Research Article

Effect of Agricultural Sulfur Application and Humic Acid Foliar Spray on Some Vegetative Growth Characteristics of Fig Seedlings (White Adriatic Cultivar)

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Abstract | In this study, the effect of sulfur and humic acid foliar application as agricultural agents on vegetative growth of fig (Ficus carica L.) seedlings cv. White Adriatic. The experiment was carried out during 2024 growing season at the Horticulture and Forestry Station, Al-Mahawil District, Babil Governorate, Iraq in a factorial (3 × 3) arrangement based on randomized complete block design with three replications. Treatments consisted of three rates:0, 500 and 1000 kg ha^{-1} soil-applied agricultural sulfur in combination with three concentrations; (0, 3 and 6 mL L^{-1} of humic acid foliar spray applied three times throughout a growing season. The conclusion was based on the fact that 1000 kg ha^{-1} sulfur had produced for all the parameters, higher growth in terms of seedling height, leaf number and area, stem diameter, fresh and dry leaf weights as well as chlorophyll index than those from control. Along the same line foliar application of 6 mL L^{-1} humic acid has significantly improved all measured growth parameters. The effect of farm sulfur on/humic acid interaction was significant with the highest increase in all vegetative growth parameters recorded under the combined treatment compared to control. In general, the co-application of agricultural sulfur and HA can be considered as a useful strategy to promote growth and physiological performance for fig seedlings cultivated in Iraqi agro-ecological conditions.

Received | January 21, 2026; **Accepted** | February 6, 2026; **Published** | July 21, 2026
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Citation | Almekh, M.A.A. 2026. Effect of agricultural sulfur application and humic acid foliar spray on some vegetative growth characteristics of fig seedlings (White adriatic cultivar). *Sarhad Journal of Agriculture,* 42(3): 1311-1319.
DOI | https://dx.doi.org/10.17582/journal.sja/2026/42.3.1311.1319
Keywords | Agricultural sulfur, Humic acid, Fig, White adriatic cultivar, Humic acid

Introduction

The fig tree (*Ficus carica* L.), belonging to the Moraceae family, is one of the most prominent deciduous fruit trees economically and nutritive wise cultivated in semi-subtropical regions around the globe. The genus Ficus includes > 800 species and has a long history of domestication for its broad ecological amplitude (Hatano *et al*., 2008). World's figs production has continued to be close to 289,818 ha and around 1.32 million tons per year (Food and Agriculture Organization (FAO, 2019). Turkey is a world leader in production, followed by Egypt, Morocco, Iran and Algeria. Within Europe, Spain leads with 51,600 tons followed by Greece (19,730 tons) and Italy (11,830 tones) (Teruel-Andreu *et al*., 2021).

The fig fruit is well known both for its economic value and for its nutritional and functional properties. It contains vitamins (C, A and most of the B-complex), minerals (potassium, calcium, iron, magnesium and zinc), dietary fibers and amino acids but not fat or cholesterol. As a result, figs have had a history of being used in human diets and traditional medicine, since it has been known to improve cardiovascular, respiratory, and muscular functions and exert anti-inflammatory properties (Mahesar *et al*., 2023).

Sulfur (S) is a macronutrient which plays an essential role in basic physiological and biochemical processes in plants, as components of S-containing amino acids, proteins, enzymes and vitamins (Hawkesford and De Kok,; Mcgrath). The dominating sulfur repository is the soil organic matter, which however can almost not be taken up directly by plants. Thus, sulfate (SO_4^{2-}) is the major absorbable sulfur species by plants (Narayan *et al*., 2023). Use of agro-sulfur: Use of agricultural sulfur has appeared increasingly suitable in recent years regarding improvement soil chemical properties, particularly on the alkaline soil. Sulfur lowers the pH of soil by its acidifying effect and increasing the availability of macro and micronutrients like N, P K, and Fe (Shah *et al*., 2022). Recent findings of Mutlak *et al*. (2025) reported soil application of agricultural sulfur (1000 kg ha^{-1}) significantly enhances availability of soil nutrients and plant growth, including available nitrogen, phosphorus, potassium and iron relative to untreated control. These results indicate that sulfur supply may be used to optimize soil fertility and plant nutritional status.

