LETTERS IN BIOMATHEMATICS
An International Journal

RESEARCH ARTICLE

OPEN ACCESS

Effect of Zeolite and Humic Acid Application and Potassium Levels on Npk Concentration in Plants and on The Growth and Productivity of Cabbage

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ABSTRACT

A field experiment was conducted during the autumn growing season of 2024 at one of the experimental fields of the College of Agricultural Engineering Sciences, University of Baghdad, Iraq (44.38° E, 33.2° N), to investigate the effect of zeolite application, humic acid levels, and potassium fertilization on potassium use efficiency, NPK concentration in plants, growth, and productivity of cabbage (Brassica oleracea L.). The experiment was arranged in a randomized complete block design with three replications and included three factors: zeolite at two levels (0 and 12 t ha^{-1}), humic acid at two levels (0 and 10 L ha^{-1}), and potassium at three levels (0, 50%, and 100% of the recommended fertilizer rate of 125 kg K ha^{-1}), applied as potassium sulfate containing 41.5% K. The results showed significant differences due to zeolite application, where the Z1 treatment (12 t ha^{-1}) produced the highest concentrations of nitrogen, phosphorus, and potassium in the inner leaves (3.94%, 0.41%, and 3.65%, respectively), in addition to the highest total yield (60.4 t ha^{-1}) and the largest head diameter (18.38 cm) compared with the Z0 treatment. The H1 level (10 L ha -1) of humic acid application gave the most favorable levels of nitrogen (3.88), phosphorus (0.39), and potassium (3.52), total yield (62.9 t ha -1) and head diameter (18.18 cm) in terms of the highest concentrations and largest total yield and head diameter respectively compared to the non-application (H0) treatment. Potassium fertilization greatly enhanced phosphorus and potassium levels in the inner leaves to 0.38 and 3.93 respectively and yielded the highest total (66.8 t ha -1) and head diameter (17.79 cm) than potassium non-application (K1). The combination of the triple interaction of zeolite, humic acid, and potassium led to the highest nitrogen, phosphorus and potassium concentration in the inner leaves (4.42%, 0.38 and 4.61, respectively), greatest total yield (75.3 t ha -1), and an overall head diameter of 17.79 cm compared with the Z0H0K1 treatment.

ARTICLE HISTORY
Received September 17, 2026
Accepted October 28, 2026

KEYWORDS
Zeolite, Humic Acids, Potassium, Head Diameter, Cabbage.

1. Introduction

The use of natural zeolite especially the clinoptilolite type is one of the new techniques to enhance the efficiency of potassium use since it has high potassium retention and exchange capacity. This quality minimizes nutrient wastage and increases their longevity to plants (Navya et al., 2024). A number of earlier experiments have demonstrated that changing soil with zeolite enhances potassium absorption, as well as the yield of field crops (Tariq et al., 2023).

Humic and fulvic acids, which are humic materials are significant in enhancing the chemical and biological characteristics of soil. They encourage the establishment of chelated complexes which augment nutrient availability to plants and inflame the activity of enzymes and vegetative growth. It is also observed that humic acids can be used to enhance the uptake of potassium and yield physiological gain and production in various vegetable crops (Abd El-Rheem et al., 2024).

Potassium is among the critical macronutrients in plant growth and plays crucial roles in the regulation of physiological activities like stomatum opening and closing, the activation of most enzymes, photosynthesis and tolerance of plants to stress factors. Although potassium is abundant in the crust of the Earth, the bioavailable form of the nutrient to be taken up by plants is not always available, in particular with light-textured soils or those with low cation exchange capacity (El-Fahdawi et al., 2020; Abd El-Rheem et al., 2024).

The combination of zeolite and humic acids can have synergistic effects on soil, as it will retain potassium over a longer duration and be more effective in plants absorbing it (Elkhatib et al., 2024). Researchers have reported that application of these treatments on vegetable crops like cauliflower and cabbage results in the enhancement of the characteristics of yield as opposed to traditional practices (Shah et al., 2024).

