Evaluation of the Efficiency of Chelating Compound Types on Copper Availability and Cauliflower Productivity in Calcareous Soil

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Abstract

The research was conducted in the College of Agricultural Engineering Sciences, University of Baghdad, Al-Jadriya, 7 November, 2024. This aimed at evaluating the effect of the chelating agents on the availability of the selected nutrients in a calcareous soil and the subsequent impacts they have on cauliflower growth parameters and yield. There were three replicates under experimental design of randomized complete block design (RCBD). The use of treatments was random. There were two factors in the experiment. The first factor was composed of the chelating sources, such as organic fertilizer of plant and animal residue which was applied at three rates (0, 5, and 10 kg ha $^{-1}$), and was coded as A, and chelating compounds HEDP and EDDHA which was applied at three rates (0, 10, and 20 kg ha $^{-1}$) and was coded as H. The sub - factor was copper applied at two rates (0 and 5 kg ha $^{-1}$) which were coded as Cu.

Measurement after harvest showed that treatment A 2 has the highest soil content of Cu, K, P, and N at 31.13, 30.0, 215.7, and 1.122mg kg^{-1} soil respectively. Treatment H_2 was also superior whereby the concentrations of Cu, K, P, and N were 32.90, 28.36, 201.6, and 0.922 mg kg^{-1} of soil, respectively. The maximum levels of Cu, K, P, and N were obtained at the level of Cu revised with organic residues that were 30.13, 27.76, 208.4, and 1.432mg kg^{-1} of Cu, K, P, and N respectively, in soil. The level of copper applied at level Cu_1 plus chelating compounds registered 33.93, 29.25, 213.1, and 1.046 mg kg $^{-1}$ soil correspondingly.

The three-way interaction of copper level, source and level of organic residues stated that case $A_2S_2Cu_0$ had the highest concentrations of Cu, K, P, and N to be 35.42, 32.63, 236.3 and 2.63 mg kg^{-1} soil respectively. The combination of the three levels of copper, chelating source and chelating compound levels has proven the superiority of treatment H_2 S_2Cu_1 which registered the highest levels of Cu, K, P, and N levels, at 42.55, 34.53, 257.6, and 1.591 mg kg^{-1} soil respectively.

Keywords: Chelates, Copper, Cauliflower, Calcareous soil, Organic fertilizers, Soil fertility.

Introduction

The soils in Mesopotamia are mainly calcareous and they have a high concentration of calcium carbonate which negatively affects various chemical, physical, and fertility qualities. One of the most significant limiting factors of agricultural productivity of such soils is the high pH of the soil that can also be up to 8.5. It is an alkaline environment that facilitates the precipitation of calcium phosphates,

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decreases the free pH-dependent ions, and may cause metal toxicity. These soils are usually characterized by low amounts of organic matter, accessible nitrogen and micronutrients like iron and zinc and may also have a potassium-magnesium imbalance caused by the antagonism with calcium (Wahba et al., 2019).

Copper is a micronutrient that is necessary in trace amounts as compared to the other macronutrients, nevertheless, it is crucial to growth and life cycle in plants. Copper deficiency interferes with the most crucial physiological functions; in calcareous soils, the occurrence of copper deficiency is common due to the reaction of soluble copper with calcium carbonate and, therefore, reducing its availability (Mohsen Jalali and Ziba Hurseresht, 2020).

Organic fertilizers do not only act as direct providers of plant nutrients but also have indirect effects through enhancement of soil physical, chemical, and biological characteristics. They are instrumental in increasing soil fertility, soil structure and buffering of soils against unwanted pH swings, and form a fundamental part of sustainable farming (Bhatt et al., 2018).

The release of heavy metals and other contaminants into soils is also environmental related issues. In contrast to organic pollutants, heavy metals cannot be mineralised or degraded; they can only be eliminated or immobilised by physical or chemical containment mechanisms. To make the processes of soil washing more effective, sometimes, Chelating compounds are used either directly or in combination with soil washing. The chelate has a wide range of complexing with soil cations and metallic ions making it stable and therefore enhancing metal bioavailability and plant uptake and recovery.

Materials and Methods

The field experiment was conducted in the Research Station E, in the College of Agricultural Engineering Sciences in the University of Baghdad in the autumn period of 20242025. The experimental location is on longitude 44.3749501 o and latitude 33.2680457 o and the texture of the soil at the site will be silty clay. The objective of the study was to test the effectiveness of various types of chelating compounds on copper and on the nutrient availability of the selected nutrients and also on the productivity of cauliflower in a calcareous soil. It was leveled and the field prepared after which the field was subdivided into three replicas. Every replicate consisted of 18 experimental units each 2 3 m in size (6 m^2). The units had four rows and an inter-row distance of 0.7 m and an intra-row distance of 0.4 m. A distance of 1m between adjacent units was maintained.

