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Interactive Effects of Foliar-Applied Nano NPK and Humic Acid on Growth and Yield of Broccoli (*Brassica oleracea* var. italica)

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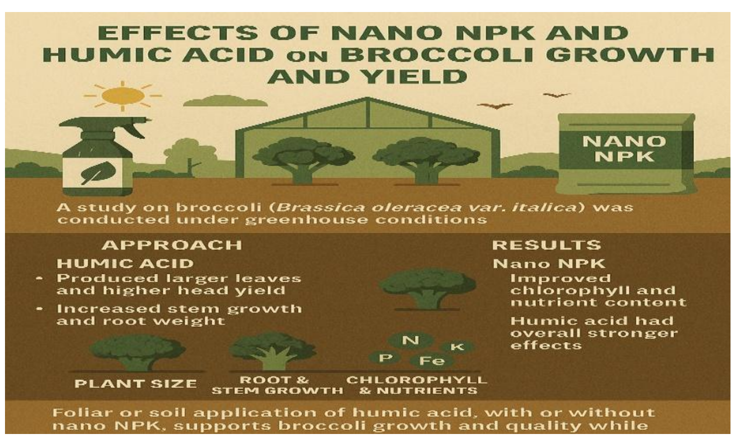
Abstract

In field conditions, the effect of nano NPK fertilizers and humic acid treatments as foliar spray on growth, yield, and nutrient content of broccoli (*Brassica oleracea* var. italica) in a greenhouse was applied. A field experiment was conducted (2022-2023 seasons) under greenhouse conditions at Bakrajo Technical Institute of Sulaimani by using RCBD with synthetic nano as fertilizer at (0, 2.0 gm, 4.0 gm, and 6.0 gm L^{-1} and humic acid at 0, 2.5, 4.5, and 6.5 ml L^{-1} and drawing on two weeks, then repeating them after a space of two weeks for six weeks. Plants were analyzed for a range of traits such as plant size, root and stem growth, chlorophyll levels, yield, and mineral content. The results showed that while both treatments improved broccoli performance, humic acid consistently had the strongest impact. Plants treated with humic acid—especially at 2.5 to 6.5 ml L^{-1} produced larger leaves, thicker stems, greater root weight, and higher head yield. The highest yield ever witnessed has been 7.54 tons per hectare under 2.5 ml L^{-1} humic acid treatment. There are also significantly higher levels of chlorophyll content and uptake of essential nutrients such as nitrogen, phosphorus, potassium, and iron in these treatments. Nanoparticulate NPK induced improvements, mostly with chlorophyll content and nutrient content, but its effects were mostly overshadowed by humic acid. All in all, this implies the application of humic acid with or without nano NPK in the production of broccoli goes well environmentally and supports the growth and quality of broccoli. This thesis strengthens the claim that combining organic biostimulants with modern nutrient delivery methods could help farmers gain better yields while cutting down on the use of standard chemical fertilizers. A path of sustainable development in present-day horticulture.

Key words: Foliar-Applied, Nano NPK, Humic Acid, Growth, Yield, Broccoli



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I. Introduction

The broccoli plant (*Brassica oleracea* var. italica) is a cruciferous vegetable known for offering nutritional and other health benefits. Containing vitamins A, C, and K, fiber, minerals, and bioactive compounds like glucosinolates and sulforaphane, broccoli is cited as a promoter of health properties and is highly anticancer (AL Salihi & Mahmood, 2020; Halshoy et al., 2023). Due to rising health awareness, consumption of broccoli on the international platter has gone up. Getting a higher yield and quality in broccoli cultivation is truly a big challenge. For meeting nutrient requirements of crops, traditional agricultural practices rely heavily on chemical fertilizers. This is less so in the short term, but prolonged application and heavy doses can engender environmental issues, including soil degradation, water pollution, and greenhouse gas emissions (Tilman et al., 2002). There, thus, exists an urgent need for sustainable fertilization practices that not only mitigate environmental impacts but also support crop productivity. Nanotechnology is fast becoming a promising solution in agriculture: it proposes to increase nutrient use efficiency and crop productivity.

Due to their particle size in the nanoscale (1–100 nm), nano fertilizers possess unique properties such as high surface area, increased solubility, and controlled release, all of which help in better uptake of nutrients by plants (DeRosa et al., 2010, Ahmed et al., 2024). Nano NPK fertilizers, composed of nitrogen (N), phosphorus (P), and potassium (K) in nanoparticulate form, have thus been said to be raising prospects for several plant growth components and yield characteristics. Foliar application imparts nutrients directly into plant tissues and thereby reduces nutrient losses through leaching or volatilization (Subramanian et al., 2015). Liu et al. (2025) state that foliar application of nano-NPK fertilizers increases chlorophyll content and photosynthesis rate and biomass accumulation in several crops, including broccoli. The impact of nano fertilizers on the cultivation of broccoli has been studied at length in recent times. As an example, it was estimated through Liu et al. (2025) that nano-fertilizer application increases nutrient absorption by broccoli, vitamin C and amino acid content, and photosynthesis, which subsequently improves soluble sugar content and thereby quality. Humic matter, and more particularly humic acid, are organic compounds arising from the decomposition of plant and animal residues. These substances are important in maintaining soil fertility and promoting the nutrition of plants because they improve soil structure, nutrient availability, and the physiological processes of plants (Canellas et al., 2015).