Cabbage (Brassica oleracea var. capitata) is a leafy vegetable economical and nutritionally significant which is a member of the

family Brassicaceae. It needs a balanced nutritional supply especially in potassium because it has a direct impact on the growth of the leaf and formation of the head. Cabbage is a nutriently sound food since it has vitamins A, B, and C, proteins, amino acids, phosphorus, potassium, calcium, iron, zinc, and dietary fibers that help in digestion. According to recent statistics of the Food and Agriculture Organization, the cultivated area worldwide reached 2,412,168 ha with an average yield of 28.77 Mg ha^{-1}, while the cultivated area in Iraq reached 1,122 ha with an average yield of 11.20 Mg ha^{-1} (Ikpeme et al., 2023).

The aim of this study was to evaluate the effect of zeolite application, humic acid levels, and potassium fertilization on NPK concentration in plants and on the productivity of cabbage.

2. MATERIAL AND METHODS

A field experiment was conducted during the autumn growing season of 2024 at one of the experimental fields of the College of Agricultural Engineering Sciences, University of Baghdad, located in the Jadriya area (44.38° E, 33.2° N). The soil of the study area is characterized as level land with a silty texture according to the modern American soil classification system (Soil Survey Staff, 2014). The experiment aimed to investigate the effect of zeolite application and humic acid levels on potassium use efficiency and productivity of cabbage (Brassica oleracea L.).

Pre-plant plowing of the land was done by plowing, harrowing, and leveling by using a five-bottom moldboard plow and mechanical leveling machines. Prior to the commencement of the experiment, the soil samples were selected randomly in various sites in the field and sampled at the depths of 0-30cm. The samples were dried in the air, ground and sieved using a 2-mm sieve. Physical, chemical and fertility tests were done on the site to identify the original soil properties in the experiment site and the findings are in Table 1.

This experiment was designed in the randomized complete block (RCBD) design and had three replicas and three factors. The first factor was zeolite at two levels 0 and 12 Mg ha -1, referred to as Z0 and Z1. The second factor was humic acids with two conditions, 0 and 10 L ha -1, and named H0 and H1, respectively. Potassium was the third variable at three levels of 0, 50, and 100 percent of the recommendation of fertilizer rate (125 kg K ha -1), the potassium sulfate fertilizer with 41.5 percent K, and these were named K1, K2, and K3, respectively. Accordingly, the experiment involved 12 treatments with three replications, and this gave a total of 36 experimental units.

Each experimental unit had an area of 5 m² (2.5 m × 2.0 m) and consisted of four planting rows. The distance between rows was 0.75 m, and the distance between plants within the same row was 0.4 m. A buffer space of 1 m was left between adjacent blocks.

Nitrogen was applied as urea (46% N) at a rate of 150 kg N ha^{-1} in two equal splits, with the first applied at planting and the second 30 days after planting, uniformly across all treatments. Phosphorus was applied as diammonium phosphate (DAP, 21% P) at a rate of 65 kg P ha^{-1} in a single application.

Cabbage seedlings were transplanted during the autumn season on 15 November 2024 using the cultivar ‘Glob Master’. Planting was carried out in rows with a spacing of 0.75 m between rows and 0.4 m between plants within the row. Each experimental unit contained four rows, with five plants per row, resulting in a total of 20 plants per experimental unit.

Table 1. Some physical, chemical, and fertility properties of the soil before planting.

Soil property	Value	Unit
Soil reaction pH (1:1)	7.09	–
Electrical conductivity EC (1:1)	2.10	dS m^{-1}
Organic matter	7.9	g kg^{-1} soil
Total carbonates	261	g kg^{-1} soil
Available nitrogen	15.00	mg kg^{-1} soil
Available phosphorus	5.10	mg kg^{-1} soil
Available potassium	120.1	mg kg^{-1} soil
6		
Sand	482	g kg^{-1} soil
Clay	128	g kg^{-1} soil
Silt	390	g kg^{-1} soil
Soil texture	Loam	–

3. RESULTS AND DISCUSSION

Nitrogen Concentration in Leaves (%)

Table 2 results indicated that differences emerged in the results because of the use of zeolites. Z1 treatment (12 t ha -1) recorded the greatest concentration of nitrogen in the inner leaves at 3.94% that was 40 percent higher than the Z0 treatment that had 2.81%. This is due to the fact that zeolite is able to regulate the release of nitrate and ammonium over time to minimize losses due to ammonia volatilization or nitrate leaching. Also, zeolite enhances the soil water retention and the cation exchange capacity (CEC) to provide a good root environment and increase the rate of nitrogen fixation and storage in plant tissues (Ippolito et al., 2011), which agrees with the results of Szatanik et al. (2021).