The experiment followed randomized complete block design (RCBD) where the treatment was randomly assigned to the units of the experiment. Copper was implemented on two levels (0 and 5kg/ha-1). Three rates (0, 5 and 10 t ha^{-1}) of organic fertilizer of plant and animal residue were applied. Two rates of Chelating compounds EDDHA and HEDP were used (0, 10 and 20 kg ha^{-1}).

Composite soil samples were sampled randomly across the whole field at depth of 030cm before planting, air dried, crushed lightly using a wooden hammer after which samples were sieved using a 2mm mesh. .

The chemical, physical and fertility analysis were performed to find out the concentration of nutrients as shown in Table 1.

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Table (1). Chemical, physical, and fertility properties of the soil before planting

Soluble cations and anions Mmole L^{-1}							Soil textue	O.M %	Available Mg kg^{-1}soil			EC $dS.m^{-1}$	pH
CO_3^{2-}	HCO_3^-	Cl^-	SO_4^{2-}	Na^+	Mg^{2+}	Ca^{2+}			K	P	N		
263	1.6	17	3.7	1.09	8	13	Clay	11.2	0.46	5.3	16	2.2	7.6

Results and Discussion

Available nitrogen concentration (mg N kg⁻ ¹ soil) after harvest

Table (2) shows that the level of copper as well as the source and quantity of organic residues had a quantifiable effect on the amount of available nitrogen after harvesting. The highest value of Cu_1 treatment was 30.13mg N kg $^{-1}$soil and the lowest 29.28mg N kg $^{-1}$ soil was recorded under the Cu_0 treatment. The differences between the two copper levels on the other hand were not statistically significant.

The information also shows how the source of organic residues also influenced nitrogen levels. Treatment A_2 produced the highest amount of available nitrogen level at 31.13 mg N kg $^{-1}$ soil, and treatment A_1 the lowest value at 28.28 at mg N kg $^{-1}$ soil. Once again, there were no important differences in sources of residue.

Based on the level of organic residues, treatment S_2 was significantly better with an available concentration of nitrogen of 31.79 mg N kg $^{-1}$ soil. Treatment-S_0 in comparison with other treatments, had the lowest concentration with 26.57mg N kg^{-1} Soil.

The tri-way interaction between copper level, source of residue and the amount of it, demonstrated a strong excellence of treatment $A_2S_2Cu_0$ with the highest available nitrogen concentration 35.42 mg N kg $^{-1}$ soil. The lowest value of 21.43 mg N kg $^{-1}$ soil was encountered in treatment $A_2S_0Cu_0$.

Table (2). Effect of copper level and the source and levels of plant and animal residues on available nitrogen (mg N kg⁻ ¹ soil) after harvest

A	S	Cu0	Cu1	S×A
A_1	S_0	23.10	30.06	26.58
	S_1	29.28	27.15	28.21
	S_2	32.67	27.44	30.05
A_2	S_0	21.43	31.70	26.56
	S_1	33.78	32.81	33.30
	S_2	35.42	31.65	33.53
LSD	5.658			4.448
				Average
Cu×A	A_1	28.35	28.22	28.28
	A_2	30.21	32.05	31.13
LSD	3.276			4.059
				Average
Cu×S	S_0	22.27	30.88	26.57
	S_1	31.53	29.98	30.75
	S_2	34.04	29.54	31.79
LSD	4.225			3.512
Average	Cu	29.28	30.13	
LSD	2.331			

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Table (3) demonstrates the effect of copper concentration and the origin and amount of chelating compounds on the harvest available nitrogen level. The level of treatment Cu_1 was much better and registered a concentration of 33.93mg of N kg^{-1} soil, and treatment Cu_0 registered the lowest level of 30.26mg of N kg^{-1} soil, thus a statistically significant difference was observed.

The source of chelating compounds analysis revealed that the highest nitrogen level at 32.90 mg N kg^{-1} soil was obtained in treatment H_2, whereas 31.29 mg kg^{-1} soil was the lowest level in treatment H_1. The difference between the chelating sources was not notable.

Concerning the amount of chelating compounds, treatment S_2 had a significant edge over the other treatments with the available nitrogen concentration of 36.31mg N kg^{-1} soil. On the other hand, the least concentration was observed in treatment S_0 at 28.44mg N kg^{-1} soil.

Three-way interaction between copper level, chelating compound source, and content of chelating compound underscored that treatment $H_2S_2Cu_1$ had the highest available nitrogen concentration of 42.55-mg N kg^{-1} soil. Minimizing value was found in the treatment of $H_2S_0Cu_0$, 22.83 mg N kg^{-1} soil.

