime	180.57	g kg^{-1} soil
Organic matter	11.10	g kg^{-1} soil
CEC	21.24	Cmol kg^{-1} soil
Available N	41.08	mg kg^{-1} soil
Available P	14.53	mg kg^{-1} soil
Available K	207.49	mg kg^{-1} soil
Available Zn	2.12	mg kg^{-1} soil
Available Fe	3.07	mg kg^{-1} soil
Clay	202	g kg^{-1} soil
Sand	155	g kg^{-1} soil
Silt	643	g kg^{-1} soil
Texture	Silty loam	

RESULTS AND DISCUSSION

Soil pH after 30 and 60 days of planting: The results of Tables (2,3) show a significant effect of adding commercial sulfuric acid H_2SO_4 with irrigation water to the soil on soil pH as A_1 achieved soil pH after 30 and 60 days of planting of 7.01 and 6.92 with an increase of 6.27% and 5.78%, respectively, compared to A_0 which achieved soil pH of 7.45 and 7.32 respectively. The reason is attributed to the increase in hydrogen ions. H^+ in the soil solution which leads to lowering soil pH (16,17), the results is good agreement with (1, 31). Results of the same Table show that there was no significant effect on soil pH after 30 and 60 days of planting as a result of adding iron and zinc to the soil. The results of Tables (2,3) show a significant effect of adding phosphorus to the soil in soil pH, as P_3 achieved soil pH after 30 and 60 days of planting 7.11 and 6.97 with an increase of 4.07% and 4.87%, respectively compared to P_0 which achieved soil pH of 7.40 and 7.31 respectively, the reason is attributed to the acidic effect of TSP fertilizer which caused an increase in soil pH as a result of the method of manufacturing the fertilizer and the resulting rock Phosphate interacts with phosphoric acid, and thus, when it is dissolved in the soil solution (12), the results is good agreement with (36). The results of Tables (2,3) show a significant effect for the triple interaction between adding sulfuric acid H_2SO_4 with irrigation water and fertilizing with phosphorus, iron and zinc to the soil in soil pH, as $A_1P_3S_1$ achieved soil pH after 30 and 60 days of planting of 6.84 and 6.74 respectively with an increase of 11.54% and 11.27%, respectively, compared to $A_0P_0S_0$ which achieved soil pH of 7.63 and 7.50 . respectively. The reason is attributed to this is until adding phosphate fertilizer, iron and zinc fertilizers to the soil, and adding commercial sulfuric acid H_2SO_4 with irrigation water contributed to reducing soil pH .

Table 2. Effect of Irrigation with commercial Sulfuric acid, phosphorous, iron, and zinc application on soil pH after 30 days of planting

Sulfuric Acid H_2SO_4 (A)	Phosphorus (P)	Iron and Zinc (S) S_0	S_1	S_2	Mean A x P
A_0	P_0	7.63	7.56	7.60	7.59
	P_1	7.56	7.50	7.46	7.50
	P_2	7.40	7.43	7.40	7.41
	P_3	7.33	7.31	7.33	7.32
A_1	P_0	7.23	7.20	7.21	7.21
	P_1	7.13	6.93	6.94	7.00
	P_2	7.00	6.91	6.97	6.96
	P_3	6.95	6.84	6.92	6.90
Mean Sulfuric Acid H_2SO_4 (A)		Mean A x S			Mean A
A_0		7.48	7.45	7.44	7.45
A_1		7.07	6.97	7.01	7.01
Mean Phosphorus (P)		Mean P x S			Mean P
P_0		7.43	7.38	7.40	7.40
P_1		7.34	7.21	7.20	7.25
P_2		7.20	7.17	7.18	7.18
P_3		7.14	7.07	7.12	7.11
Mean Iron and Zinc (S)		7.27	7.21	7.22	
$LSD_{0.05}$	A	P	S		A * P
	0.270	0.147	N S		0.231
$LSD_{0.05}$	A x S		P x S		A x P x S
	0.215		0.199		0.280

Table 3. Effect of Irrigation with commercial Sulfuric acid, phosphorous, iron, and zinc application on soil pH after 60 days of plantin

Sulfuric Acid H_2SO_4 (A)	Phosphorus (P)	Iron and Zinc (S) S_0	S_1	S_2	Mean A x P
A_0	P_0	7.50	7.46	7.50	7.48
	P_1	7.43	7.40	7.36	7.40
	P_2	7.33	7.26	7.20	7.26
	P_3	7.20	7.18	7.16	7.18
A_1	P_0	7.20	7.13	7.10	7.14
	P_1	7.00	6.96	6.93	6.96
	P_2	6.86	6.83	6.86	6.85
	P_3	6.76	6.74	6.80	6.77
Mean Sulfuric Acid H_2SO_4 (A)		Mean A x S			Mean A
A_0		7.36	7.32	7.30	7.32
A_1		6.95	6.91	6.92	6.92
Mean Phosphorus (P)		Mean P x S			Mean P
P_0		7.35	7.29	7.30	7.31
P_1		7.21	7.18	7.14	7.17
P_2		7.09	7.04	7.03	7.05
P_3		6.98	6.96	6.98	6.97
Mean Iron and Zinc (S)		7.15	7.11	7.11	
$LSD_{0.05}$	A	P	S		A * P
	0.242	0.135	N S		0.210
$LSD_{0.05}$	A x S		P x S		A x P x S
	0.207		0.213		0.293