Foliar application of humic acid enhances the nutrient uptake by plants and stimulates root growth while boosting stress tolerance (Nardi et al., 2002; Al-douri & Al-Douri, 2024). Hence, applying humic acid to broccoli cultivation greatly increased plant growth parameters such as plant height, leaf area, and weight of heads. For instance, according to research done in the University of Sulaimani, foliar application of Humic acid at 2.5, 3.5, and 4.5 ml/L concentrations significantly raised the height of the plant, the fresh weight of the main head, and the total yield of broccoli (Hawall et al., 2018). Similarly, another study mentioned that foliar application of humic acid enhanced the agronomic growth, total yield, and head quality of broccoli plants grown under saline water irrigation conditions (Selim & Mosa, 2012). Both nano NPK fertilizers and Humic acid are effective in improving plant growth and yield; therefore, a combined application may have synergistic effects. The synergism between nano fertilizers and Humic substances may lead to better nutrient uptake, enhanced hormonal activities, and better overall plant health, as compared to their separate application (Moradinezhad & Ranjbar, 2024). Limited research exists regarding the interactive effect of foliar nano NPK and Humic acid, especially for broccoli cultivation. Nevertheless, this has yielded positive results in other crops. For instance, it was found that the combination of nano NPK and Humic acid improved seed yield and oil content of black cumin (Nigella sativa) more promisingly than their individual applications (Safaei et al., 2014). It can be hypothesized that such synergism may be achieved in broccoli, and more research is needed in this respect. This work is intended to study the individual effects of foliar application of nano NPK and humic acid on the growth and yield of broccoli, interactive effects of combined foliar application of nano NPK+ humic acid for better performance of broccoli, and to fix on suitable concentrations and frequencies of foliar application to enhance the growth and yield of broccoli.

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II. Material and Methods

1. Experimental Site:

The field experiment was set up in greenhouses at the Bakrajo Technical Institute, an integral part of Sulaimani Polytechnic University, during the growing season of 2022–2023. The site is located at an altitude of 838 eit **(Abdullah et al., 2015).** The area is known for its temperate climate, with moderate temperatures and relative humidity. Before planting, the soil was analyzed and identified as clay loam, as presented in Table 1.

Table 1: Soil traits of experimental site: Site

Properties	Sand gKg^{-1}	Silt gKg^{-1}	Clay gKg^{-1}	EC dsm^{-1}	pH	N $mgKg^{-1}$	Available p $mgKg^{-1}$	Soluble K^+ (mM.L-1)
Sample	121.3	457.6	421.1	0.34	7.1	0.14	31.2	0.29

The soil analysis was conducted by the Directorate of the Agricultural Research Center in Sulaimaniyah.

2. Plant Material, Land Preparation, and Cultivation

The soil was thoroughly plowed and leveled before transplanting. Healthy broccoli seedlings (*Brassica oleracea* var. *italica*, cultivar: Tokita), aged 30–40 days, were transplanted on October 23, 2022. The seedlings were planted in rows with a spacing of 40 cm between plants and 60 cm between rows. Harvesting took place from December 15, 2022, through January 2023. Throughout the growing season, temperatures ranged between 10°C and 30°C. Standard crop management practices were uniformly applied across all treatments, including pest and disease control.

Drip irrigation was used consistently throughout the experimental period. The experiment consisted of four blocks, each comprising seven treatments. To evaluate the effects of the treatments, five representative plants were selected per treatment for data collection based on observable growth and yield characteristics during the growing period.

2. Experimental Design

A factorial experiment (4 × 4) was conducted using a randomized complete block design (RCBD) with three replications. The study included two main factors:

1. Nano foliar fertilization with balanced NPK (20-20-20) at four concentrations:
   - Control (no application)
   - Low concentration (2 g L^{-1})
   - Medium concentration (4 g L^{-1})
   - High concentration (6 g L^{-1})
2. Humic acid at four different levels:
   - 2.5 $ml.L^{-1}$
   - 4.5 $ml.L^{-1}$
   - 6.5 $ml.L^{-1}$

4. Treatment Application

Nano NPK foliar fertilizer was applied using a handheld sprayer, beginning in the third week after transplanting. Applications were repeated every 15 days for a total of six weeks. Humic acid was also applied as a foliar spray half an hour after the NPK treatment, following the same schedule of 15-day intervals for six weeks.

5. Data Collection and Measurements

Data were collected at various stages of plant growth. The following parameters were measured:

- Leaves numbers
- Plant height (cm)
- Stem diameter (mm)
- Head weight (g)
- Head diameter (cm)
- Stem length (cm)
- Root weight (g)

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- Root length (cm)
- Chlorophyll content (SPAD value)
- Leaf width (cm)
- Leaf length (cm)
- Leaf surface area (dm^2)
- Dry matter content (%)
- Moisture content (%)
- Total yield (kg/dunum or tons/hectare)

6. Chemical Analysis

In addition to the agronomic parameters, chemical analyses were conducted to determine nutrient content in head, including nitrogen (N), phosphorus (P), potassium (K), and iron (Fe)—from the experimental plots. Standard procedures were followed, and results were expressed in appropriate scientific units.

