International Journal of Advanced Biochemistry Research

ISSN Print: 2617-4693
ISSN Online: 2617-4707
NAAS Rating (2025): 5. 29
IJABR 2025; SP-9(9): 430-434
www.biochemjournal.com
Received: 13-06-2025
Accepted: 16-07-2025

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Effect of humic acid and iron on growth and yield of rabi maize (*Zea mays* L.)

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DOI: https://www.doi.org/10.33545/26174693.2025.v9.i9Sf.5531

Abstract
In the *Rabi* season of 2024-25, a field experiment was meticulously conducted at the Crop Research Farm, Department of Agronomy, Sam Higginbottom University of Agriculture, Technology and Sciences, Prayagraj, on sandy loam soil with a neutral pH. The study aimed to explore the impact of foliar applications combining humic acid and iron, administered at varying dosage levels, to assess their efficacy and influence on growth, yield and economics of the crop Maize. The experiment was designed using a randomized block design (RBD) with ten treatments and three replications. The treatment details are as follows T_1. Humic Acid (Control) + Iron 0. 1%, T_2. Humic Acid (Control) + Iron 0. 2%, T_3. Humic Acid (Control) + Iron 0. 3%, 4. Humic Acid (2 gm/lit.) + Iron 0. 1%, T_5. Humic Acid (2 gm/lit.) + Iron 0. 2%, T_6. Humic Acid (2 gm/lit.) + Iron 0. 3%, 7. Humic Acid (4 gm/lit.) + Iron 0. 1%, T_8. Humic Acid (4 gm/lit.) + Iron 0. 2%, T_9. Humic Acid (4 gm/lit.) + Iron 0. 3% and T_{10}: Control (120:60:40) NPK kg/ha.
The results revealed that Treatment 7 (Humic Acid 4 gm/L + Iron 0. 1%) produced the tallest plants, reaching an impressive height of 167. 47 cm. Meanwhile, Treatment 8 (Humic Acid 4 gm/L + Iron 0. 2%) had the highest yields and productivity. It delivered the most cobs per plant (1. 80), the highest number of rows per cob (16), and the heaviest plant dry weight (109. 16 g). It achieved the highest grain yield (6. 52 t/ha) and stover yield (14. 48 t/ha).

Keywords: Rabi maize, humic acid, iron, growth, yield and economics

Introduction

Maize (*Zea mays* L.), a staple cereal crop, is one of the most versatile crops globally, used for food, fodder, and industrial purposes. Originating in Mexico, it belongs to the Poaceae family and thrives in diverse agro-climatic conditions. Maize is rich in carbohydrates, proteins, and vitamins, making it a vital food security crop. Globally, it ranks third after wheat and rice, with a production of approximately 1. 2 billion metric tons in 2023, led by the USA, China, and Brazil (FAO, 2024) [11]. In India, maize occupies 9. 9 million hectares, yielding about 34. 6 million metric tons annually, with major contributions from Karnataka, Madhya Pradesh, and Uttar Pradesh (DAC&FW, 2024) [7]. Its importance lies in its role in food, livestock feed, and bioethanol production. Productivity enhancements through hybrid varieties and modern agronomic practices are crucial for meeting rising global demand. Maize is cultivated throughout the year in the season of kharif, Rabi and Zaid. Rabi maize cultivation in India, typically sown between October and December, plays a significant role in enhancing agricultural productivity, particularly in states like Bihar, Uttar Pradesh, and Andhra Pradesh. Grown under irrigated conditions, rabi maize benefits from cooler temperatures, resulting in higher yields compared to kharif maize, with an average productivity of 3. 5-4. 5 tons per hectare (DAC&FW, 2024) [7]. It is a vital crop for food security, livestock feed, and industrial use, driven by high-yielding hybrid varieties and improved agronomic practices. The crop's adaptability to diverse soils and its shorter duration make it a preferred choice for farmers in the rabi season. However, challenges like water availability and pest management require sustainable practices to maintain productivity.