Active lime (g kg^{-1} soil): The results of Tables (4,5) show a significant effect of adding commercial sulfuric acid H_2SO_4 with irrigation water to the soil on active lime content, as A_1 achieved active lime after 30 and 60 days of planting reached 140.5 and 102.9 g kg^{-1} soil with an increase of 17.22% and 27.50% respectively compared to A_0 which achieved active lime content of 164.7 and 131.2 g kg^{-1} soil, respectively. The reason was attributed to the role of sulfuric acid in dissolving the active calcium carbonate minerals and releasing CO_2 in the soil (30). The results is good agreement with (2,31). Results of the same table show that there was no significant effect in active lime in the soil as a result of adding phosphorus, iron and zinc to the soil. The results of Tables (4,5) show a significant effect for the triple interaction between adding commercial sulfuric acid H_2SO_4 with irrigation water and fertilizing with phosphorus, iron and zinc to the soil in active lime, as $A_1P_3S_2$ achieved active lime in the soil after 30 and 60 days of planting reached 135.6 and 99.8 g kg^{-1} soil with an increase of 24.77% and 35.47% respectively compared to $A_0P_0S_0$ which achieved active lime content in the soil of 169.2 and 135.2 g kg^{-1} soil respectively.

Table 4. Effect of Irrigation with commercial Sulfuric acid, phosphorous, iron, and zinc application on active lime in the soil after 30 days of planting (g kg^{-1} soil)

Sulfuric Acid H_2SO_4 (A)	Phosphorus (P)	Iron and Zinc (S) S_0	S_1	S_2	Mean A x P
A_0	P_0	169.2	167.1	168.5	168.2
	P_1	166.4	164.4	165.1	165.3
	P_2	164.5	163.7	163.8	164.0
	P_3	162.9	161.5	160.3	161.5
A_1	P_0	145.0	143.6	142.4	143.6
	P_1	143.6	141.8	140.2	141.8
	P_2	140.7	139.3	139.1	139.7
	P_3	138.9	136.1	135.6	136.8
Mean Sulfuric Acid H_2SO_4 (A)		Mean A x S			Mean A
A_0		165.7	164.1	164.4	164.7
A_1		142.0	140.2	139.3	140.5
Mean Phosphorus (P)		Mean P x S			Mean P
P_0		157.1	155.3	155.4	155.9
P_1		155.0	153.1	152.6	153.5
P_2		152.6	151.5	151.4	151.8
P_3		150.9	148.8	147.9	149.2
Mean Iron and Zinc (S)		153.9	152.1	151.8	
$LSD_{0.05}$	A	P	S		A * P
	5.39	N S	N S		8.53
$LSD_{0.05}$	A x S		P x S		A x P x S
	8.89		N S		16.36

Table 5. Effect of Irrigation with commercial Sulfuric acid, phosphorous, iron, and zinc application on active lime in the soil after 60 days of planting (g kg^{-1} soil)

Sulfuric Acid H_2SO_4 (A)	Phosphorus (P)	Iron and Zinc (S) S_0	S_1	S_2	Mean A x P
A_0	P_0	135.2	132.8	131.3	133.1
	P_1	133.8	131.0	130.5	131.7
	P_2	132.0	130.6	129.2	130.6
	P_3	131.3	128.9	128.4	129.5
A_1	P_0	106.2	105.9	105.1	105.7
	P_1	104.6	103.8	103.2	103.8
	P_2	102.7	101.3	100.9	101.6
	P_3	100.8	100.7	99.8	100.4
Mean Sulfuric Acid H_2SO_4 (A)		Mean A x S			Mean A
A_0		133.0	130.8	129.8	131.2
A_1		103.5	102.9	102.2	102.9
Mean Phosphorus (P)		Mean P x S			Mean P
P_0		120.7	119.3	118.2	119.4
P_1		119.2	117.4	116.8	117.8
P_2		117.3	115.9	115.0	116.1
P_3		116.0	114.8	114.1	114.9
Mean Iron and Zinc (S)		118.3	116.8	116.0	
$LSD_{0.05}$	A	P	S		A * P
	3.79	N S	N S		8.07
$LSD_{0.05}$	A x S		P x S		A x P x S
	9.47		N S		10.91

Available phosphorus (mg P kg^{-1} soil): The results of Tables (6,7) show a significant effect of adding commercial sulfuric acid H_2SO_4 with irrigation water to the soil, as A_1 achieved available phosphorus after 30 days of planting and after harvest of 23.74 and 19.25 mg P kg^{-1} soil with an increase of 9.45% and 15.54% compared to A_0 which achieved available phosphorous of 21.69 and 16.66 mg P kg^{-1} soil respectively, the reason is attributed to sulfuric acid H_2SO_4 works to reduce soil pH and dissolve some phosphate compounds, turning them from the unavailable to available form for plants (16), the results is good agreement with (1,4,21).The results of Tables (6,7) show a significant effect of adding phosphorus to the soil on available phosphorus, as P_3 achieved available phosphorus after 30 days of planting and after harvest of 25.62 and 20.75 mg P kg^{-1} soil with an increase of 35.91% and 43.69% compared to the P_0 which having 18.85 and 14.44 mg P kg^{-1} soil, respectively, the reason is that TSP fertilizer increased the availability of soil phosphorus due to its high solubility and low pH (6), the results is good agreement with (10 ,23). The results of the same table showed a significant effect of adding iron on soil, as S_1 achieved available phosphorus after 30 days of planting and after harvest 22.82 and 18.05 mg P kg^{-1} soil with an increase of 5.55% and 5.92% compared to the S_0 which achieved available phosphorus on soil of 21.62 and 17.04 mg P kg^{-1} soil, respectively, the reason is attributed to the addition of iron sulfate to the soil could lead to decrease soil pH and affect the solubility and availability of phosphorus in the soil by dissolution of some phosphorus compounds, as well as iron can form insoluble compounds with phosphorus leading to precipitation of phosphorus in soil (29), the results is good agreement with (18).