7. Statistical analysis

Statistical analysis of the recorded data was performed using analysis of variance (ANOVA) based on the randomized complete block design (RCBD), following the method described by Stell et al., (1980). The least significant difference (LSD) test at a 5% probability level was applied to compare treatment means.

III. Results and Discussion

3.1 Effects of Nano NPK and Humic Acid on Vegetative Growth Traits

Table 2 reveals that both nano NPK and Humic acid positively impacted the vegetative growth of broccoli, though Humic acid consistently outperformed nano NPK across key traits. The most notable difference appeared in leaf area: plants treated with 6.5 $ml.L^{-1}$ Humic acid developed the largest leaves, up to 12.6 dm^2, significantly more than those treated with nano NPK, especially at 2 and 4 $g.L^{-1}$. This reflects the ability of humic substances to enhance leaf expansion through improved photosynthesis and cell division (Canellas et al., 2023; Calvo et al., 2014). Leaf length and width followed the same pattern, with the longest and widest leaves resulting from 6.5 and 2.5 $ml.L^{-1}$ Humic acid treatments. These effects likely stem from humic-induced stimulation of auxins and cytokinins, which promote leaf development (Trevisan et al., 2011; Maffia et al., 2025). Conversely, while nano NPK fertilizers offer advanced nutrient delivery due to their small particle size, their performance at lower doses may be limited by uptake efficiency or inadequate root stimulation (Solanki et al., 2015). In terms of leaf number, the difference between treatments was less pronounced but still favored Humic acid. The highest count, 19.4 leaves, occurred under 2.5 $g.L^{-1}$ Humic acid, though this was not statistically different from the control or 6 $g.L^{-1}$ nano NPK. Still, Humic acid treatments generally produced slightly more leaves, possibly due to better nutrient absorption and enhanced root development (Zulfiqar et al., 2020). Statistical analysis using LSD at the 5% level confirmed that differences across treatments were significant for most traits. Treatments sharing the same letter in the table indicate no significant difference, yet the overall trend supports the superior effectiveness of Humic acid. Its biostimulant nature—stimulating enzyme activity, improving root-soil interaction, and enhancing plant stress tolerance—adds to its agronomic value (Canellas et al., 2024; Yakhin et al., 2017). Although nano NPK fertilizers have potential in precision agriculture, Humic acid, particularly at concentrations between 2.5 and 6.5 g/L, demonstrated a more pronounced effect on broccoli's vegetative growth under greenhouse conditions. These findings suggest that Humic acid is not just a supplementary input but a sustainable, biologically active agent that can significantly enhance plant performance.

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Table 2: Interactive Effects of Foliar-Applied Nano NPK and Humic Acid on Some Growth Traits of Broccoli

Treatments		**Traits**			
		leaf area	**leaf length**	**leaf width**	**leaf no.**
Nano particles	**Control**	10.626 a	47.240 b	19.420 b	18.400 a
	2 gm	6.730 b	41.680 c	16.880 c	16.400 bc
	4 gm	6.732 b	38.820 c	15.140 c	16.000 c
	6 gm	7.598 b	40.240 c	16.940 c	18.400 ab
Humic acid	**2.5 ml**	11.142 a	52.320 a	21.640 a	19.400 a
	4.5 ml	12.314 a	53.920 a	21.220 ab	17.600 abc
	6.5 ml	12.616 a	54.420 a	21.220 ab	18.200 ab
LSD		**2.131**	**3.342**	**1.485**	**1.536**

Similar letters in the same column indicate no significant differences (P>0.05).