Humic acid (HA) is a complex, organic molecule derived from the decomposition of plant and animal residues, playing a vital role in enhancing soil fertility, nutrient retention, and plant growth. It is a key component of humic substances (HS), which also include fulvic acids and humin, formed through chemical and biological processes in soils, sediments, and natural waters. HA improves soil physical, chemical, and biological properties, such as structure, water retention, cation exchange capacity, and microbial activity, thereby supporting sustainable agriculture. It is sourced from coal, lignite, soils, and organic materials, with recent advancements exploring fermentation-based production (Ampong *et al.*, 2024) [3]. HA's functional groups, notably carboxylic and phenolic, enable nutrient chelation and plant growth promotion (Nardi *et al.*, 2021) [19]. Despite its benefits, variability in HA composition and application methods necessitates further field-based research to optimize its agricultural efficacy (Rose *et al.*, 2014; De Melo *et al.*, 2016) [21, 9].

Foliar humic acid application at 2 and 4 L/ha under drought stress increased seed yield, zinc, and iron content, though the yield benefits decreased with greater water deficits, indicating better efficacy under optimal irrigation and a positive correlation with plant density (Kiani *et al.*, 2020). Combining soil-applied humic acid at sowing with foliar salicylic acid at the V8 stage significantly boosted maize growth and yield compared to individual applications, suggesting a synergistic effect (Ali *et al.*, 2023) [2]. Foliar humic acid application (0. 1% and 0. 2%) in greenhouse conditions on calcareous soils increased maize dry matter and nutrient uptake (nitrogen, phosphorus, potassium), particularly at higher doses, though it had little impact on post-harvest soil nutrient availability compared to soil application (Kaya *et al.*, 2018) [13].

Iron (Fe) is an essential micronutrient for agricultural plants, playing a critical role in various physiological processes such as photosynthesis, respiration, and nitrogen metabolism. It is a vital component of enzymes like cytochromes and ferredoxin, which are involved in electron transfer and chlorophyll synthesis, directly impacting plant growth, yield, and quality. Iron deficiency, common in calcareous or alkaline soils, leads to chlorosis, reduced biomass, and lower crop productivity, making its supplementation crucial for optimal plant health. In maize (*Zea mays* L.), foliar application of iron has been shown to significantly enhance growth and yield parameters. Research indicates that maize treated with nitrogen fertilizer combined with foliar iron application under intercropping systems exhibits improved physio-agronomic indices, higher chlorophyll content, and enhanced photosynthetic characteristics, including increased activity of enzymes like rubisco, nitrate reductase, and glutamate synthase, leading to better photosynthetic nitrogen uses efficiency (PNUE) and higher yields compared to monocropping (Nasar *et al.*, 2022) [20]. Another study found that foliar application of 0. 2% iron on maize cultivars, such as DK-6142, significantly increased plant height, grain weight per cob, and grain yield, with DK-6142 achieving a grain yield of 7515. 1 kg ha^{-1} (Yousefi, 2016) [22]. Additionally, the application of iron nanoparticles (FeNPs) at critical growth stages, such as male and female flowering, was shown to enhance photosynthesis, increase chlorophyll content, and boost grain yield by improving the number of fertilized florets and vegetative cover (Mutlag *et al.*, 2023) [18].

These findings highlight the efficacy of foliar iron application, particularly in nano-form, in addressing iron deficiency, enhancing maize growth, and improving grain quality in diverse agricultural settings.