Table 6. Effect of Irrigation with commercial Sulfuric acid, phosphorous, iron, and zinc application on available Phosphorus in the soil after 30 days of planting (mg P kg^{-1} soil)

Sulfuric Acid H_2SO_4 (A)	Phosphorus (P)	Iron and Zinc (S) S_0	S_1	S_2	Mean A x P
A_0	P_0	16.89	17.97	18.87	17.91
	P_1	19.51	21.24	22.70	21.15
	P_2	22.68	23.36	24.13	23.39
	P_3	23.27	24.35	25.40	24.34
A_1	P_0	18.05	20.04	21.31	19.80
	P_1	22.61	23.67	23.92	23.40
	P_2	24.09	25.06	25.49	24.88
	P_3	25.93	26.90	27.87	26.90
Mean Sulfuric Acid H_2SO_4 (A)			Mean A x S		Mean A
A_0		20.58	21.73	22.77	21.69
A_1		22.67	23.91	24.64	23.74
Mean Phosphorus (P)			Mean P x S		Mean P
P_0		17.47	19.00	20.09	18.85
P_1		21.06	22.45	23.31	22.27
P_2		23.38	24.21	24.81	24.13
P_3		24.60	25.62	26.63	25.62
Mean Iron and Zinc (S)		21.62	22.82	23.71	
LSD $_{0.05}$	A	P	S		A * P
	1.711	1.509	1.651		2.192
LSD $_{0.05}$	A x S		P x S		A x P x S
	2.096		2.295		3.239

Table 7. Effect of Irrigation with commercial Sulfuric acid, phosphorous, iron, and zinc application on available Phosphorus in the soil after harvest (mg P kg^{-1} soil)

Sulfuric Acid H_2SO_4 (A)	Phosphorus (P)	Iron and Zinc (S) S_0	S_1	S_2	Mean A x P
A_0	P_0	12.21	13.42	13.64	13.09
	P_1	15.47	16.85	17.33	16.55
	P_2	16.93	17.35	18.67	17.65
	P_3	18.22	19.27	20.65	19.38
A_1	P_0	14.82	16.02	16.56	15.80
	P_1	17.10	18.35	19.18	18.21
	P_2	20.06	20.87	21.74	20.89
	P_3	21.57	22.31	22.48	22.12
Mean Sulfuric Acid H_2SO_4 (A)		Mean A x S			Mean A
A_0		15.70	16.72	17.57	16.66
A_1		18.38	19.38	19.99	19.25
Mean Phosphorus (P)		Mean P x S			Mean P
P_0		13.51	14.72	15.10	14.44
P_1		16.28	17.60	18.25	17.38
P_2		18.49	19.11	20.20	19.27
P_3		19.89	20.79	21.56	20.75
Mean Iron and Zinc (S)		17.04	18.05	18.78	
$LSD_{0.05}$	A	P	S		A * P
	0.653	0.606	0.594		0.800
$LSD_{0.05}$	A x S		P x S		A x P x S
	0.657		0.972		1.355

The results of the same table showed a significant effect of adding zinc on soil, as S_2 achieved available phosphorus in the soil after 30 days of planting and after harvest achieved to 23.71 and 18.78 mg P kg^{-1} soil with an increase of 9.66% and 10.21% compared to S_0 treatment which achieved available phosphorus of 21.62 and 17.04 mg P kg^{-1} soil, respectively, the reason is attributed to the addition of zinc sulfate to the soil could lead to reduce soil pH and affect the solubility and availability of phosphorus in the soil by dissolution of some phosphorus compounds, as well as zinc can form insoluble compounds with phosphorus leading to precipitation of phosphorus in soil, thus increasing the availability of phosphorus in the rhizosphere (35), the results is good agreement with (22,27). The results of Tables (6,7) show a significant effect of triple interaction between adding sulfuric acid H_2SO_4 with irrigation water and fertilizing soil with phosphorus, iron and zinc on available phosphorus in the soil, as $A_1P_3S_2$ achieved available phosphorus in the soil after 30 days of planting and after harvest of 27.87 and 22.48 mg P kg^{-1} soil with an increase of 65.00% and 84.11% compared to $A_0P_0S_0$ which achieved available phosphorus of 16.89 and 12.21 mg P kg^{-1} soil respectively, this is due to the sulfuric acid and p levels.