There were also significant changes observed in the same table as a result of the use of humic acid. H1 treatment (10 L ha -1) produced the highest nitrogen content in the inner-leaf 3.88 which is 35 percent higher than the H0 treatment which was 2.87. This is because the presence of humic and fulvic acids promotes root growth, increases the rate of density and surface area of root hairs which promotes the uptake of nutrients and promotes metabolic activity including the assimilation of nitrogen. As a result, the plants will become more competent in terms of their ability to absorb the available nitrogen in the soil, which means that humic acids enhance the ability of plants to absorb nitrogen (Mahmood et al., 2020; Ma et al., 2024).

Table 2. Effect of zeolite, humic acids, and potassium levels on nitrogen concentration in inner leaves (%)

Zeolite level	Pot assium level	Humic acid level		Mean Z × K
		Humic acid H0	Humic acid H0	
Z0	K1	2.18	3.32	2.75
	K2	2.19	3.30	2.74
	K3	2.53	3.34	2.93
Z1	K1	3.45	4.44	3.94
	K2	3.42	4.46	3.94
	K3	3.44	4.42	3.93
LSD 0.05		0.35		0.26
Zeolite level		Zeolite × Humic acids		Mean Z
Z0		2.30	3.32	2.81
Z1		3.44	4.44	3.94
LSD 0.05		0.25		0.30
Potassium level		Potassium × Humic acids		Mean K
K1		2.81	3.88	3.35
K2		2.80	3.88	3.34
K3		2.98	3.88	3.43
LSD 0.05			0.24	0.17
Mean H		2.87	3.88	
LSD 0.05		0.18		

The findings in Table 2, also showed that potassium applicability to the soil did not realize any substantial differences in the concentration of nitrogen in inner leaves.

Triple interaction of zeolite, humic acids, and potassium levels also differed significantly in the same table. Z1H1K3 treatment had the greatest nitrogen content in inner leaves of 4.42, whereas Z0H0K1 treatment had a nitrogen content of 2.18. This is explained by the porous nature of zeolite that gives it high cation exchange capacity whereby, nutrients can be absorbed and stored. On top of the soil, zeolite helps to minimize the loss of nitrogen to the atmosphere through volatilization or runoff, retaining nitrogen in the rhizosphere, which plants absorb (سلامة وحبيب , 2019), in line with Kakabouki et al. (2025). Humic acids augment the membrane permeability of cells, leading to uptake of nutrients, consequently elevating the level of nitrogen in the inner leaves (Canellas et al., 2014). Also, sufficient potassium promotes water movement, some physiological functions, enzymatic activities, and osmotic regulation in plants, which increases nitrogen uptake (Zhang et al., 2018), which is in agreement with Al-Hamdani and Al-Hadithi (2017), Al-Barakat et al. (2018), Al-Azzawi (2020), Xu et al. (2020), and Yin et al. (2023).

Concentration Phosphorus in Leaves (%)

The values in Table 3 showed that there were considerable differences between the application of zeolites. Z1 treatment (12 t ha -1) reached the highest phosphorus level in inner leaves 0.41% which is 36 percent higher than the Z0 treatment which had 0.30%. This is explained by the fact that the geometric framework of the zeolite material consists of the channels and cavities that are interconnected and increase adsorption capacity and the capacity to hold the water and nutrients (Jarosz et al., 2022), which is consistent with the observations of Hashemi (2025).