Materials and Methods

During the *Rabi* season of 2024-25, a field experiment was conducted at the Crop Research Farm of the Department of Agronomy, SHUATS, Prayagraj, U. P. The soil of experimental plot was sandy loam, having a nearly neutral soil reaction (pH 7. 3), electrical conductivity 0. 527 (ds/m), medium in available nitrogen (232. 5 kg/ha) and potassium (246. 7 kg/ha), and low in available phosphorous (36. 5 kg/ha). One deep ploughing followed by harrowing was done to create a fine seedbed and to ensure good seed-to-soil contact. Field was well-levelled to avoid water stagnation and for uniform irrigation. The sowing of the Rabi Maize seeds variety SIMBA 9321 (PMH 966) were sown on 3rd December with a spacing of 60 cm x 25 cm. The experiment was conducted in a Randomized Block Design consisting of 10 treatment combinations and 3 replications. Fertilizers were applied as band placement, for which 4-5 cm deep furrows were made along the seed rows with a hand hoe. The Recommended dose of Fertilizer was N-P-K:120-60-40 Kg/ha. There were two factors which were applied as foliar application to the plants of experimental field at different growth stages. First factor was Humic acid, it was applied at 25 DAS (days after sowing) and 50 DAS, second factor was Iron which was applied at 30 DAS and 60 DAS. The treatment details are as follows T_1. Humic Acid (Control) + Iron 0. 1%, T_2. Humic Acid (Control) + Iron 0. 2%, T_3. Humic Acid (Control) + Iron 0. 3%, 4. Humic Acid (2 gm/lit.) + Iron 0. 1%, T_5. Humic Acid (2 gm/lit.) + Iron 0. 2%, T_6. Humic Acid (2 gm/lit.) + Iron 0. 3%, 7. Humic Acid (4 gm/lit.) + Iron 0. 1%, T_8. Humic Acid (4 gm/lit.) + Iron 0. 2%, T_9. Humic Acid (4 gm/lit.) + Iron 0. 3% and T_{10}: Control (120:60:40) NPK kg/ha. Manual weeding was done with the help of Khurpi at 30 DAS and 50 DAS. A total of 5 irrigations were provided to the field at various growth stages of the crop. The crop was harvested at 141 DAS. Plant growth parameters *viz.*, plant height (cm), dry weight (g/plant), Crop Growth Rate (g/m^2/day), Relative Growth Rate (g/g/day) were measured at a regular interval from germination till 100 DAS and yield metrics *viz.*, cobs/plant, rows/cob, seeds/row, test weight (g), seed yield (kg/ha), stover yield (kg/ha) and harvest index (%) were measured at harvest. The observed data was statistically analyzed using analysis of variance (ANOVA) as applicable to randomized block design (Gomez and Gomez, 1984) [12]. Economics were also calculated, *viz.*, Cost of cultivation, Gross return, Net return and benefit-cost ratio.

Results and Discussion

Growth and Yield attributes

1. Plant Height (cm)

The result showed that the application of Humic acid (4 gm/lit.) along with Iron (0. 1%) (Treatment no. 7) was found significantly higher in terms of Plant Height (167. 47 cm) at 100 DAS. However, all of the treatments were found to be statistically at par with Treatment no. 7 except Treatment no. 1 and control plot. Humic acid enhances maize growth attributes, including plant height, by improving nutrient uptake (e. g., nitrogen, phosphorus, and zinc), which accelerates biological processes like photosynthesis, leading to increased plant height and biomass Brodowska *et al.*, (2022) [4]. Humic substances, including humic acid, contribute to plant iron nutrition by acting as chelators and bio stimulants, promoting maize root growth and overall plant height under nutrient-deficient conditions Zanin *et al.*, (2019) [23]. Application of humic acid (HA) at 25 kg ha^{-1} significantly increased maize plant height, likely due to its physiological effects, including enhanced cell membrane permeability, accelerated cell division, and improved root system development Daur *et al.*, (2013) [8].

2. Plant Dry Weight (gm)

Treatment no. 8, which combined Humic acid (4 gm/lit.) and Iron (0. 2%), resulted in a significantly higher plant dry weight of 109. 16 gm. However, the treatment combinations of [Humic acid (control) + Iron (0. 3%)], [Humic acid (2 gm/lit.) + Iron (0. 2%)], [Humic acid (2 gm/lit.) + Iron (0. 3%)], [Humic acid (4 gm/lit.) + Iron (0. 1%)], and [Humic acid (4 gm/lit.) + Iron (0. 3%)] were statistically at par with Treatment no. 8.