Available iron (mg Fe kg^{-1} soil): The results of Tables (8,9) show a significant effect of adding commercial sulfuric acid H_2SO_4 with irrigation water to the soil in available iron in the soil, as A_1 was achieved available iron after 30 days of planting and after harvest of 6.805 and 6.652 mg Fe kg^{-1} soil with an increase of 10.273% and 12.402% compared to A_0 which achieved available iron of 6.171 and 5.918 mg Fe kg^{-1} soil respectively. The reason is attributed to the role of sulfuric acid in dissolving some iron-containing compounds, such as iron oxides and silicate minerals, which leads to the liberation of iron from those compounds into the soil solution, as well as the dissolution of calcium carbonate, which has a negative release instead in the availability of micronutrients, including iron, and thus increasing the availability of iron in the soil, as well as the role of sulfuric acid in reducing soil pH of the rhizosphere, which made iron more available in the soil (17,33), the results is good agreement with (2,21).The results of Tables (8,9) show a significant effect of adding phosphorus to the soil on available iron in the soil, as P_3 achieved available iron in the soil after 30 days of planting and after harvest 6.911 and 6.781 mg Fe kg^{-1} soil with an increase of 17.654% and 20.422% compared to P_0 which achieved available iron 5.874 and 5.631 mg Fe kg^{-1} soil respectively, this can due to the acidic effect of TSP fertilizer which caused reducing soil pH and increases the growth of roots and their secretions of organic acids, which lead to a decrease soil pH and chelation of iron, thus increasing its availability in the soil (13), the results is good agreement with (15). The results of the same table showed a significant effect of adding iron on soil, as S_1 achieved available iron in the soil after 30 days of planting and after harvest which achieved to 6.636 and 6.503 mg Fe kg^{-1} soil with an increase of 5.033% and 8.275% compared to the S_0 treatment which achieved available iron of 6.318 and 6.006 mg Fe kg^{-1} soil respectively, the reason is due to the iron sulphate fertilizer containing iron which leads to an increase in its concentration in the soil (29), the results is good agreement with (18).

Table 8. Effect of Irrigation with commercial Sulfuric acid, phosphorous, iron, and zinc application on available Iron in the soil after 30 days of planting (mg Fe kg^{-1} soil)

Sulfuric Acid H_2SO_4 (A)	Phosphorus (P)	Iron and Zinc (S) S_0	S_1	S_2	Mean A x P
A_0	P_0	4.810	6.063	5.606	5.493
	P_1	5.825	6.281	6.155	6.087
	P_2	6.374	6.596	6.425	6.465
	P_3	6.643	6.752	6.531	6.642
A_1	P_0	6.128	6.352	6.285	6.255
	P_1	6.576	6.833	6.766	6.725
	P_2	7.024	7.020	7.145	7.063
	P_3	7.171	7.197	7.172	7.180
Mean Sulfuric Acid H_2SO_4 (A)		Mean A x S			Mean A
A_0		5.913	6.423	6.179	6.171
A_1		6.724	6.850	6.842	6.805
Mean Phosphorus (P)		Mean P x S			Mean P
P_0		5.469	6.207	5.945	5.874
P_1		6.200	6.557	6.460	6.406
P_2		6.699	6.808	6.785	6.764
P_3		6.907	6.974	6.851	6.911
Mean Iron and Zinc (S)		6.318	6.636	6.510	
$LSD_{0.05}$	A	P	S		A * P
	0.362	0.244	0.105		0.350
$LSD_{0.05}$	A x S		P x S		A x P x S
	0.290		0.354		0.527

Table 9. Effect of Irrigation with commercial Sulfuric acid, phosphorous, iron, and zinc application on available Iron in the soil after harvest (mg Fe kg^{-1} soil)

Sulfuric Acid H_2SO_4 (A)	Phosphorus (P)	Iron and Zinc (S) S_0	S_1	S_2	Mean A x P
A_0	P_0	4.630	5.523	5.375	5.176
	P_1	5.369	6.054	5.716	5.713
	P_2	6.044	6.386	6.227	6.219
	P_3	6.437	6.565	6.690	6.564
A_1	P_0	5.762	6.318	6.181	6.087
	P_1	6.327	6.814	6.722	6.621
	P_2	6.686	7.159	6.864	6.903
	P_3	6.795	7.210	6.989	6.998
Mean Sulfuric Acid H_2SO_4 (A)		Mean A x S			Mean A
A_0		5.620	6.132	6.002	5.918
A_1		6.392	6.875	6.689	6.652
Mean Phosphorus (P)		Mean P x S			Mean P
P_0		5.196	5.920	5.778	5.631
P_1		5.848	6.434	6.219	6.167
P_2		6.365	6.772	6.545	6.561
P_3		6.616	6.887	6.839	6.781
Mean Iron and Zinc (S)		6.006	6.503	6.345	
$LSD_{0.05}$	A	P	S		A * P
	0.176	0.257	0.292		0.323
$LSD_{0.05}$	A x S		P x S		A x P x S
	0.308		0.393		0.521

The results of the same table showed the effect of adding zinc on soil, as S_2 achieved available iron in the soil after 30 days of planting and after harvest of 6.510 and 6.345 mg Fe kg^{-1} soil with an increase of 3.038% and 5.644% compared to the S_0 treatment which achieved available iron in the soil of 6.318 and 6.006 mg Fe kg^{-1} soil respectively, the reason is attributed to the role of zinc in activating biological activities in the soil and by increasing the absorption of iron from the soil (28), the results is good agreement with (22). The results of Tables (8,9) show a significant effect of triple interaction between adding commercial sulfuric acid H_2SO_4 with irrigation water and fertilizing soil with phosphorus, iron and zinc on available iron in the soil, as $A_1P_3S_1$ achieved available iron in the soil after 30 days of planting and after harvest of 7.197 and 7.210 mg Fe kg^{-1} soil with an increase of 49.625% and 55.723% compared to $A_0P_0S_0$ which achieved available iron in the soil of 4.810 and 4.630 mg Fe kg^{-1} soil respectively.