Humic acid, a principal fraction of humic substances resulting from the decomposition of organic matter, is known to act as a regulator in plant growth and soil–plant processes. Its beneficial effects have been related to its stimulation of metabolic processes such as photosynthesis, respiration and nutrient assimilation, together with its induction of enzyme activation and plantâ€"hormone homeostasis. Humic acid stimulates cell division and elongation, especially in root tissues, enhances cell membrane permeability, and acts as a conditioners for the biosynthesis of carbohydrates and proteins for plant structure/morphological functions. Furthermore, it triggers some important enzymes such as phytase, peroxidase and oxidase which mediates overall plant physiological activity (Dantas *et al*., 2007). For this reason, the use of humic acid-based fertilizers has been an increasingly accepted rooted agronomic practice to enhance crop growth and yields (Zheng *et al*., 2022). Noroozisharaf and Kaviani (2018) also highlighted that HS play the role of natural bio-stimulants with positive effects on plant growth, yield and quality.

Humic acid application In fig, former work have shown that there are positive effects of vegetative growth to humic acid. Al-Khafaji *et al*. (2017) reported that foliar application of humic acid at levels up to 6 mL L^{-1} increased plant height, leaf number, leaf area and stem diameter in fig seedlings. Nevertheless, although the individual impacts of sulfur and humic acid are known, not much is known with respect to their joint use and synergistic effects on fig seedling vegetative growth especially under Iraqi agro-ecological conditions.

Recent approach and development Recently, studies increasingly focused on the integrated nutrient management strategies like sulfur in agriculture, humic substances and biostimulant used together for enhancing plant growth performance and nutrient use effciency of agricultural plant grown under semi-arid and alka- line soil conditions. Elements such as nitrogen, phosphorus, potassium and micronutrients (MNs) are usually deficient in these soils, and soil acidification is essential in improving the chemical properties of alkaline soils via increasing the availability of these nutrients. The recent studies have revealed that S application improves vegetative growth, nutrient acquisition and plant health in horticultural plants (Narayan *et al*., 2023; Shah *et al*., 2022; Mutlak *et al*., 2025).

Appropriate land and water management, soil improvement and integrated nutrient management are important aspects of increasing agricultural productivity in arid and semi-arid regions as suggested by recent research. The evaluation of groundwater quality is very important for irrigation purposes and sustainable environmental land planning, especially in Babil Governorate (Hamid *et al*., 2025). Other investigations have shown that nutrients availability and vegetative growth of different fruit seedlings, pomegranate, apricot, citrus and mandarin are significantly increased with potassium in form foliar sprays, combined or not with some organic residues additions as well as poultry (Almakh *et al*., 2025; Almekh, 2025; Abo Al-Meekh *et al*., 2020; Assi *et al*., 2021). The addition of organic matter as well with the application of nano-fertilizers and chelated micronutrients also results to improved crop production under salinity stressed conditions (Ali *et al*., 2023, Al-Shahbani and Abu Al-Mikh Al-Mamouri, 2022). Moreover, a potential of biological reclamation with plant-based methods to reduce heavy metal contamination and improve soil environmental quality has been indicated (Hamid and Almaeakh, 2024; Tarkhan Abo Almeekh *et al*., 2020).

Meanwhile, humic acid has been reported to be an effective biostimulant for its positive effects on the physiological and biochemical processes of plants, such as improved cell membrane permeability, enhanced growth (root and shoot), increased chlorophyll synthesis, and promoted nutrient uptake. A number of recent studies hav shown that soil or foliar application with HA greatly increases the vegetative growth parameters, leaf chemical composition and yield attributes in a variety of crops, including myrtle (Fadalah *et al*., 2023), hot pepper (Fadala *et al*., 2023), cucumber (Al-Rikabi *et al*., 2025; Kashash *et al*., 2025; Omar and Fadala, 2025), onion and sweet pepper. Furthermore, addition of humic acid to other biostimulants or foliar treatments has been reported to induce synergistic effects on plant growth, photosynthetic activity and biochemical traits leading to increasing crop productivity in protective and open field (Fadala *et al*., 2021; Al-Rikabi *et al*., 2025).