Table 3. Effect of Zeolite, Humic Acids, and Potassium Levels on Phosphorus Concentration in Inner Leaves (%)

Zeolite level	Potassium level	Humic acid level		Mean Z × K
		Humic acid H0	Humic acid H0	
Z0	K1	0.26	0.32	0.29
	K2	0.26	0.35	0.30
	K3	0.26	0.35	0.31
Z1	K1	0.33	0.43	0.38
	K2	0.39	0.44	0.42
	K3	0.43	0.46	0.45
LSD 0.05		0.03		0.02
Zeolite level		Zeolite × Humic acids		Mean Z
Z0		0.26	0.34	0.30
Z1		0.38	0.44	0.41
LSD 0.05		0.01		0.008
Potassium level		Potassium × Humic acids		Mean K
K1		0.29	0.38	0.33
K2		0.32	0.40	0.36
K3		0.35	0.41	0.38
LSD 0.05		0.02		0.17
Mean H		0.32	0.39	
LSD 0.05		0.01		

Table 3 also provided significant results that were attributed to application of humic acid. H1 treatment (10 L ha -1) had the highest phosphorus content in the inner leaves, 0.39, which was a 21% increment than H0 treatment, which registered 0.32. It is explained by the fact that humic acids increase the nutrient absorption and improve the soil conditions, especially in the soils with low organic matter content (Eyheraguibel et al., 2008). Humic acids also elevate the rhizosphere population of microorganisms, which improve the availability of phosphorus (Marschner et al., 2010), which is also found by Mahmood et al. (2019) and Al-Mashhadani (2021).

There were also significant differences that were attributable to the application of potassium. K3 treatment (125 kg K ha -1) gave the highest phosphorus concentration in inner leaves 0.38%, which was 15 percent higher than that of K1 treatment which was 0.33%. Sufficient potassium raises cation exchange capacity (CEC) and accelerates microbial activities, which facilitates the release of phosphorus. Potassium as well enhances the growth of roots, enabling them to browse more soil volume and assimilate more nutrients, including phosphorus (Bsghour et al., 2001; Havlin and Heiniger, 2020), which is in line with Meenakshi et al. (2025) and Bayindir et al. (2025).

Triple interaction of zeolite, humic acids, and potassium had a strong influence on phosphorus concentration in which the Z1H1K3 had a concentration of 0.46% compared to Z0H0K1 at 0.26%. This is explained by the improved growth of root systems and a decrease in phosphorus fixation in the soil, which is more accessible by plants (Havlin et al., 2017), as it is in accordance with Al-Dhallimi (2021) and Legese et al. (2024).

Potassium Concentration in Leaves (%)

Table 4 results indicated that there were significant differences because of the use of zeolites. The highest potassium level in inner leaves was observed under Z1 treatment (12 t ha -1), 3.65%, which is a 39-percent increase over the Z0 treatment, which attained a value of 2.62. This is explained by the fact that zeolite helps to decrease the potassium leaching and fix potassium in the soil, and also,

through cation exchange, zeolite provides potassium and other nutrients to the roots, which could be absorbed by roots (Reyes- Jimenez et al., 2023), which agrees with Abbas (2023).

Table 4. Effect of Zeolite, Humic Acids, and Potassium Levels on Potassium Concentration in Inner Leaves (%)

Zeolite level	Potassium level	Humic acid level		Mean Z × K
		Humic acid H0	Humic acid H0	
Z0	K1	1.78	2.07	1.92
	K2	2.48	2.81	2.64
	K3	3.25	3.34	3.30
Z1	K1	2.29	2.67	2.48
	K2	3.21	4.61	3.91
	K3	3.51	5.62	4.57
LSD 0.05		0.17		0.17
Zeolite level		Zeolite × Humic acids		Mean Z
Z0		2.50	2.74	2.62
Z1		3.00	4.30	3.65
LSD 0.05		0.18		0.22
Potassium level		Potassium × Humic acids		Mean K
K1		2.03	2.37	2.20
K2		2.85	3.71	3.28
K3		3.38	4.48	3.93
LSD 0.05		0.08		0.06
Mean H		2.75	3.52	
LSD 0.05		0.06		

able 4 revealed that there was a significant variation of the results with the use of humic acid. H1 treatment (10 L ha -1) had the highest level of potassium in inner leaves 3.52% which is an increment of 28 percent as compared to H0 treatment which had 2.75 percent. This is due to the fact that humic acids increase the availability of potassium. Humic acids contain significant negative charges (phenolic and carboxylic) which aid in cation exchange and release potassium ions on surfaces of the micropores or clay minerals. This increases the potassium solubility and movement in the soil solution. They increase the size of roots and outgrowth when the amount of potassium and humic acids is adequate, enhancing the absorption and concentration of potassium in plant tissues (Shah et al., 2018; Kareem et al., 2025; Canellas et al., 2024; Souza et al., 2022).