Available zinc (mg Zn kg^{-1} soil): The results of Tables (10,11) show a significant effect of adding commercial sulfuric acid H_2SO_4 with irrigation water to the soil on available zinc in the soil, as A_1 achieved available zinc after 30 days of planting and after harvesting 1.604 and 1.565 mg Zn kg^{-1} soil with an increase of 8.305% and 11.546% compared to A_0 which achieved available zinc of 1.481 and 1.403 mg Zn kg^{-1} soil respectively, the reason is due to the role of sulfuric acid in dissolving some compounds containing zinc, such as carbonates and oxides, which led to the reduction of calcium carbonate in the soil and release of zinc from those compounds into the soil solution, thus increasing the available zinc in the soil, in addition to the role of sulfuric acid in reducing soil pH in rhizosphere which made zinc available in the soil solution (17), the results is good agreement with (1,4,26). The results of Tables (10,11) indicate that there were significant effect of adding phosphorus in available zinc in the soil, as P_3 achieved available zinc in the soil after 30 days of planting and after harvest achieved 1.772 and 1.721 mg Zn kg^{-1} soil with an increase of 49.66% and 47.72% compared to P_0 which achieved available zinc in the soil of 1.184 and 1.165 mg Zn kg^{-1} soil, the reason is attributed to the acidic effect of TSP fertilizer which caused reducing soil pH and increases the growth of roots and their secretions of organic acids, which lead to a decrease soil pH in the rhizosphere and chelation of zinc, thus increasing availability of zinc in the soil (13), the results is good agreement with (27). The results of the same table showed a significant effect of adding iron on soil, as S_1 achieved available zinc in the soil after 30 days of planting and after harvest achieved of 1.514 and 1.460 mg Zn kg^{-1} soil with an increase of 3.274% and 2.961% compared to S_0 treatment which achieved available zinc in the soil of 1.466 and 1.418 mg Zn kg^{-1} soil respectively, the reason is attributed to the role of iron in encouraging root and vegetative growth, and then increasing the ability of the roots to absorb water and nutrients from the soil (8), the results is good agreement with (18). The results of the same table showed a significant effect of adding zinc on soil, as S_2 achieved available zinc in the soil after 30 days of planting and after harvest achieved of 1.647 and 1.573 mg Zn kg^{-1} soil with an increase of 12.346% and 10.930% compared to S_0 which achieved available zinc in the soil of 1.466 and 1.418 mg Zn kg^{-1} soil respectively, the reason is that zinc sulphate contains zinc which increases the concentration of zinc in the soil solution, as well as increasing plant root secretions which acts to reduce soil pH and chelate nutrients in the rhizosphere through the release of siderophores which increase the availability of zinc in the rhizosphere (7), the results is good agreement with (24).

Table 10. Effect of Irrigation with commercial Sulfuric acid, phosphorous, iron, and zinc application on available Zinc in the soil after 30 days of planting (mg Zn kg^{-1} soil)

Sulfuric Acid H_2SO_4 (A)	Phosphorus (P)	Iron and Zinc (S) S_0	S_1	S_2	Mean A x P
A_0	P_0	0.936	1.057	1.196	1.063
	P_1	1.382	1.489	1.572	1.481
	P_2	1.633	1.571	1.755	1.653
	P_3	1.720	1.676	1.785	1.727
A_1	P_0	1.260	1.249	1.409	1.306
	P_1	1.430	1.587	1.696	1.571
	P_2	1.612	1.699	1.858	1.723
	P_3	1.755	1.789	1.907	1.817
Mean Sulfuric Acid H_2SO_4 (A)		Mean A x S			Mean A
A_0		1.417	1.448	1.577	1.481
A_1		1.514	1.581	1.717	1.604
Mean Phosphorus (P)		Mean P x S			Mean P
P_0		1.098	1.153	1.302	1.184
P_1		1.406	1.538	1.634	1.526
P_2		1.622	1.635	1.806	1.688
P_3		1.737	1.732	1.846	1.772
Mean Iron and Zinc (S)		1.466	1.514	1.647	
$LSD_{0.05}$	A	P	S		A * P
	0.102	0.185	0.098		0.244
$LSD_{0.05}$	A x S		P x S		A x P x S
	0.163		0.233		0.330

Table 11. Effect of Irrigation with commercial Sulfuric acid, phosphorous, iron, and zinc application on available Zinc in the soil after harvest (mg Zn kg^{-1} soil)

Sulfuric Acid H_2SO_4 (A)	Phosphorus (P)	Iron and Zinc (S) S_0	S_1	S_2	Mean A x P
A_0	P_0	0.901	1.057	1.153	1.037
	P_1	1.250	1.365	1.522	1.379
	P_2	1.510	1.497	1.613	1.540
	P_3	1.672	1.620	1.679	1.657
A_1	P_0	1.207	1.259	1.413	1.293
	P_1	1.423	1.398	1.517	1.446
	P_2	1.660	1.735	1.810	1.735
	P_3	1.724	1.751	1.883	1.786
Mean Sulfuric Acid H_2SO_4 (A)		Mean A x S			Mean A
A_0		1.333	1.384	1.491	1.403
A_1		1.503	1.535	1.655	1.565
Mean Phosphorus (P)		Mean P x S			Mean P
P_0		1.054	1.158	1.283	1.165
P_1		1.336	1.381	1.519	1.412
P_2		1.585	1.616	1.711	1.637
P_3		1.698	1.685	1.781	1.721
Mean Iron and Zinc (S)		1.418	1.460	1.573	
$LSD_{0.05}$	A	P	S		A * P
	0.063	0.101	0.036		0.126
$LSD_{0.05}$	A x S		P x S		A x P x S
	0.131		0.168		0.262