3.2 Effects of Nano NPK and Humic Acid on Root and Stem Traits

Table 3 presents an overview showing the interactive effects of nano NPK and Humic acid foliar application on some root and stem characteristics of broccoli, viz. root length, root weight, stem diameter, and stem length. It was found that while the variable termed root length seemed to remain stable among treatments, whereby values ranged between 14.26 and 16.80, no significant differences were observed ($P > 0.05$). Thus, it may be concluded that neither nano NPK nor Humic acid caused a noticeable effect on root elongation under the conditions of this experiment, which partly supports past studies because they found that root length varies under nutrient-applying environments (Maffia et al., 2025). Conversely, root weight revealed clear treatment differences. The maximum root weight accumulation was 26.79 g in plants treated with 2.5 $g.L^{-1}$ Humic acid, which was significantly higher than the lowest recorded root weight of 14.83 g seen in the plants treated with 2 $g.L^{-1}$ nano NPK. Thus, humic substances seem to enhance root biomass formation possibly by enhancing root nutrient uptake and stimulating root cell division (Calvo et al., 2014; Zulfiqar et al., 2020). Furthermore, humic materials stimulate root branching, thereby increasing their surface area for nutrient absorption, minimizing the vigor of the plant (Canellas et al., 2024). Stem diameter was another aspect where humic acid treatments' service was given better performance compared to nano NPK; hence, the thickest stems of 39.92 mm were obtained from the 4.5 $ml.L^{-1}$ concentration of Humic acid, with further slight decreases with the 6.5 $ml.L^{-1}$ and 2.5 $ml.L^{-1}$ treatments. On the other hand, nano NPK at 2 and 4 $g.L^{-1}$ created stems that were significantly thinner. Also, these results indicate that humic acid can enhance below-ground development and strengthen above-ground sturdiness, perhaps by interacting with secondary growth and vascular differentiation (Trevisan et al., 2011; Yakhin et al., 2017). Regarding stem length, the differences were fewer and less consistent. The control group showed the tallest stems (21.76 cm), but this value was not statistically different from most treatments. Interestingly, the shortest stems (18.48 cm) were observed with the 6.5 $ml.L^{-1}$ Humic acid treatment, indicating a potential trade-off between stem elongation and stem thickening or a hormonal shift toward radial growth. This aligns with previous work suggesting that humic substances may modulate gibberellin levels, which could influence stem elongation (Maffia et al., 2025). Humic acid demonstrated a clear advantage in increasing root weight and stem thickness, outperforming nano NPK in these traits. However, its effects on root length and stem height were limited or inconsistent. These results reinforce the role of humic acid as a biostimulant that enhances nutrient use efficiency, structural development, and overall plant resilience, particularly under greenhouse conditions.

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Table 3: Interactive Effects of Foliar-Applied Nano NPK and Humic Acid on Some Root and Stem Traits of Broccoli

Treatments		Traits			
		root length	**root weight**	**stem diameter**	**Stem length**
Nano particles	**Control**	16.800 a	22.359 ab	34.990 bc	21.760 a
	2 gm	15.020 a	14.830 c	31.740 c	20.520 ab
	4 gm	15.300 a	18.020 bc	31.380 c	20.420 ab
	6 gm	16.320 a	19.006 bc	31.880 c	19.400 b
Humic acid	**2.5 ml**	16.320 a	26.792 a	38.460 ab	20.220 ab
	4.5 ml	14.260 a	22.102 ab	39.920 a	20.320 ab
	6.5 ml	16.560 a	18.292 bc	38.540 ab	18.480 b
LSD		**2.59**	**4.652**	**3.608**	**1.905**

Similar letters in the same column indicate no significant differences (P>0.05).

3.3 Effects of Nano NPK and Humic Acid on Plant Productivity and Head Traits

Table 4 highlights the comparative effects of foliar-applied Humic acid and nano NPK on broccoli productivity and head development. Across all measured traits—plant weight, plant height, and head diameter—Humic acid consistently outperformed nano NPK, particularly at 2.5 and 6.5 ml L^{-1} concentrations. These treatments led to the highest yields, reaching 301.6 kg/dunum (7.54 t/ha) and 290.0 kg/dunum (7.25 t/ha), respectively. Conversely, Nano NPK at 4 and 6 $g.L^{-1}$ brought about significantly lesser plant weights with yields of 114.0 and 127.0 kg/dunum, respectively. These findings are consistent with earlier findings that humic substances increase the uptake of nutrients and stimulate metabolism as well as the buildup of biomass (Al-Falahi et al., 2022; Chen et al., 2022). Height showed the same trend. The tallest broccoli plants, measuring 67.8 cm and 67.0 cm, were recorded under 6.5 and 2.5 ml L^{-1} Humic acid treatments, while nano NPK, particularly 6 g/L, produced significantly shorter plants (55.6 cm). This may be due to Humic acid enhancing root activity and water uptake, which in turn promote vigorous shoot development (Filho et al., 2020). Humic substances are also known to enhance the activity of cytokinins and auxins, which direct shoot elongation and structural integrity (Abdel-Razzak & El-Sharkawy, 2013). Head diameter—another vital feature for marketable yield in broccoli—further emphasized the value of Humic acid. The 2.5 ml L^{-1} application produced the largest heads (21.44 cm), followed by 4.5 ml L^{-1} (19.32 cm) and 6.5 ml L^{-1} (18.20 cm). In contrast, the smallest heads (12.04 cm) were found in the 6 g/L nano NPK treatment, reflecting a less favorable response to high nano fertilizer concentration. Humic substances may promote assimilate partitioning and enhance sink strength, resulting in larger and better-formed heads (Ismael & Sarhan, 2025). The LSD test at a 5% significance level confirmed that differences between treatments were statistically significant for all traits. While some treatments shared statistical groupings, the overall pattern clearly favored Humic acid in both vegetative and yield components. These outcomes suggest that Humic acid offers more stable and beneficial effects on broccoli productivity, particularly when applied at moderate to high concentrations. Compared to nano NPK, Humic acid provided more consistent improvements in biomass, structural development, and head formation under greenhouse conditions. Its biostimulant properties—improving nutrient availability, metabolic efficiency, and hormonal balance—make it a valuable tool for optimizing crop yield and quality. For producers aiming to maximize productivity and market value, Humic acid presents a sustainable and economically sound alternative to conventional nano-fertilizers.