Table (3). Effect of copper level and the source and levels of chelating compounds on available nitrogen (mg N kg^{-1} soil) after harvest

H	S	Cu0	Cu1	H×S
HEDP H1	S_0	24.66	30.53	27.59
	S_1	36.50	29.28	32.89
	S_2	35.09	31.69	33.39
EDDHA H2	S_0	22.83	35.74	29.29
	S_1	26.56	33.78	30.17
	S_2	35.92	42.55	39.23
LSD	7.180			4.691
				Average
Cu×H	H_1	32.08	30.50	31.29
	H_2	28.44	37.35	32.90
	3.929			3.849
				Average
Cu×S	S_0	23.75	33.13	28.44
	S_1	31.53	31.53	31.53
	S_2	35.51	37.12	36.31
LSD	5.311			3.805
Average	Cu	30.26	33.93	
LSD	3.449			

Available phosphorus concentration (mg P kg^{-1} soil) after harvest

Table (4) shows that copper stage, source, and amount of plant and animal residues determine the amount of phosphorus available at the end of harvesting. Treatment Cu_1 showed a big difference with the highest concentration of 27.76mg P kg^{-1} soil and the lowest concentration of

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26.23mg P kg^{-1} soil being recorded under treatment Cu_0.

The details also highlight the impact of sources of residue. Treatment A_2 gave the highest possible concentration of phosphorus at 30.02mg P kg^{-1} soil and treatment A_1 gave the lowest concentration at 23.97mg P kg^{-1} soil. There were no major differences observed between these sources of residues.

In regard to the amount of residue, treatment S_1 was evident with the highest achievable phosphorus concentration of 28.46 mg P kg^{-1} soil. Treatment S_0 on the other hand registered the least, 24.28mg P kg^{-1} soil.

The tripartite interplay of the copper level, residue source, as well as the residue amount, revealed a significant superiority of $A_2S_2Cu_0$, in which the maximum concentration of phosphorus was 32.63 2 mg P kg^{-1} soil. The least value, 21.97 mg P kg^{-1} soil, was recorded in treatment $A_1S_0Cu_0$.

Table (4). Effect of copper level and the source and levels of plant and animal residues on available phosphorus (mg P kg^{-1} soil) after harvest

A	S	Cu0	Cu_1	A×S
A_1	S_0	21.97	22.63	22.30
	S_1	23.30	27.27	25.28
	S_2	22.63	26.03	24.33
A_2	S_0	25.37	27.13	26.25
	S_1	31.77	31.77	31.63
	S_2	32.63	31.70	32.17
LSD	7.270			6.382
				Average
Cu×A	A_1	22.63	25.31	23.97
	A_2	29.83	30.20	30.02
LSD	7.660			8.235
				Average
Cu×S	S_0	23.67	24.88	24.28
	S_1	27.40	29.52	28.46
	S_2	27.63	28.87	28.25
LSD	4.151			3.520
Average	Cu	26.23	27.76	
LSD	1.296			

Available phosphorus concentration (mg P kg^{-1} soil) after harvest

The findings discussed in Table 5 show that copper concentration and the origin and amount of chelating compounds affect the available concentration of phosphorus at harvest. Treatment Cu_1 also performed significantly better with 29.25mg P kg^{-1} soil being its highest phosphorus concentration, 25.13mg P kg^{-1} soil being the lowest phosphorus concentration.

The evaluation of the sources of chelating compounds showed that the greatest phosphorus concentration, which is available, 28.36 mg P kg^{-1} soil, was recorded in treatment H_1, whereas the lowest phosphorus concentration, 26.02 mg P kg^{-1} soil, could be found in treatment H_2. The chelating sources did not experience any significant differences.

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In terms of the number of chelating compounds, treatment I was rather advantaged, as the attained phosphorus concentration was 29.88mg P kg^{-1}soil. On the other hand, 24.12 mg kg^{-1} of P was the lowest value, and occurred in the other treatments.

The three-way interaction among the copper level, the chelating compound source, and the quantity of chelating compounds showed that treatment $H_2S_2Cu_1$, with the highest available phosphorus concentration, 34.53mg kg^{-1} soil, was significantly better. The minimum, 16.87 0 mg P kg^{-1}soil, was obtained in treatment $H_2S_0Cu_0$.