3. Crop Growth Rate (g/m^2/day)

Crop growth rates (CGR) of maize were evaluated across different vegetative growth stages, specifically at intervals of 20-40, 40-60, 60-80, and 80-100 days after sowing (DAS). The CGR values at 40-60 DAS and 60-80 DAS showed no significant differences among the treatments. However, significant variations were observed at 20-40 DAS and 80-100 DAS. During the 20-40 DAS interval, Treatment 7, comprising Humic acid (4 g/lit.) combined with iron (0. 1%), recorded a significantly higher CGR of 3. 03 g/m²/day compared to other treatments. Treatments 6 (Humic acid 2 g/lit. + Iron 0. 3%), Treatment 8 (Humic acid 4 g/lit. + Iron 0. 2%), and Treatment 9 (Humic acid 4 g/lit. + Iron 0. 3%) were statistically at par with Treatment 7. At 80-100 DAS, Treatment 8 (Humic acid 4 g/lit. + Iron 0. 2%) exhibited a significantly higher CGR of 16. 80 g/m²/day compared to other treatments, with all treatments except Treatment 1 (Humic acid-control + Iron 0. 1%) and Treatment 10 (control) being statistically at par with Treatment 8. Application of humic acid in combination with iron supplementation significantly enhances the growth rate of maize (*Zea mays* L.), with increased plant height, leaf area, and biomass production observed due to improved nutrient uptake and soil fertility Alhasany *et al.*, (2021) [1].

4. Relative Growth Rate (g/g/day)

The relative growth rate (RGR) of the crop Maize was evaluated at 20-day intervals from 20 to 100 days after sowing (DAS). During 20-40 DAS, treatment T_4 [Humic Acid (2 gm/lit.) + Iron (0. 1%)] recorded the highest RGR of 0. 114 g/g/day, while T_2 [Humic Acid (control) + Iron (0. 2%)] showed the highest RGR of 0. 058 g/g/day during 40-60 DAS. From 60-80 DAS, T_7 [Humic Acid (4 gm/lit.) + Iron (0. 1%)] exhibited the highest RGR of 0. 043 g/g/day, and during 80-100 DAS, T_4 again recorded the highest RGR of 0. 031 g/g/day. Despite these variations, differences among treatments were statistically non-significant across all intervals.

5. Number of Cobs/Plant

At harvest, the application of $T_{8,}$ [Humic Acid (4 gm/lit.) + Iron (0. 2%)] resulted in a significantly higher number of cobs per plant (1. 80), outperforming all other treatments. However, treatment T_9 [Humic Acid (4 gm/lit.) + Iron (0. 3%)] was found to be statistically comparable to T_8, indicating similar efficacy in enhancing cob production. These findings align with previous research, which has demonstrated that humic acid, when combined with micronutrients like iron, significantly improves maize yield parameters by enhancing nutrient uptake and stimulating plant growth processes **(**Khan *et al.*, 2018) [15]. The synergistic effect of humic acid and iron likely contributed to improved physiological processes, leading to increased cob development in maize.

6. Number of Rows/Cob

At harvest, the application of T_8 [Humic Acid (4 gm/L) + Iron (0. 2%)] resulted in a significantly higher number of rows per cob (16. 13), outperforming all other treatments. This treatment was statistically on par with T_3 [Humic Acid (control) + Iron (0. 3%)], T_5 [Humic Acid (2 gm/lit.) + Iron (0. 2%)], T_6 [Humic Acid (2 gm/lit.) + Iron (0. 3%)], T_7 [Humic Acid (4 gm/lit.) + Iron (0. 1%)], and T_9 [Humic Acid (4 gm/lit.) + Iron (0. 3%)]. These findings underscore the synergistic effect of humic acid and iron in enhancing maize cob development, likely due to improved nutrient uptake and physiological processes. Supporting this, a study by El-Ghamry *et al.*, (2009) [10] demonstrated that humic acid combined with micronutrients like iron significantly increased maize yield parameters, including the number of rows per cob, by enhancing soil fertility and nutrient availability. Similarly, Khaled and Fawy (2011) [14] reported that humic acid applications at optimal concentrations improved maize growth and yield components through better root development and nutrient absorption, further corroborating the efficacy of combined humic acid and iron treatments observed in the present study.