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Table 4: Interactive Effects of Foliar-Applied Nano NPK and Humic Acid on Some Plant and Fruit Traits of Broccoli.

Treatments		Traits				
		Plant weight	Plant weight (kg/dunum)	Plant weight(t/ha)	plant height	fruit diameter
Nano particles	Control	291.300 a	728.250 a	2.913000 a	65.340 a	15.580 bc
	2 gm	200.000 bc	500.000 bc	200000 bc	58.400 b	13.400 cd
	4 gm	114.000 d	285000 d	1140000 d	56.500 b	13.980 cd
	6 gm	127.000 cd	317500 cd	1.270000 cd	55.600 b	12.040 d
Humic acid	2.5 ml	301.600 a	754000 a	3016000 a	67.000 a	21.440 a
	4.5 ml	243.000 ab	607500 ab	2430000 ab	64.200 a	19.320 a
	6.5 ml	290.000 a	725000 a	2900000 a	67.800 a	18.200 ab
LSD		**60.528**	**151,320**	**605,280**	**3.988**	**2.44**

Similar letters in the same column indicate no significant differences (P>0.05).

3.4 Effects of Nano NPK and Humic Acid on Plant Tissue Composition

Table 5 presents the effects of foliar-applied nano NPK and Humic acid on key biochemical traits of broccoli, including moisture content, dry matter percentage, and chlorophyll concentration. The data indicate that moisture and dry matter content remained relatively unaffected by either treatment. Moisture values ranged from 8.26% to 9.25%, while dry matter content varied slightly between 90.81% and 91.67%. Statistical analysis ($P > 0.05$) confirmed that these differences were not significant, suggesting limited influence of foliar-applied nutrients on tissue hydration or solid accumulation under the conditions of this experiment. However, the highest dry matter value was observed with the 6.5 ml L^{-1} Humic acid treatment, which could reflect its role in maintaining osmotic and metabolic balance (Rouphael & Colla, 2020). In contrast, chlorophyll content showed more substantial and statistically significant variation among treatments. The most chlorophyll accumulation was in plants fertilized by humic acid, especially when the concentration was 4.5 ml L^{-1} (27.574 SPAD units); after that, 6.5 and 2.5 ml L^{-1}. This indicates a positive effect of Humic acid on PS pigment formation. This may be substantiated by previous research that demonstrated that humic substances could increase the production of chlorophyll by enhancing the magnesium that is required to make chlorophyll molecules (Nardi et al., 2021). Effect of the nano NPK treatments A similar trend was observed for the influence of nano NPK treatments on the chlorophyll content, where a peak value (26.228SPAD) was noticed for 6 g/L, but all nano NPK values were lower than the Humic acid treatment. This also may be attributed to the slower nutrient delivery of nano fertilizers, which might restrict the availability of instant nutrients that is very essential for biosynthesis of pigment (Kah et al., 2018). Furthermore, the chlorophyll number was 23.088 for the control treatment, which would bring external nutrient application to the fore in enhancing the photosynthetic potential. The high efficacy of Humic acid on increasing pigment content might be due to biostimulant effects, such as elevation of nutrient-uptake capability, activation of enzymatic system activity, and hormonal pathways responsible of chloroplast development (Mahmood & Addaheri, 2024). These physiological traits could be crucial for enhancing plant productivity, because greater chlorophyll values are closely associated with greater photosynthetic efficiency and greater biomass production. Although total moisture and dry matter contents were little affected by Humic acid application when compared with nano NPK. These findings

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reinforce the multifaceted role of Humic substances—not only in supporting structural and metabolic growth but also in promoting physiological performance at the cellular level. This makes Humic acid a valuable input for improving the functional quality of crops like broccoli under greenhouse conditions.

Table 5: Interactive Effects of Foliar-Applied Nano NPK and Humic Acid on Some Plant Content of Broccoli

Treatments		Traits		
		Moisture	**Dry matter**	**chlorophyl**
Nano particles	**Control**	8.965 a	91.035 a	23.088 b
	2 gm	8.362 a	91.226 a	25.404 ab
	4 gm	9.134 a	90.866 a	25.186 ab
	6 gm	9.190 a	90.810 a	26.228 a
Humic acid	**2.5 ml**	8.488 a	91.514 a	26.794 a
	4.5 ml	9.248 a	90.910 a	27.574 a
	6.5 ml	8.266 a	91.670 a	27.214 a
LSD		**0.764**	**0.705**	**2.211**

Similar letters in the same column indicate no significant differences (P>0.05).