Although there is a growing body of literature on sulphur and Humic acid as separate factors, relatively little research has been conducted on their combined effect in fig (*Ficus carica* L.) seedlings, particularly of cultivar White Adriatic under Iraq agro-ecological conditions. Therefore, in the present study, we set out to determine the independent and combined effects of agricultural sulfur soil application and foliar humic acid application on vegetation characteristics of fig seedlings with a view to scientifically guiding fig nursery management.

Accordingly, this work aimed to investigate the combined and single effects of agricultural sulfur soil application or humic acid foliar spraying on vegetative growth attributes of fig (*Ficus carica* L.) seedlings cv. White Adriatic to an extent that could offer a reliable scientific basis for enhancing the fig seedling production and management practices.

Materials and Methods

The experiment was carried out at the Horticulture Station, in Al-Mahawil District- Babil Governorate which belongs to the Ministry of Agriculture, Iraq. Materials and methods Fig seedlings (*Ficus carica* L.) cv. White Adriatic were employed in this study. Totally 81 uniform seedlings in growth and height were chosen and transplanted into plastic pots (30 × 25 cm, volume of 7 kg / pot). The pots were filled with a river sand and peat moss mixture at a ratio of 2:1 (v/v) growth medium. The vegetative growth measurements of the seedlings were recorded at transplanting time.

The experiment was conducted in a factorial (3 × 3) completed randomized block design with three replications. Twenty-seven seedlings were used for each replicate, with three seedlings in each experimental unit. soil applied agricultural sulfur (agricultural recommended dose) at three levels: 0, 500 and 1000 kg ha^{-1} marked as S0, S1and S2. The other factor was foliar applied humic acid at 0, 3 and 6 mL L^{-1} (H0, H1 and H2). Foliar sprayings also emerged in the once, twice and thrice: on 1 March 2025, 1 April 2025 and 1 May 2025 respectively. Cultural practices were the same for all treatments and throughout the experimental season.

Table 1: *Physicochemical properties of the growth medium before planting*

Parameter	Value	Unit
Soil pH (1:1)	7.52	—
Electrical conductivity (EC)	2.85	dS m^{-1}
Cation exchange capacity (CEC)	17.4	cmolc kg^{-1} soil
Organic matter (OM)	8.2	g kg^{-1}
Available nitrogen (N)	24.2	mg kg^{-1} soil
Available phosphorus (P)	7.5	mg kg^{-1} soil
Available potassium (K)	115.4	mg kg^{-1} soil
Sand	653	g kg^{-1}
Silt	193	g kg^{-1}
Clay	154	g kg^{-1}
Soil texture class	Sandy loam	—

Growth medium samples were taken from the fig seedling pots and mixed well before analysis. The physical and chemical properties of the growing media were analyzed in the soil and water technologies laboratories, Department of Soil Water Technologies, Al-Musayyib Technical College, Al-Furat Al-Awsat Technical University according to standard methods adopted by Black (1965), Page *et al.* (1982). The physicochemical data are shown in Table 1.

Measured parameters

At the 225th day of the experiment, data from all measurements were obtained on July 1st, 2025 as:

Mean increase of seedling height (cm):

At the end of this experiment, seedling height was measured with the help of metric tape, from surface of soil to apical meristam. The average height increase was calculated by subtracting the observed initial height at planting from the final observed height at the end of experiment.

Average increase in total no. of leaves:

Leaf number increment per experimental unit was the difference of total leaf number at the start, and at the end of experiment.

Leaf area per seedling (cm² seedling⁻¹):

Leaf area was measured at the end of the experiment by a planimeter. Three completely expanded leaves were selected from each seedling in each experimental unit. Mean leaf area per seedling was calculated with the following formula:

$$\text{Number of leaves per seedling} \times \left(\frac{\text{Area of three leaves} \sum}{3} \right) = \text{Leaf area per seedling (cm}^2\text{)}$$

Main stem diameter (mm):

Main stem diameter was measured by a vernier caliper.