Table (5). Effect of copper level and the source and levels of chelating compounds (EDDHA and HEDP) on available phosphorus (mg P kg^{-1} soil) after harvest

H	S	Cu_0	Cu_1	H ×S
HEDP H_1	S_0	23.70	25.80	24.76
	S_1	33.40	27.27	30.33
	S_2	33.97	26.03	30.00
EDDHA H_2	S_0	16.87	30.10	23.48
	S_1	17.90	30.10	24.83
	S_2	24.97	34.53	29.75
LSD	6.149			4.716
				Average
Cu×H	H_1	30.36	26.37	28.36
	H_2	19.91	32.13	26.02
LSD	5.961			7.717
				Average
Cu×S	S_0	20.28	27.95	24.12
	S_1	25.65	29.52	27.58
	S_2	29.47	30.28	29.88
LSD	4.656			3.832
Average	Cu	25.13	29.25	
LSD	2.609			

Available potassium concentration in soil after harvest

The outcomes of Table (6) show how the level of copper, sources of residues, and amount of residues influence the concentration of potassium available in soil after harvesting. Cu_1 was far much better with the highest concentration of 208.4 mg K kg^{-1} soil, and the lowest concentration of 183.7 mg K kg^{-1} soil was registered in treatment Cu_0.

The data also indicate a large impact that can be attributed to the source of residue. The highest available potassium concentration was measured in treatment A_2 with 215.7 mg K kg^{-1} soil and the lowest value of A1 with 176.4 mg K kg^{-1} soil. Treatment S_1 performed far better in terms of the amount of residue, with the highest value of 206.1mg K kg^{-1} soil, compared to 177.5mg K kg^{-1} soil in treatment S_0.

The three-way interaction between the copper level, source of residues and the amount of residues showed a great superiority of treatment $A_2S_2Cu_0$ which depicted the highest available potassium level of 236.3 mg K kg^{-1} of soil. Under $A_2S_0Cu_0$ treatment, the lowest value of 152.1 mg K kg^{-1}soil was recorded.

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Table (6). Effect of copper level and the source and levels of plant and animal residues on available potassium (mg K kg⁻ ¹ soil) after harvest

A	S	Cu_0	Cu_1	A×S
A_1	S_0	153.0	186.8	169.9
	S_1	168.7	197.4	183.1
	S_2	163.9	188.5	176.2
A_2	S_0	152.1	218.0	185.0
	S_1	228.1	230.0	229.1
	S_2	236.3	229.5	232.9
LSD	17.94			40.14
				Average
Cu×A	A_1	161.9	190.9	176.4
	A_2	205.5	225.8	215.7
LSD	30.31			39.53
				Average
Cu×S	S_0	152.5	202.4	177.5
	S_1	198.4	213.7	206.1
	S_2	200.1	209.0	204.6
LSD	26.33			17.94
Average	Cu	183.7	208.4	
LSD	17.69			

The findings in Table 7 indicate the effect of the copper concentration, the specific sources, and concentrations of chelating agents (EDDHA and HEDP) on the concentration of the available potassium in the post-harvest soil. Treatment Cu_1 produced the best response with the highest level of potassium of 213.1 mg K kg $^{-1}$ soil, and treatment Cu_0 the lowest level of 189.6 mg K kg $^{-1}$ soil.

Comparative analysis of sources of chelating compounds showed that the highest potassium concentration was obtained in treatment H_2, being 201.6mg K kg^{-1} soil and treatment H_1 had a potassium concentration of 201.1mg K kg^{-1}soil; the difference between the two treatments was not statistically significant. On the concentrations of the chelating compounds, treatment S_2 had a better effect with a maximum value of 221.5mg K kg $^{-1}$ soil and the lowest value of 168.3 mg K kg $^{-1}$ soil was recorded under treatment S_0.

The three-way interaction of copper level, source of chelating compounds, and the concentration of chelating compounds showed that treatment $H_2S_2Cu_1$ was the highest and achieved the highest available potassium level of 257.6 mg K kg $^{-1}$ soil. On the other hand, the minimum of 122.1 mg K kg^{-1} soil was the smallest in treatment $H_2S_0Cu_0$.

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Table (7). Effect of copper level and the source and levels of chelating compounds (EDDHA and HEDP) on available potassium (mg K kg^{-1} soil) after harvest

H	S	Cu_0	Cu_1	H ×S
HEDP H_1	S_0	146.2	186.8	166.5
	S_1	241.9	197.4	219.7
	S_2	246.0	188.5	217.2
EDDHA H_2	S_0	122.1	218.0	170.0
	S_1	187.8	230.0	208.9
	S_2	193.9	257.6	225.7
LSD	60.49			43.87
				Average
Cu×H	H_1	211.3	190.9	201.1
	H_2	167.9	235.2	201.6
LSD	39.28			49.18
				Average
Cu×S	S_0	134.1	202.4	168.3
	S_1	214.8	213.7	214.3
	S_2	219.9	223.0	221.5
LSD	42.64			31.10
Average	Cu	189.6	213.1	
LSD	27.32			

Available copper concentration in soil after harvest

In Table 8, it can be seen how the copper levels, the source and holdings of plant and animal residues affect the available copper concentration after harvest. Treatment Cu_1 yielded the maximum copper concentration of 1.432 mg Cu kg^{-1} soil. The impact of organic sources of residue was also of great importance; in this case, the maximum value of 1.122 mg Cu kg^{-1} soil was found in treatment A_2, and a minimum value of 0.959 mg Cu kg^{-1} soil was found in treatment A_1.