3.5 Effects of Nano NPK and Humic Acid on Plant Mineral Content

Table 6 summarizes the interactive effects of foliar-applied nano NPK and Humic acid on the mineral composition of broccoli plants, with specific attention to iron (Fe), potassium (K), phosphorus (P), and nitrogen (N). The results reveal that both treatments significantly improved nutrient content compared to the control, with Humic acid—especially at 6.5 ml L^{-1} consistently providing the highest values. Iron content showed clear differences. The highest Fe concentration (245.75 mg/kg) was recorded with 6.5 ml L^{-1} Humic acid, surpassing both the 6 g.L^{-1} nano NPK (233.69 mg/kg) and 4.5 ml L^{-1} Humic acid (223.65 mg/kg). The control group had the lowest Fe content (159.64 mg/kg). This suggests that both fertilizers enhance Fe availability, but Humic acid, known for its metal-chelating properties, may facilitate greater Fe mobility and uptake within plant tissues (Zanin et al., 2019; Jindo et al., 2020). Potassium content also increased significantly with treatment. The 6.5 ml L^{-1} Humic acid and 6 g.L^{-1} nano NPK treatments produced the highest K levels (2.04% and 1.93%, respectively), well above the control (1.34%). Potassium plays a vital role in stomatal regulation, enzymatic function, and overall plant stress tolerance. Foliar-applied Humic substances have been reported to stimulate potassium uptake by modifying root architecture and increasing membrane permeability (Bezuglova & Klimenko, 2022). Phosphorus content followed a similar trend. The highest level (0.767%) was obtained from 6.5 g/L Humic acid, with nano-NPK treatments also showing improvements, peaking at 0.707% with 6 g/L. Phosphorus is essential for energy transfer and root development, and Humic acid likely improves its availability by enhancing root exudation and microbial solubilization of bound P (Lumactud et al., 2022). Nitrogen content showed the most pronounced treatment-related changes. The highest N level (3.157%) was recorded in the 6.5 ml L^{-1} Humic acid group, with 6 g.L^{-1} nano NPK (2.993%) and 4.5 ml L^{-1} Humic acid (3.003%) also showing strong responses. As nitrogen is key for chlorophyll formation and protein synthesis, this confirms the effectiveness of foliar feeding—especially when combined with bioactive compounds like Humic acid (Wang et al., 2023). Overall, while both nano NPK and Humic acid improved mineral content, Humic acid—particularly at higher concentrations—proved more effective across all nutrients. This enhanced nutrient profile may be attributed to the synergistic action of Humic substances, which promote solubility, facilitate membrane transport, and enhance enzymatic assimilation of essential elements. These results reinforce the multifunctional role of Humic acid in improving plant nutrition, contributing to healthier, more nutrient-dense crops.

Table 6: Interactive Effects of Foliar-Applied Nano NPK and Humic Acid on Plant Mineral Content of Broccoli

Treatments		Traits			
		Fe	K	P	N
Nanoparticles	Control	159.640 d	1.343 d	0.443 f	2.043 d
	2 gm	184.540 c	1.537 c	0.563 e	2.423 c
	4 gm	198.977 c	1.687 b	0.637 c	2.883 b
	6 gm	233.687 ab	1.927 a	0.707 b	2.993 ab
Humic acid	2.5 ml	189.253 c	1.530 c	0.573 de	2.347 c
	4.5 ml	223.650 b	1.753 b	0.620 cd	3.003 ab
	6.5 ml	245.750 a	2.040 a	0.767 a	3.157 a
LSD		11.581	0.081	0.038	0.126

Similar letters in the same column indicate no significant differences (P>0.05).

IV. Conclusion

In conclusion, the use of humic acid, with or without nano NPK, in broccoli cultivation is environmentally beneficial and enhances both growth and quality. This thesis reinforces the assertion that integrating organic biostimulants with contemporary nutrient delivery techniques may enhance agricultural yields while reducing reliance on conventional chemical fertilizers. A trajectory of sustainable advancement in contemporary horticulture.

1. References

2. Abdulla, A. R., J. O Ahmed and S. Q. Mahmood, (2015). Comparisons of six hybrids corn (*Zea mays* L.), in terms of yields and components in Sulaimania. American Eurasian J. Agric. & Environ. Sci, 15(.5), pp.848-852.
3. Al-douri, M. F., & Al-Douri, E. F. (2024). Response of 'Rubygem'strawberry cultivar plants to balanced NPK fertilizer and humic acid application under greenhouse conditions. *Tikrit Journal for Agricultural Sciences*, *24*(4), 11-20. https://doi.org/10.25130/tjas.24.4.2
4. AL Salihi, M., & Mahmood, C. (2020). Efect of Two Broccli (*Brassica oleracea* var.italica) Varieties to Different Transplanting Time and Spraying levels of Sea Weed Extracts on som growth chozaeteztion and yield. *Kirkuk University Journal For Agricultural Sciences*, *11*(2), 68-79. https://doi.org/ 10.58928/ku20.11209
5. Ahmed, G. O., Halshoy, H. S., Mahmood, C. H., & Hama, J. R. (2024). Titanium nanoparticle and humic acid applications improve seed germination, growth development, and phytochemical contents of lettuce (*Lactuca sativa*) plants. *BioNanoScience*, *14*(5), 4930-4941. https://doi.org/10.1007/s12668-024-01545-3
6. Abdel-Razzak, H. S., & El-Sharkawy, G. A. (2013). Effect of biofertilizer and humic acid applications on growth, yield, quality and storability of two garlic (*Allium sativum* L.) cultivars. *Asian Journal of Crop Science*, 5 (1), 48-64. https://doi.org/10.3923/ajcs.2013.48.64
7. Al-Falahi, M. N., Al-Dulaimi, K. H., Ghani, E. T. A., Al-Taey, D. K., & Farhan, K. J. (2022). Effect of humic acids and the amount of mineral fertilizer on some characteristics of saline soil, growth and yield of broccoli plant under salt stress conditions. Agraarteadus. https://doi.org/ 10.15159/jas.22.24
8. Bezuglova, O., & Klimenko, A. (2022). Application of Humic Substances in Agricultural Industry. *Agronomy*, *12*(3), 584. https://doi.org/10.3390/agronomy12030584