The results of Tables (10,11) show a significant effect for the triple interaction between adding sulfuric acid H_2SO_4 with irrigation water and fertilizing soil with phosphorus, iron and zinc on available zinc as $A_1P_3S_2$ achieved available zinc after 30 days of planting and after harvest of 1.907 and 1.883 mg Zn kg^{-1} soil with an increase of 103.73% and 108.990% compared to $A_0P_0S_0$ which achieved available zinc 0.936 and 0.901 mg Zn kg^{-1} soil respectively.

Plant Yield: Results of Table (12) show a significant effect of adding commercial sulfuric acid H_2SO_4 with irrigation water on plant yield as A_1 achieved plant yield 59.58 Mg ha^{-1} with an increase 16.64 % compared to A_0 which achieved plant yield 51.08 Mg ha^{-1}, the reason is attributed to the role of sulfuric acid in enhancing the accessibility of nutrients such as nitrogen, phosphorus, and potassium for the plant. This is primarily due to the low soil pH in the rhizosphere, which facilitates the absorption of sulfuric acid and subsequent increase in its concentration in the leaves. Consequently, this increase in sulfuric acid content leads to heightened activity of crucial physiological processes and regulatory mechanisms, this physiological response contributes to an augmentation in plant yield (30), the results is good agreement with (1,2).The results of Table (12) show a significant effect of adding phosphate to the soil on plant yield, as P_3 achieved plant yield of 64.49 Mg ha^{-1} with an increase of 41.23 % compared with P_0 which achieved Plant yield of 45.66 Mg ha^{-1}, the reason is the role of phosphate fertilizer in facilitating plant growth and the development of a robust root system capable of penetrating the soil, this enables the plant to enhance its absorption of available nutrients from soil solution, which is crucial for carrying out vital metabolic processes, particularly carbon metabolism (6), the results is good agreement with (5,8,23). Data of the same table show a significant effect of adding iron to soil as S_1 achieved plant yield of 56.12 Mg ha^{-1} with an increase of 8.54 % compared to S_0 which achieved plant yield of 51.70 Mg ha^{-1}, the reason is due to the supply of iron to the plant and its absorption by the plant, which increased vegetative growth and nutrient assimilation and increased chlorophyll content, as well as the process of carbon metabolism and then increase the weight of the head and increase plant yield (8), the results is good agreement with (11,32). The results of the same Table show a significant effect of adding zinc to soil, as S_2 achieved plant yield of 58.16 Mg ha^{-1} with an increase of 12.49 % compared to S_0 which achieved plant yield of 51.70 Mg ha^{-1}, the reason is attributed to the important role of zinc in increasing the process of cell division and the process of carbon metabolism as a result of the availability of energy needed to absorb water and nutrients, and increase plant yield (13), the results is good agreement with (9,34). Results of Table (12) show a significant effect of triple interaction between the addition of sulfuric acid H_2SO_4 with irrigation water and fertilization soil with phosphorus, iron and zinc on plant yield, as $A_1P_3S_2$ achieved plant yield of 70.64 Mg ha^{-1} with an increase of 81.12 % compared to $A_0P_0S_0$ which achieved plant yield of 39.00 Mg ha^{-1}.

Table 12. Effect of Irrigation with commercial Sulfuric acid, phosphorous, iron, and zinc application on Plant Yield (Mg ha^{-1})

Sulfuric Acid H_2SO_4 (A)	Phosphorus (P)	Iron and Zinc (S) S_0	S_1	S_2	Mean A x P
A_0	P_0	39.00	41.67	43.34	41.33
	P_1	45.33	49.00	50.65	48.32
	P_2	50.66	53.67	55.64	53.32
	P_3	59.67	61.68	62.67	61.34
A_1	P_0	46.00	50.67	53.32	49.99
	P_1	52.01	57.65	59.35	56.33
	P_2	57.33	66.02	69.67	64.34
	P_3	63.65	68.67	70.64	67.65
Mean Sulfuric Acid H_2SO_4 (A)			**Mean A x S**		**Mean A**
A_0		48.66	51.50	53.07	51.08
A_1		54.74	60.75	63.24	59.58
Mean Phosphorus (P)			**Mean P x S**		**Mean P**
P_0		42.50	46.17	48.33	45.66
P_1		48.67	53.32	55.00	52.33
P_2		53.99	59.84	62.65	58.83
P_3		61.66	65.17	66.65	64.49
Mean Iron and Zinc (S)		51.70	56.12	58.16	
LSD $_{0.05}$	A	P	S		A * P
	9.666	7.342	2.344		10.135
LSD $_{0.05}$	A x S			P x S	A x P x S
	7.678			8.373	11.966

CONCLUSIONS

Results show that there were significant effect of adding Sulfuric acid, P, Fe and Zn in soil on available phosphorus, iron and zinc in the leaves after 30 days of planting and after harvest. Sulphuric acid used in Iraqi soil with irrigation water, especially when commercial sulphuric acid works to reduce soil pH and dissolve some phosphate, Iron and Zinc turning them from the unavailable to available form for plants.