In terms of residue levels, the most effective treatment was once more treatment S_2, with an available copper concentration of 1.725 mg Cu kg^{-1} to soil, and the least efficacious was treatment S_0, with 0.446 mg Cu kg^{-1} to soil. The total three-way interacting effect of copper level, source of residue, and concentration of residue showed that treatment $A_2S_2Cu_1$ was the best response, achieving optimum value of 2.63mgCu kg^{-1} soil. The lowest, 0.147 mg Cu kg^{-1} soil, was determined in the condition of treatment $A_1S_0Cu_0$.

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Table (8). Effect of copper level and the source and levels of plant and animal residues on available copper (mg Cu kg^{-1} soil) after harvest

A	S	Cu_0	Cu_1	A×S
A_1	S_0	0.147	0.607	0.377
	S_1	0.759	0.992	0.876
	S_2	0.898	2.352	1.625
A_2	S_0	0.200	0.830	0.515
	S_1	0.879	1.175	1.027
	S_2	1.017	2.633	1.825
LSD	0.6002			0.527
				Average
Cu×A	A_1	0.601	1.317	0.959
	A_2	0.699	1.546	1.122
LSD	0.2913			0.3645
				Average
Cu×S	S_0	0.173	0.719	0.446
	S_1	0.819	1.084	0.951
	S_2	0.958	2.492	1.725
LSD	0.4771			0.4389
Average	Cu	0.650	1.432	
LSD	0.2028			

Table 9 shows how the level of copper, source and dosage of chelating compounds (EDDHA and HEDP) affect the amount of the available copper in the harvest. Again treatment Cu_1 indicated the best result (highest copper concentration) of 1.046 mg Cu kg^{-1} soil, with the lowest result of 0.555mg Cu kg^{-1} soil.
The source of chelating compound was strong and the treatment H_2 resulted in the highest value of 0.922 mg Cu kg^{-1} soil compared to the treatment H_1 which reached the lowest value of 0.610 mg Cu kg^{-1} soil. In the analysis of chelating compound concentrations, both treatments S_1 and S_2 had the best performance with 0.871 mg Cu kg^{-1} of soil, and the lowest one with treatment S_0 had 0.660 mg Cu kg^{-1} of soil.
The three-way interaction of copper level, source of chelating compounds, and chelating compounds proportion showed that treatment $H_2S_2Cu_1$ was significantly better with a available copper level of 1.591 mg Cu kg^{-1} soil. The lowest treatment, 0.311mg Cu kg^{-1} soil, was associated with treatment $H_1S_0Cu_0$.

Table (9). Effect of copper level and the source and levels of chelating compounds (EDDHA and HEDP) on available copper (mg Cu kg^{-1} soil) after harvest

H	S	Cu_0	Cu_1	H ×S
HEDP H_1	S_0	0.311	0.706	0.509
	S_1	0.595	0.783	0.689
	S_2	0.528	0.735	0.631
EDDHA H_2	S_0	0.606	1.017	0.812
	S_1	0.663	1.444	1.054
	S_2	0.629	1.591	1.110
LSD	0.3116			0.2206
				Average

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Cu×H	H_1	0.478	0.741	0.610
	H_2	0.633	1.351	0.992
LSD	0.1688			0.1793
				Average
Cu×S	S_0	0.459	0.862	0.660
	S_1	0.629	1.113	0.871
	S_2	0.578	1.163	0.871
LSD	0.2330			0.1793
Average	Cu	0.555	1.046	
LSD	0.1422			

Tables 2, 4, 6 and 8 together demonstrate that there is an enhancement in the concentrations of Cu, K, P, and N respectively and this is an indication that incorporation of copper levels, copper sources, and plant and animal residue levels have a quantifiable effect in the post-harvest levels of the mentioned elements in the soil.

A number of soil properties determine copper availability. The pH of soils, especially, is a very crucial determinant of copper mobility, as it determines the ability of soils to form soluble species at low-pH values. Also the content of organic matter also regulates copper availability; usage of plant and animal remains can properly reduce the pH of the soil and also serve to fill the soil with organic matter. Copper is also a key factor in the activation of a set of enzymes that are involved in the process of nitrification, i.e. changing ammonium to nitrate, and activating bacteria that fix nitrogen in case of an organic matter presence (Brodowska et al., 2024; Mahmood et al., 2019; Elrys et al., 2024).