ISSN Onlin:2708-9347, ISSN Print: 2708-9339 Volume 14, Issue 2 (2025) PP 282-292

https://jam.utq.edu.iq/index.php/main *https://doi.org/10.54174/utjagr.v13i1.323*

9. Calvo, P., Nelson, L., & Kloepper, J. W. (2014). Agricultural uses of plant biostimulants. Plant and Soil, 383(1-2), 3–41. https://doi.org/10.1007/s11104-014-2131-8
10. Canellas, L. P., da Silva, R. M., Busato, J. G., & Olivares, F. L. (2024). Humic substances and plant abiotic stress adaptation. *Chemical and Biological Technologies in Agriculture*, *11*(1), 66. https://doi.org/10.1186/s40538-024-00575-z
11. Canellas, L. P., Canellas, N. O. A., da Silva, R. M., Spaccini, R., Mota, G. P., & Olivares, F. L. (2023). Biostimulants Using Humic Substances and Plant-Growth-Promoting Bacteria: Effects on Cassava (*Manihot esculentus*) and Okra (*Abelmoschus esculentus*) Yield. *Agronomy*, *13*(1), 80. https://doi.org/10.3390/agronomy13010080
12. Canellas, L. P., Olivares, F. L., Aguiar, N. O., Jones, D. L., Nebbioso, A., Mazzei, P., & Piccolo, A. (2015). Humic and fulvic acids as biostimulants in horticulture. Scientia Horticulturae, 196, 15-27. https://doi.org/10.1016/j.scienta.2015.09.013
13. Chen, Q., Qu, Z., Ma, G., Wang, W., Dai, J., Zhang, M., ... & Liu, Z. (2022). Humic acid modulates growth, photosynthesis, hormones, and the osmolyte system of maize under drought conditions. *Agricultural Water Management*, *263*, 107447. https://doi.org/10.1016/j.agwat.2021.107447
14. DeRosa, M. C., Monreal, C., Schnitzer, M., Walsh, R., & Sultan, Y. (2010). Nanotechnology in fertilizers. Nature Nanotechnology, 5(2), 91. https://doi.org/10.1038/nnano.2010.2
15. Filho, J. F. D. C. L., Thomason, W. E., Evanylo, G. K., Zhang, X., Strickland, M. S., Chim, B. K., & Diatta, A. A. (2020). The synergistic effects of humic substances and biofertilizers on plant development and microbial activity: a review. *Int. J. Plant Soil Sci.*, *32*, 56-75. https://doi.org/10.9734/IJPSS/2020/v32i730306
16. Halshoy, H., Mahmood, A., & Tofiq, G. (2023). Effect of plant biostimulants on growth, yield and some mineral composition of broccoli plants (*Brassica oleracea* var. Italica). *Tikrit Journal for Agricultural Sciences*, *23*(1), 130-140. https://doi.org/10.25130/tjas.23.1.16
17. Hawall, I., Raheem, S., Tofiq, G. (2018). Growth and Yield of Broccoli (Brassica oleracea L. Var. Corato) as affected by humic acid application. Journal of Plant Production, 9(9), 739-741. https://doi.org/10.21608/jpp.2018.36398
18. Ismael, S. F., & Sarhan, T. Z. (2025). Effect Of Humic Acid, Seaweed Extracts And Organic Fertilizer On Yield Quality Of Broccoli (*Brassica Oleracea*) Grown Under Plastic House. *Science Journal of University of Zakho*, *13*(2), 172-178. https://doi.org/10.25271/sjuoz.2025.13.2.1339
19. Jindo, K., Olivares, F. L., Malcher, D. J. D. P., Sánchez-Monedero, M. A., Kempenaar, C., & Canellas, L. P. (2020). From lab to field: Role of humic substances under open-field and greenhouse conditions as biostimulant and biocontrol agent. Frontiers in plant science, 11, 426. https://doi.org/10.3389/fpls.2020.00426
20. Kah, M., Kookana, R. S., Gogos, A., & Bucheli, T. D. (2018). A critical evaluation of nanopesticides and nanofertilizers: Risks and regulatory challenges. Nature Nanotechnology, 13(8), 677–684. https://doi.org/10.1038/s41565-018-0131-1
21. Liu, X., Sun, Y., & Rui, Y. (2025). Nanomaterials in Broccoli Production: Current Applications and Future Prospects. Agronomy, 15(5), 1193. https://doi.org/10.3390/agronomy15051193
22. Lumactud, R. A., Gorim, L. Y., & Thilakarathna, M. S. (2022). Impacts of humic-based products on the microbial community structure and functions toward sustainable agriculture. *Frontiers in Sustainable Food Systems*, *6*, 977121. https://doi.org/10.3389/fsufs.2022.977121
23. Maffia, A., Oliva, M., Marra, F., Mallamaci, C., Nardi, S., & Muscolo, A. (2025). Humic Substances: Bridging Ecology and Agriculture for a Greener Future. Agronomy, 15(2), 410. https://doi.org/10.3390/agronomy15020410
24. Mahmood, E. K., & Addaheri, M. S. (2024). Impact of Humic Substances on Alleviation of Soil Salinity and the Enhancement of Plant Productivity: a review. *Thi-Qar University Journal for Agricultural Researches*, *13*(1). https://doi.org/10.54174/szm42027