A lot of variation was also brought about by the application of potassium. K3 treatment (125 kg K ha -1) was the one that got the highest concentration of potassium in the inner leaves, 3.93, which is 78% higher than that of K1 which was 2.20. This is explained by the presence of potassium content in the used fertilizer (potassium sulfate), which raises the concentration of potassium in the soil solution that allows uptake and translocation of potassium in the roots of the plant (Dokbua et al., 2021; Huai et al., 2022; Al-Tameemi et al., 2024).

Triple zeolite, humic acid, and potassium interaction had a significant impact on the concentration of potassium. The highest concentration of 4.61% was registered by Z1H1K3 compared to 1.78% of Z0H0K1. This is attributed by the fact that zeolite helps in the retention of potassium ions and inhibits their depletion in the rhizosphere, which serves as a slow-release storage of potassium (Mondal et al., 2021). The humic acids increase the cell membrane permeability and root structure, activate potassium transporters, and applied potassium, together with zeolite and humic acids, maximizes potassium intake (Jun et al., 2017); Dincsoy et al., 2019).

Total Yield of Cabbage

Table 5 shows significant differences in total cabbage yield due to zeolite application. The Z1 treatment (12 t ha^{-1}) achieved the highest total yield, 60.4 t ha^{-1}, compared with 57.9 t ha^{-1} for Z0. This effect is attributed to zeolite's porous structure and large surface area, which improves soil physical and chemical properties, retains water, and increases soil moisture. These conditions enhance root growth, nutrient and water uptake, and reduce nutrient losses through leaching, volatilization, or fixation (Mondal et al., 2021; Saleh, 2023).

Humic acid application also significantly affected total yield. The H1 treatment (10 L ha^{-1}) achieved 62.9 t ha^{-1} compared with 55.4 t ha^{-1} for H0. Humic acids improve soil structure by increasing porosity and moisture, promoting deeper and larger root systems for

efficient nutrient and water absorption. They also enhance nutrient availability by releasing nutrients from unavailable forms, providing plants with greater nutrient access (Liu, 1998; Mahmood et al., 2020; Al-Abody et al., 2021; Juma et al., 2024).

Table 5. Effect of Zeolite, Humic Acids, and Potassium Levels on Total Cabbage Yield (t ha^{-1})

Zeolite level	Potassium level	Humic acid level		Mean Z × K
		Humic acid H0	Humic acid H0	
Z0	K1	44.3	62.3	53.3
	K2	56.0	53.3	54.7
	K3	66.3	65.3	65.8
Z1	K1	54.0	63.7	58.8
	K2	52.0	57.3	54.7
	K3	60.0	75.3	67.7
LSD 0.05		6.23		4.42
Zeolite level		Zeolite × Humic acids		Mean Z
Z0		55.6	60.3	57.9
Z1		55.3	65.4	60.4
LSD 0.05		5.11		2.01
Potassium level		Potassium × Humic acids		Mean K
K1		49.2	63.0	56.1
K2		54.0	55.3	54.7
K3		63.2	70.3	66.8
LSD 0.05		4.54		3.47
Mean H		62.9	55.4	
LSD 0.05		2.92		

Table 5 results also indicated significant differences between the results based on the application of potassium. The total yield of the K3 treatment (125 kg K ha -1) was 66.8 t ha -1 as compared to 56.1 t ha -1 with K1. With the necessary role in physiological processes, including stomatal control, osmotic adaptation, sugar delivery, and the activation of key enzymes, which are beneficial to plant development, the growth of the plant is increased with the addition of potassium (Polara et al., 2009; Xu et al., 2020), which is congruent with the findings of Rani et al. (2021), Choudhary et al. (2024), and Al-Maamori et al. (2025).