Copper indirectly increases the amount of potassium available by competitively adsorbing the already adsorbed potassium on clay minerals, and, therefore, decreases the amount of potassium deposited on soil surfaces. The incorporation of copper guarantees more concentration of this element in the soil by decomposing organic materials that tie copper and keep it in a chelated and easily reachable form besides reducing its linkage with carbonates. The use of copper sulfate in form of fertiliser significantly increases the availability of nutrients, thus positively affecting the crop production and the overall production of agriculture.

In the analysis of sources of plant and animal residues, no significant differences were statistically significant. Comparing the properties of organic fertilisers made of plant and animal material on the nutrient availability, both types have been noted to enhance the soil nutrient density, increase soil organic matter, and promote the well-being of microbes and, consequently, drive nutrient availability (Sheoran et al., 2025; El-Naqma et al., 2023; Mahmood et al., 2020).

Increasing the supply of organic fertiliser changes the physical and chemical properties of soils by significantly decreasing bulk density, enhancing porosity and moisture retention, and affecting the important chemical variables of reducing pH, increasing organic matter and cation-exchange capacity, which increase the store of available nutrients in the soil (Juma et al., 2024).

Plant and animal remains are also involved in the release of nutrients through slow decomposition which sustain balanced nutrient proportions and offer an efficient source of carbon to support microbial growth which on the other hand increases the nutrient availability. K, P, and N are usually abundant in animal residues and moderately high levels of copper can trigger a rapid rise in the available NPK due to the production of complexed and chelated substances (Ahmed et al., 2024). The use of increased concentrations of organic fertiliser also enhances the physical, chemical, and microbiological properties of soil (Alonen et al., 2025) and has a decisive impact on the copper chelation by organic matter, which has a significant effect on its availability (Gamal, 2024; Agbede, 2025; Araujo et al., 2019; Kuziemska et al., 2021).

The findings of Table 3, Table 5, Table 7 and Table 9 demonstrate a significant rise in copper (Cu), potassium (K), phosphorus (P) and nitrogen (N) concentrations respectively. The trend shows that addition of copper at different concentration levels together with the source and use of chelating agents like EDDHA and HEDP has a strong effect on the mobilization of the elements on the soil matrix once harvest has taken place. It is important to note that only a small percentage of copper is dissolved and absorbed into the soil solution but about 98 percent is still in complex state, depending on the presence of organic material and the soil pH level. The chelating agents are organic ligands that form complex with the micronutrient metals to different degrees making them become more bioavailable to plants. The EDDHA complex, specifically, is known to be efficient; it helps in dissolving copper and bringing it out gradually in the calcareous soils with high PH and thus, enhances the extractable fraction of copper. The chemically synthesized polycarboxylates of the amino carboxylate group of chemically react to produce chelating compounds, which are characterized by high stability constants and high nutrient delivery properties (Lopez et al., 2023; Klem et al., 2021). The metal-ion binding capacity permits them to develop stable complexes, which have effects on the cation uptake pathways and modify the soil pH, therefore, modifying both micronutrient and macronutrient profiles. These ligands increase the supply of nitrogen through slow release of metal and copper at optimal levels is essential in nitrification and ammonium oxidation and in activating the soil microbial community, which is a major source of nutrient cycling. Moreover, copper chelation facilitates the accessibility of phosphorus because it inhibits its deposition as copper phosphate (Rijk et al., 2023; Adhikari et al., 2021; Edwards et al., 2013).

The EDDHA chelator can work on a wide range of pH, even to pH 9, whereas HEDP aids in the solubilisation and fixation of phosphorus. Quantitative determination of levels of chelating compounds is used as a measure of sequestration of metal ions, which corrects nutritional deficiencies in the soil, enhancing its physical, chemical, and biological characteristics. These advantages are seen in high nutrient levels after harvest (Zekuan et al., 2022, Bai et al., 2019).

Influence of copper concentration and levels and organic residue source and level on cauliflower curd diameter.

The results presented in Table: 10 show that both the copper level and the source and the amount of organic fertilizer used have a significant effect on the cauliflower curd diameter. Treatment Cu1 was the most preferable and registered the highest curd diameter of 22.77 -1; the lowest curd diameter of treatment Cu0 was recorded 19.24 -1. On organic fertilizer dimension, level S2 was better with a maximum curd diameter of 22.62 cm and level S0 was the worst with a minimum value of 18.84 cm, and there was no significant difference between them. The three-way interaction showed that treatment A2S2Cu0 was superior to all the rest with a curd diameter of 26.22cm, the lowest value of 13.86cm was registered in treatment A1S0Cu0.