CONFLICT OF INTEREST

The authors declare that they have no conflicts of interest.

DECLARATION OF FUND

The authors declare that they have not received a fund.

REFERENCES

1. Abdul Qadir, A.; G. Murtaza; M. Zia-ur-Rehman and E. Waraich. 2022. Application of gypsum or sulfuric acid improves physiological traits and nutritional status of rice in calcareous saline-sodic soils. Journal of Soil Science and Plant Nutrition. 22(2): 1846–1858.
https://doi.org/10.1007/s42729-022-00776-1

2. Al-balawna, Z. A. and I. I. Abu-Abdoun. 2021. Effect of adding dilute sulphuric acid on calcareous soil properties in Jordan Valley. Arch Agri Res Technol 2(1): 1-4.
http://dx.doi.org/10.54026/AART/1023

3. Al-Dulaimi, H. N. O. and H. A. Margan. 2014. Effect of foliar fertilization with calcium and the addition of sulfuric acid on the content of corn *Zea mays* L.. bohoth 106 of the elements phosphorus and nitrogen. Al Furat Journal of Agricultural Sciences. 6(4): 148-154.
https://www.iasj.net/iasj/download/3e7d922bc10d0ef6

4. Al-Fatlawi, A. U. H. and H. N. O. Al-Dulaimi. 2015. Effect of foliar fertilization with potassium element and addition of dilute sulfuric acid on yield and components of corn *Zea mays* L. Furat cultivar. Al Furat Journal of Agricultural Sciences. 7(4): 137-146.
https://www.iasj.net/iasj/article/111503

5. Al-Halfi, D. A. N and S. S. J. Al-Azzawi. 2022. Effect of organic fertilizer sources and chemical fertilization on some soil physical traits and yield of summer squash (*Cucurbta Pepo* L.). Iraqi Journal of Market Research and Consumer Protection. 14(2): 74-81.
http://dx.doi.org/10.28936/jmracpc14.2.2022.(9)

6. Ali, N. S., S. H. Radi and A. Shaker, 2014. Soil Fertility. College of Agricultural Engineering Sciences. University of Baghdad. Scientific Book House Corporation for printing, publishing and distribution. Iraq. PP: 307.

7. Ali, N. S., M. M. Allawi and N. H. Majeed, 2022. Rhizospheric Management and Agricultural Sustainability. University of Baghdad/ College of Agricultural Engineering Sciences. Science Center for Printing Office. PP: 323.

8. Al-Mawsili, M. A. D.; W. A. Al-Badrani; F. A. S. H. and S. M. Al-Rashidi. 2019. Plant Nutrition (Theoretical and Practical). International Book House. Beirut. PP: 464.

9. Al-Mashhadany, A. H. and M. Z. K. Al-Mharib. 2023. Effect of fertilizers starter solutions on growth and production of broccoli (*Brassica oleracea* var. italica). Research on Crops. 24 (1): 119-122.
doi: 10.31830/2348-7542.2023.roc-11155

10. Al-Mharib, M. Z. K., F. M. J. Al-Saadi and A. H. Almashhadany. 2020. Studies on growth and yield indicators for kohlrabi (*Brassica oleracea*) plant treated with mineral fertilizers and root enhancers. Research on Crops. 21(2): 333–338.
doi: 10.31830/2348-7542.2020.56

11. Al-Tameemi, A. J. H.; Y. A. Mahmood and J. J. A. Noora. 2019. Effect of spraying chelated and nano of both iron and zinc on the growth and yield of broccoli(*Brassica oleraceavar*. Italica). Plant Archives. 19(1): 1783-1790.
http://www.plantarchives.org/PDF%2019-1/1783-1790%20(4757).pdf

12. Barrow, N. J.. 2017. The effects of pH on phosphate uptake from the soil. Plant Soil. 410(12): 401–410.
doi:10.1007/s11104-016-3008-9

13. Dotaniya, M. L. and V. D. Meena. 2015. Rhizosphere effect on nutrient availability in soil and its uptake by plants. Proceeding of the National Academy of Sciences, India, Section B. 85(1):1–12.
doi: 10.1007/s40011-013-0297-0

14. FAO STAT. 2018. Available at http: //www.fao.org/faostat/ar/#data/QC.

15. Gao, F., and C. Dubos 2021. Transcriptional integration of plant responses to iron availability. J. Exp. Bot. 72(9): 2056–2070.
doi: 10.1093/jxb/eraa556.