7. Number of seeds/rows

At harvest, the highest number of grains per row (38. 8) was recorded in treatment T_8 [Humic Acid (4 gm/lit.) + Iron (0. 2%)], demonstrating a statistically significant increase compared to other treatments. Treatments T_5 [Humic Acid (2 gm/lit.) + Iron (0. 2%)], T_6 [Humic Acid (2 gm/lit.) + Iron (0. 3%)], T_7 [Humic Acid (4 gm/lit.) + Iron (0. 1%)], and T_9 [Humic Acid (4 gm/lit.) + Iron (0. 3%)] were statistically comparable to T_8, indicating similar efficacy in enhancing grain yield per row.

These findings align with previous research, which suggests that humic acid enhances nutrient uptake and root development, while iron supplementation improves chlorophyll synthesis and photosynthesis, thereby boosting grain production. For instance, studies have shown that humic acid application increases nutrient availability and crop yield (Canellas *et al.*, 2015) [5], and iron foliar sprays enhance grain number and quality in cereals (Zhang *et al.*, 2010) [24]. These synergistic effects likely contributed to the observed outcomes in the present study.

8. Test weight (g)

Test weight was found non-significant among all the treatments and highest test weight (19. 47 g) was recorded in T_6 [Humic Acid (2 gm/lit.) + Iron (0. 3%)].

9. Grain Yield (t/ha)

The application of humic acid combined with iron significantly influenced seed yield, with treatment T_8 [Humic Acid (4 gm/L) + Iron (0. 2%)] achieving the highest yield of 6. 52 t/ha. Notably, treatments T_7 [Humic Acid (4 gm/L) + Iron (0. 1%)] and T_9 [Humic Acid (4 gm/L) + Iron (0. 3%)] were statistically comparable to $T_{8,}$ indicating that variations in iron concentration within this range, when paired with humic acid, consistently enhanced seed production. These findings align with previous research demonstrating that humic acid enhances nutrient uptake and soil fertility, thereby improving crop yields (Chen *et al.*, 2004) [6]. Similarly, iron supplementation has been shown to boost photosynthetic efficiency and enzymatic activity, contributing to higher seed yields (Marschner, 2012) [17]. The synergistic effect of humic acid and iron likely facilitated improved nutrient availability and plant vigor, as supported by studies showing enhanced micronutrient absorption in the presence of humic substances (Mackowiak *et al.*, 2001) [16]. These results underscore the potential of combined humic acid and iron applications for optimizing agricultural productivity.

10. Stover Yield (t/ha)

The highest stover yield of 14. 48 t/ha was recorded in treatment T_8, which combined humic acid (4 gm/lit.) and iron (0. 2%), demonstrating significant superiority over all other treatments. Statistical analysis revealed that all treatments were at par, except for T_1 (humic acid control + 0. 1% iron), T_9 (humic acid gm/lit. + 0. 3% iron), and T_{10} (control), which exhibited lower yields. These findings underscore the synergistic effect of humic acid and optimized iron concentrations in enhancing stover yield, likely due to improved nutrient uptake, enhanced photosynthesis, and better soil microbial activity. Previous studies support these results, as humic acid is known to improve soil fertility and nutrient availability, thereby boosting crop productivity (Chen *et al.*, 2004) [6]. Similarly, iron, as a micronutrient, plays a critical role in chlorophyll synthesis and enzymatic processes, contributing to higher biomass accumulation (Zuo & Zhang, 2011) [25]. The combination of humic acid and iron at specific concentrations likely optimizes these physiological processes, leading to superior stover yield, aligning with research by Canellas *et al.* (2015) [5], which highlighted humic substances' role in promoting root growth and nutrient assimilation.

11. Harvest Index (%)

Highest Index (30. 36%) was recorded in T_9 [Humic Acid (4 gm/lit.) + Iron (0. 3%)] though there was no significant difference among the treatments.

Table 1: Effect of Humic acid and Iron on Growth attributes of Rabi Maize.