ISSN Onlin:2708-9347, ISSN Print: 2708-9339 Volume 14, Issue 2 (2025) PP 282-292

https://jam.utq.edu.iq/index.php/main *https://doi.org/10.54174/utjagr.v13i1.323*

25. Moradinezhad, F., & Ranjbar, A. (2024). Foliar application of fertilizers and plant growth regulators on pomegranate fruit yield and quality: A review. Journal of Plant Nutrition, 47(5), 797-821. https://doi.org/10.1080/01904167.2023.2280152
26. Nardi, S., Pizzeghello, D., Muscolo, A., & Vianello, A. (2002). Physiological effects of Humic substances on higher plants. Soil Biology and Biochemistry, 34(11), 1527-1536. https://doi.org/10.1016/S0038-0717(02)00174-8
27. Nardi, S., Schiavon, M., and Francioso, O. (2021). Chemical structure and biological activity of humic substances define their role as plant growth promoters. Molecules 26, 2256. https://doi.org/10.3390/molecules26082256
28. Rouphael, Y., & Colla, G. (2020). Biostimulants in agriculture. Scientia Horticulturae, 243, 109367. https://doi.org/10.1016/j.scienta.2019.109367
29. Safaei, Z., Azizi, M., Davarynejad, G., & Aroiee, H. (2014). The effect of foliar application of humic acid and nanofertilizer (Pharmks®) on yield and yield components of black cumin (Nigella sativa L.). *Journal of Medicinal Plants and By-products*, *3*(2), 133-140. https://doi.org/10.22092/jmpb.2014.108725
30. Selim, E. M., & Mosa, A. A. (2012). Fertigation of Humic substances improves yield and quality of broccoli and nutrient retention in a sandy soil. Journal of Plant Nutrition and Soil Science, 175(2), 273-281. https://doi.org/10.1002/jpln.201100062
31. Solanki, P., Bhargava, A., Chhipa, H., Jain, N., & Panwar, J. (2015). Nano-fertilizers and their smart delivery system. Nanotechnologies in food and agriculture, 81-101. https://doi.org/10.1007/978-3-319-14024-7_4
32. Stell, R., Torrie J., & Dickey D. (1980). Principles and procedures of statistics: A biometrical approach. New York: MacGraw-Hill. https://trove.nla.gov.au/work/9171434/version/49088515
33. Subramanian, K. S., Manikandan, A., Thirunavukkarasu, M., & Rahale, C. S. (2015). Nano-fertilizers for balanced crop nutrition. In Nanotechnologies in Food and Agriculture (pp. 69-80). Springer. https://doi.org/10.1007/978-3-319-14024-7_3
34. Tilman, D., Cassman, K. G., Matson, P. A., Naylor, R., & Polasky, S. (2002). Agricultural sustainability and intensive production practices. Nature, 418(6898), 671-677.
35. Trevisan, S., Francioso, O., Quaggiotti, S., & Nardi, S. (2011). Humic substances biological activity at the plant-soil interface: From environmental aspects to molecular factors. Plant Signaling & Behavior, 6(5), 635–643. https://doi.org/10.4161/psb.6.5.15029
36. Wang, Y., Lu, Y., Wang, L., Song, G., Ni, L., Xu, M., & Bai, Y. (2023). Analysis of the molecular composition of humic substances and their effects on physiological metabolism in maize based on untargeted metabolomics. *Frontiers in Plant Science*, *14*, 1122621. https://doi.org/10.3389/fpls.2023.1122621
37. Yakhin, O. I., Lubyanov, A. A., Yakhin, I. A., & Brown, P. H. (2017). Biostimulants in plant science: A global perspective. Frontiers in Plant Science, 7, 2049. https://doi.org/10.3389/fpls.2016.02049.
38. Zanin, L., Tomasi, N., Cesco, S., Varanini, Z., & Pinton, R. (2019). Humic substances contribute to plant iron nutrition acting as chelators and biostimulants. *Frontiers in Plant Science*, *10*, 675. doi: 10.3389/fpls.2019.00675
39. Zulfiqar, F., Casadesús, A., Brockman, H., & Munné-Bosch, S. (2020). An overview of plant-based natural biostimulants for sustainable horticulture with a particular focus on moringa leaf extracts. *Plant Science*, *295*, 110194. https://doi.org/10.1016/j.plantsci.2019.110194.