16. Getaneh, S. and W. Kidanemariam. 2021. Soil acidity and its managements. Int. J. Adv. Res. Biol. Sci. 8(3): 70-79.
http://dx.doi.org/10.22192/ijarbs.2021.08.03.008

17. Goulding, K. W. T. 2016. Soil acidification and the importance of liming agricultural soils with particular reference to the United Kingdom. Soil Use and Management. 32(3). 390-399.
https://doi.org/10.1111/sum.12270

18. Jagtap, P. B.: M. B. Kadam and S. U. Chalak. 2016. Response of cabbage to foliar and soil application of iron and zinc in inceptisol. Advances in Life Sciences. 5(17): 6823-6827.
https://www.researchgate.net/profile/Sunil Chalak/publication/326772804

19. Jozdaemi, E. and A. Golchin. 2017. The effects of Iron fertilization and sulfuric acid application in irrigation water on root growth and chemical composition of bean cultivars in a calcareous soil. UCT Journal of Research in Science, Engineering and Technology. 5(2):8-13.
https://doi.org/10.24200/jrset.vol5iss02pp8-13

20. Kamal, A. M. and A. A. Rashid. 2020. The nature of iron oxide distribution in some calcareous and gypsiferous soils. Tikrit Journal for Agricultural Sciences. 20(2): 107-119.
https://doi.org/10.25130/tjas.20.2.10

21. Khorsandi, F.. 2015. Sulfuric acid effects on iron and phosphorus availability in two calcareous soils. Journal of Plant Nutrition. 17(9):1611-1623.
https://doi.org/10.1080/01904169409364833

22. Kumar, M. S. K. Chaudhary, Shashikant, S., Ravi K., S. K. Singh, M. K. Prabhakar and P. K. Singh. 2023. Effect of boron and zinc on growth and yield attributes in early cauliflower (*brassica oleracea* var. botrytis L.). International Journal of Plant & Soil Science. 35(Issue 6). P: 177-188.
doi: 10.9734/ijpss/2023/v35i62844

23. Mahmood, Y. A., I. Q. Mohammed , Firas W. Ahmed and K. A. Wheib. 2020. Effect of organic, mineral fertilizers and foliar application of humic acid on growth and yield of corn (*Zea mays* L.). Indian Journal of Ecology. 47 Special Issue (10): 39-44.
https://www.researchgate.net/publication/340793103

24. Mam-Rasul, Gh. A.. 2019. Zinc sorption in calcareous soils of the Kurdistan Region of Iraq. Soil Science. 184(2): 60-68.
doi: 10.1097/ss.0000000000000252

25. Narvall, R. P. and B. R. Singh. 2001. Soil phase speciation of iron and manganese in alum shale soils studied by parallel and sequential extraction. Commun. Soil Sci. Plant Anal. 32(Issue 3-4):331-349.
https://doi.org/10.1081/css-100103011

26. Naser, K. M., A. J. H. Al-Tameemi and H. A. Baqir, 2020. Effect of applying selenium element and ascorbic acid on reducing the harmful effect of environmental stress on wheat plants irrigated by water contaminated with lead and cadmium. Plant Archives. 20(1): 1805–1811.
https://www.researchgate.net/publication/349966847_effect_of_applying_selenium_element

27. Pongrac, P.; S. Fischer;J.A. Thompson; G. Wright and Ph. J. White. 2020. Early Responses of *Brassica oleracea* roots to zinc supply under sufficient and sub-optimal phosphorus supply. Front. Plant Sci. 10:1645.
doi: 10.3389/fpls.01645.

28. Reddy, N. S. and K. Kumari. 2022. Importance of zinc in plant nutrition. Asian Journal of Microbiology, Biotechnology and Environmental Sciences. 24(3):490-493.
http://www.envirobiotechjournals.com/article_abstract.php?aid=12864&iid=361&jid=1

29. Rengel, Z., 2015. Availability of Mn, Zn and Fe in the rhizosphere. Journal of Soil Science and Plant Nutrition. 15(2): 397-409.
doi: 10.4067/s0718-95162015005000036

30. Ryan, J. and J. L. Stroehlein. 1979. Sulfuric acid treatment of calcareous soils: effects on phosphorus solubility, inorganic phosphorus forms and plant growth. Soil Science Society of America Journal. 43(4): 731-735.
https://doi.org/10.2136/sssaj1979.03615995004300040022x

31. Salih, H. O. 2021. Effect of fertigation-applied sulfuric acid on phosphorus availability and some microelements for greenhouse cucumber. Polish Journal of Environmental Studies. 30(5):4901-4909.
doi: https://doi.org/10.15244/pjoes/133235

32. Salman, A. D. and A. H. Abdul Razzaq. 2022. Effect of cultivation dates and different sources of soil fertilization on vegetative characteristics, quality and yield of broccoli. International Journal of Agricultural and Statistical Sciences. 18(1): 165-171.
docid:https://connectjournals.com/03899.2022.18.165

33. 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.
doi: 10.1097/ss.0000000000000255

34. Singh, V. and R. Singh. 2017. Effect of zinc nutrition on yield, quality and uptake of nutrients in Cabbage (*Brassica oleracea* L.). Annals of Plant and Soil Research. 19(3): 299-302.
https://www.gkvsociety.com/control/uploads/vinay%20singh%20and%20ranvir%20singh1.pdf

35. White, P. J., P. Pongrae, C. C. Sneddon, J. A. Thompson and G. Wright. 2018. Limit to the bio fortification of leafy brassicas with zinc. Agriculture. 8(3): P:32.
doi:10.3390/agriculture8030032

36. Yesmin, Laila. 2021. Effect of integrated nutrient management on the growth and yield of broccoli (*Brassica oleracea* L. var. italica). Sher-E-Bangla Agricultural University, Dhaka. 11(2): 52-59.
http://archive.saulibrary.edu.bd:8080/xmlui/bitstream/handle/123456789/4084/14-05964.pdf?sequence=1&isAllowed=y