The zeolite, humic acids, and potassium triplet interaction had a great impact on the total yield. Z1H1K3 treatment had the highest total yield of 75.3 t ha -1 as compared to Z0H0K1 which was 44.3 t ha -1. It has been enhanced by the synergistic effect of the three factors, i.e., zeolite offers a porous structure that retains nutrients and water during the rhizosphere (Mondal et al., 2021), humic acids increase the rhizosphere root structure and permeability of the cell membrane (Al-Abody et al., 2021), and potassium regulates the osmotic pressure, stomatal activity, and other physiological functions to produce high-quality yield (Rani et al., 2021

Cabbage Head Diameter

Table 6 results depicted that there were significant differences in results with the application of zeolites. Z1 (12 t ha -1) had the highest cabbage head diameter, 18.38 cm which is a 4% increase over Z0 which registered 14.5 cm. This is due to the porous nature and cation exchange capacity of zeolite (Ca 2 +, K 2 +, NH 4 2 +), which prolongs the nutrient retention in the rhizosphere, enhancing the availability of nitrogen and potassium during the head formation (Nooprom et al., 2022) in agreement with Al-Kabi et al. (2025).

Table 6. Effect of Zeolite, Humic Acids, and Potassium Levels on Cabbage Head Diameter (cm)

Zeolite level	Potassium level	Humic acid level		Mean Z × K
		Humic acid H0	Humic acid H0	
Z0	K1	12.24	15.54	13.89
	K2	13.09	15.62	14.36

	K3	14.15	16.63	15.39
Z1	K1	16.02	17.36	16.69
	K2	15.91	20.64	18.27
	K3	17.09	23.28	20.18
LSD 0.05		1.20		0.82
Zeolite level		Zeolite × Humic acids		Mean Z
Z0		13.16	15.93	14.55
Z1		16.34	20.42	18.38
LSD 0.05		0.50		0.21
Potassium level		Potassium × Humic acids		Mean K
K1		14.13	16.45	15.29
K2		14.50	18.13	16.32
K3		15.62	19.95	17.79
LSD 0.05		0.89		0.70
Mean H		14.75	18.18	
LSD 0.05		0.51		

Table 6 also revealed that there was a significant difference in the results due to the application of humic acid. H1 (10 L ha -1) gave a cabbage head diameter that was at 18.18 cm or a 14 per cent higher than H0 where 14.75 cm was observed.

Strong variations were found with the use of potassium. The K3 solution (125 kg K ha -1) gave a cabbage head diameter of 17.79 cm, which is 19% more than that of K1 that was 15.29 cm. The reason is that potassium is required by the plant during the head formation, which provides energy and sugars and enhances the transportation of water and nutrients, resulting in an increase in the diameter of the head (Guo et al., 2007; Ali et al., 2014; Choudhary et al., 2024).

The triple interplay among potassium, humic acids and zeolite had a great impact on the diminution of cabbage head. The diameter of the Z1H1K1 treatment was 23.28 cm as opposed to 12.24 cm in Z0H0K1 treatment. Proper potassium increases the plant nutrient uptake and translocation that facilitates physiological activities including photosynthesis and sugar transportation that lead to increased head size (Khatun et al., 2008; Ali et al., 2022)..

4. CONCLUSION

This experiment showed that the use of zeolite and humic acids at varying levels of potassium aided in enhancing the availability of nutrient in the soil that consequently raised the concentrations of the NPKs in cabbage leaves. Zeolite increased the cation exchange capacity (CEC) of the soil and prevented nutrient loss whereas humic acids boosted the root absorption and the efficiency of using the fertilizer. Zeolite, humic acid, and potassium combination is a viable approach that can maximize nutrition of plants, enhance their production, and minimize the use of nutrients in agriculture.

5. ACKNOWLEDGEMENT (If any)

The authors gratefully acknowledge the Department of Soil Science and Water Resources, College of Agricultural Engineering Sciences, University of Baghdad, for providing facilities and technical support. Special thanks are extended to Dr. Sinan Samir Juma for his supervision, guidance, and continuous support throughout this research.

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