S. No	Treatment combinations	At 100 DAS At 80-100 DAS			
		Plant height (cm)	Plant Dry weight (g)	CGR (g/m²/day)	RGR (g/g/day)
1.	Humic acid 0 gm/lit. + Iron 0. 1%	148. 8	90. 91	13. 36	0. 028
2.	Humic acid 0 gm/lit. + Iron 0. 2%	155. 42	98. 10	14. 32	0. 028
3.	Humic acid 0 gm/lit. + Iron 0. 3%	160. 71	102. 84	15. 04	0. 028
4.	Humic acid 2 gm/lit. + Iron 0. 1%	162. 07	98. 04	15. 31	0. 031
5.	Humic acid 2 gm/lit. + Iron 0. 2%	162. 89	103. 20	14. 93	0. 026
6.	Humic acid 2 gm/lit. + Iron 0. 3%	163. 37	103. 68	15. 70	0. 030
7.	Humic acid 4 gm/lit. + Iron 0. 1%	167. 47	105. 85	15. 06	0. 027
8.	Humic acid 4 gm/lit. + Iron 0. 2%	163. 53	109. 16	16. 80	0. 030
9.	Humic acid 4 gm/lit. + Iron 0. 3%	158. 05	105. 47	15. 67	0. 029
10.	Control	143. 73	81. 36	10. 27	0. 023
	F-Test	S	S	S	NS
	S. Em (±)	4. 602	3. 522	0. 877	0. 001
	CD (p = 0. 05)	13. 67	10. 467	2. 607	-

Table 2: Effect of Humic acid and Iron on yield attributes and yield of Rabi Maize.

S. No.	Treatment combinations	At harvest						
		Cob/ plant	rows/ Cob	Grains/ rows	Test Weight (gm)	Grain yield (t/ha)	Stover yield (t/ha)	Harvest Index (%)
1.	Humic acid 0 gm/lit. + Iron 0. 1%	1. 06	14. 33	33. 73	19. 29	4. 17	11. 95	25. 67
2.	Humic acid 0 gm/lit. + Iron 0. 2%	1. 20	14. 80	34. 07	18. 20	4. 51	13. 28	25. 32
3.	Humic acid 0 gm/lit. + Iron 0. 3%	1. 33	15. 07	34. 87	18. 67	5. 21	13. 69	27. 54
4.	Humic acid 2 gm/lit. + Iron 0. 1%	1. 13	14. 40	33. 73	17. 78	4. 91	13. 32	27. 06
5.	Humic acid 2 gm/lit. + Iron 0. 2%	1. 20	15. 00	36. 93	19. 29	5. 17	12. 96	28. 71
6.	Humic acid 2 gm/lit. + Iron 0. 3%	1. 40	15. 60	38. 53	19. 47	5. 30	13. 98	27. 34
7.	Humic acid 4 gm/lit. + Iron 0. 1%	1. 33	15. 33	38. 02	19. 12	5. 57	13. 99	28. 98
8.	Humic acid 4 gm/lit. + Iron 0. 2%	1. 80	16. 0	38. 8	17. 98	6. 52	14. 48	30. 09
9.	Humic acid 4 gm/lit. + Iron 0. 3%	1. 73	15. 33	37. 47	18. 55	5. 45	12. 67	30. 36
10.	Control	1. 03	13. 6	32. 93	17. 86	3. 73	9. 91	27. 03
	F - Test	S	S	S	NS	S	S	NS
	S. Em (±)	0. 109	0. 436	1. 143	0. 19	0. 375	0. 772	1. 656
	CD (p = 0. 05)	0. 324	1. 296	3. 396	-	1. 115	2. 294	-

Conclusion

The experiment demonstrated that the application of 4 g/L humic acid combined with 2% iron was the most efficacious treatment, significantly enhancing both growth and yield attributes.

This synergistic combination optimally promoted plant development and productivity, outperforming other tested formulations.

Acknowledgement

I express my deepest gratitude to my advisor, Prof. (Dr.) Vikram Singh, Department of Agronomy, Naini Agricultural Institute, Sam Higginbottom University of Agriculture, Technology and Sciences, Prayagraj, Uttar Pradesh, India, for his invaluable guidance, unwavering support, and insightful feedback throughout the course of this research. His expertise and encouragement were instrumental in shaping this work. I also extend my heartfelt appreciation to all the faculty members of the Department of Agronomy for providing the necessary facilities and fostering an environment conducive to academic and research excellence. Their collective support significantly contributed to the successful completion of this study.

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