The results of Table 11 prove that copper level, the source, and amounts of chelating compounds have a strong impact on the diameter of cauliflower curd. The maximum diameter was 23.22cm in treatment Cu1 and 23.06cm in Cu0 without

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statistically significant difference. The maximum diameter was produced by Chelating compound level S2 (26.32cm) and S0 (20.57cm), Treatment H2 (23.33cm) and H1 (22.95cm) with no statistically significant difference. The relationship between all three factors showed that H2S2Cu1 was the best with a curd diameter of 28.76 cm, H1S0Cu0 was the lowest with a curd diameter of 16.64 cm.

Table (10): Effect of Copper Level, Source, and Levels of Plant and Animal Residues on Cauliflower Flower Diameter (cm)

A	S	Cu_0	Cu_1	A×S
A_1	S_0	13.86	24.17	19.02
	S_1	18.61	23.90	21.26
	S_2	20.79	22.06	21.42
A_2	S_0	14.44	22.89	18.67
	S_1	21.50	22.20	21.85
	S_2	26.22	21.41	23.81
LSD	5.870			5.593
				Average
Cu×A	A_1	17.75	23.38	20.57
	A_2	20.72	22.17	21.44
LSD	5.924			7.180
				Average
Cu×S	S_0	14.15	23.53	18.84
	S_1	20.06	23.05	21.55
	S_2	23.50	21.73	22.62
LSD	3.459			3.044
Average	Cu	19.24	22.77	
LSD	1.699			

Table (11): Effect of Copper Level, Source, and Levels of Chelating Compounds (EDDHA and HEDP) on Cauliflower Flower Diameter (cm)

H	S	Cu_0	Cu_1	H×S
HEDP H_1	S_0	20.80	20.65	20.73
	S_1	26.13	19.81	22.97
	S_2	28.22	22.10	25.16
EDDHA H_2	S_0	16.64	24.17	20.41
	S_1	21.36	22.85	22.10
	S_2	26.20	28.76	27.48
LSD	5.862			5.161
				Average
Cu×H	H_1	25.05	20.85	22.95
	H_2	21.40	25.26	23.33
LSD	4.255			5.542
				Average
Cu×S	S_0	18.72	22.41	20.57
	S_1	23.74	21.33	22.53
	S_2	27.21	25.43	26.32
LSD	4.225			3.781
Average	Cu	23.06	23.22	
LSD	1.982			

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Effect of copper level and organic residue source and levels on total cauliflower yield

Table 12 indicates that the level of copper and the source and amount of organic residues have significant effects on the total cauliflower yield. Cu_1 was the most beneficial treatment with a top yield of 28.83 g ha $^{-1}$ and Cu_0 yielded 25.60 g ha $^{-1}$. The result of treatment A_2 obtained 28.54g ha^{-1} and A_1 obtained 25.88g ha^{-1} without any significant difference between them. S_2 was the most useful with 32.21g ha^{-1}organic residue as compared to S_0 21.73g ha $^{-1}$organic residues. The three-way interaction showed the highest yield of treatment $A_2S_2Cu_1$ of 38.84g ha^{-1} when compared to the lowest yield of 19.81g ha^{-1} in treatment $A_2S_0Cu_0$.

Equally, Table 13 indicates that the level of copper and the source and amount of the chelating compounds have a large effect on overall yield of cauliflower. Treatment Cu_1 once again became the most fruitful with 26.23 g ha^{-1} and Cu_0 posted 23.29 g ha^{-1}. The highest yield is H_2 with the yield of 25.97g ha $^{-1}$, compared to H_1 with the yield of 23.55g ha $^{-1}$, with no statistical difference. Level S_2 of the Chelating compounds gave the highest yield of 29.31g ha $^{-1}$ and S_0 gave 19.78g ha $^{-1}$. $H_2S_2Cu_1$ gave the best value at 35.34 g ha $^{-1}$ and $H_2S_0Cu_0$ was the least productive at 18.03 g ha $^{-1}$.

Table (12): Effect of Copper Level, Source, and Levels of Plant and Animal Residues on Total Yield of Cauliflower (g plant^{-1})

A	S	Cu_0	Cu_1	A×S
A_1	S_0	21.31	23.25	22.28
	S_1	27.31	24.75	26.03
	S_2	25.31	33.35	29.33
A_2	S_0	19.81	22.57	21.19
	S_1	28.50	30.20	29.35
	S_2	31.33	38.84	35.09
LSD	5.593			3.713
				Average
Cu×A	A_1	24.64	27.11	25.88
	A_2	26.55	30.54	28.54
LSD	3.551			4.243
				Average
Cu×S	S_0	20.56	22.91	21.73
	S_1	27.91	27.48	27.69
	S_2	28.32	36.09	32.21
LSD	3.924			2.584
Average	Cu	25.60	28.83	
LSD	2.685			

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Table (13): Effect of Copper Level, Source, and Levels of Chelating Compounds (EDDHA and HEDP) on Total Yield of Cauliflower (g plant⁻ ¹)

H	S	Cu_0	Cu_1	H×S
HEDP H_1	S0	19.39	21.15	20.27
	S1	24.85	22.52	23.69
	S2	23.04	30.34	26.69
EDDHA H_2	S0	18.03	20.54	19.28
	S1	25.94	27.49	26.71
	S2	28.51	35.34	31.93
LSD	5.090			3.379
				Average
Cu×H	H_1	22.42	24.67	23.55
	H_2	24.16	27.79	25.97
LSD	3.232			3.861
				Average
Cu×S	S_0	18.71	20.85	19.78
	S_1	25.39	25.00	25.20
	S_2	25.77	32.84	29.31
LSD	3.571			2.352
Average	Cu	23.29	26.23	
LSD	2.444			

As shown in Tables 10 and 12, addition of copper and its different sources, use of both plant and animal residue also led to a significant gain in the diameter of cauliflower flower and the overall yield. Copper being a vital micro nutrient, coordinates a multitude of biochemical processes ,moderate amounts of supplementation promote its absorption, translocation, and distribution, thereby supporting normal development in plants. Copper levels of plant tissues are closely associated with the concentration levels of copper in the soil, and translocation into the plant. Furthermore, copper is dependent on the control of photosynthesis as well as involvement in electron transport chains of mitochondria and chloroplasts, regulation of metabolic activities that overall affect growth and quality of crops (Wang et al., 2022; Kumar et al., 2021; Chen et al., 2022; Naser et al., 2020). Even though copper is abundant in majority of soils, its bioavailability is regulated by site-specific issues like pH and redox condition. The calcareous alkaline soils with high PH levels and high organic materials tend to be deficient which results in impaired growth and reduced quality of crops.

Plant and animal residues have been found to improve the physical and chemical characteristics of the soil when included in the soil. These amendments increase the biomass of microbes, enzyme activities, and the availability of the micronutrients. They are also used to reduce pH and increase total nitrogen, available phosphorus, exchangeable potassium; such modifications work synergistically to increase plant growth and productivity and quality. Compared to plant residues, animal residues tend to be better because they contain larger amounts of the macro-nutrients nitrogen, phosphorus, and potassium and the micronutrients (Varsha et al., 2022; Shotykow et al., 2020; Cheng et al., 2023). Since cauliflower is a crop with significant nutritional requirements, the supply of soils with the recommended

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amounts of animal residues, which contain both macro- and micronutrients, enhance the soil biological activity, activate plant enzyme systems, and significantly improve soil chemical and physical properties, which have a positive effect on crop growth and quality (Aldolaimy et al.; Mahmood et al., 2020, 2024).

Table 11 and Table 13 further explain that when copper is added to it, its different forms and its chelating agents like EDDHA and HEDP, flower diameter and total yield were significantly enhanced. The accompanying provision of micronutrients like copper plus balanced macronutrients, promotes plant growth and increases the quality of crops (Hasan et al., 2025). Nevertheless, copper bioavailability can significantly decrease in alkaline or organically rich soils even under copper supplementation conditions resulting in dramatic nutrient imbalances that negatively impact production and growth. The cheating agents, binding the micronutrients and transforming them into a solution form, allow the plants to avail the other unavailable nutrients, thus promoting growth and yield (Xu et al., 2024; Manik et al., 2023).

The chelate EDDHA is effective within a wide pH range, as far as soils of pH up to 9. Its use, in the absence of direct deficiency, enhances production, by not allowing the chelate bound micronutrient ions to react with the components of the solutions, so that it protects the micronutrient ions against leaching and allows a controlled uptake by the plant. This reduces the high absorption and maintains the constant supply of nutrients. Moreover, the chelate interacts with micronutrients and inhibits the fixation of phosphorus with a strong chemical bond, which enhances the supply of phosphorus to plants (Klem et al., 2021; Edwards et al., 2013). Chelating compounds in this way enrich the soil microbial communities by alleviating their adverse effects, activate microbes that execute the decomposition of organic substances, and increase the content of vital nutrients, eventually influencing plant growth and the quality of crops (Naz et al., 2024).

Conclusions

An increase in copper level, strategic application of various sources of plant and animal residues, and inclusion of chelating compounds (EDDHA and HEDP) all positively influenced avenues of essential nutrients at the soil level (nitrogen, phosphorus, potassium, and copper) after harvest. These treatments led to larger cauliflower curd diameter and higher total yield, and the strongest effects were observed due to the three-way interaction of copper and the source of residue or chelate and the level of treatment. The results highlight the pivotal position of copper in plant physiology, the importance of organic residues in enhancing physical and chemical properties of the soil, and the ability of chelating agents to increase the availability of micronutrients and reduce fixation, hence leading to crop growth, yield, and quality.

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