Leaf dry weight (g):

Leaves were harvested and kept in paper bags, oven-dried at 65 °C to a constant weight. Dry weight was subsequently recorded.

Leaf chlorophyll content (SPAD units):

Chlorophyll content was measured with a chlorophyll meter (SPAD-502). Measurements were made in 15 leaves per experimental unit and expressed as means in SPAD units (Jemison and William, 2006).

Results and Discussion

Influence of agricultural sulfur and humic acid on mean height increase (cm)

Table 2 shows that mean difference in plant heights between the highest and lowest sulfur application rates was highly significant. The highest increase in plant height was observed from the S2 (31.83 cm) treatment to control (S0, 17.36 cm), with an increment of 83.35%.

In addition, plant height was significantly increased by foliar application of humic acid. The mean increase under H2 was 28.68 cm and 20.38 cm for the control treatment (H0) i.e., an average increase of 40.72 %.

For the interaction between agricultural sulfur application and foliar spraying with humic acid, combination treatment S2 × H2 consistently showed statistically significant higher degree of superiority than control treatment (S0 × H0) in average plant height increase (37.00 vs. 12.50 cm). This represents a dramatic increase of 196%.

Table 2: *Effect of agricultural sulfur application and humic acid foliar spray on the mean increase in total leaf number of fig seedlings*

Agricultural Sulfur	Humic acid (mL L^{-1})			Average
Kg h-1	H0	H1	H2	
S0	3.33	5.56	7.67	5.52
S1	8	9.33	9.67	9
S2	9.55	11.55	13.67	11.59
Average	6.96	8.81	10.34	

Table 3: *Effect of agricultural sulfur application and humic acid foliar spray on the mean increase in total leaf number of fig seedlings*

Agricultural sulfur	Humic acid (mL L^{-1})			Avereage
Kg h-1	H0	H1	H2	
S0	3.33	5.56	7.67	5.52
S1	8	9.33	9.67	9
S2	9.55	11.55	13.67	11.59
المعدل	6.96	8.81	10.34	

Effect of agricultural sulfur and humic acid on the mean increase in total leaf number per seedling

The results presented in Table 3 demonstrate a significant effect of agricultural sulfur application on the mean increase in total leaf number of fig seedlings. The S2 treatment resulted in the highest increase in leaf number (11.59 leaves seedling^{-1}) compared with the control treatment (S0), which recorded 5.52 leaves seedling^{-1}, corresponding to an increase of 109.96%.

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Similarly, foliar application of humic acid significantly enhanced the mean increase in leaf number. The H2 treatment recorded 10.33 leaves $seedling^{-1}$, whereas the control treatment (H0) recorded 6.96 leaves $seedling^{-1}$, representing an increase of 48.41%.

With respect to the interaction effect between agricultural sulfur application and humic acid foliar spraying, the combined treatment S2 × H2 exhibited the greatest significant increase in total leaf number, achieving 13.67 leaves $seedling^{-1}$, compared with only 3.33 leaves $seedling^{-1}$ for the control interaction S0 × H0, which reflects a pronounced increase of 310.51%.

Influence on leaf area per seedling (cm^2 $seedling^{-1}$) by agricultural sulfur and humic acid

It is clear from Table 4 that the leaf area per seedling was significantly affected by agricultural sulfur application. Leaf area was the highest under S2 treatment (261.60 cm^2 $seedling^{-1}$) as against (S0) 180.48 cm^2 $seedling^{-1}$, showing an enhanced more of (44.94%).

Similarly, leaf area was significantly promoted by FA humic acid foliar spray. Mean leaf area of 240.38 cm^2 $seedling^{-1}$ was observed in the H2 treatment, while this value for the control treatment (H0) was 187.89 cm^2 $seedling^{-1}$, with a potential development of 27.93%.

In terms of the interaction effect, overlay S2 × H2 presented as the highest and significantly higher leaf area enhancement with 307.80 cm^2 $seedling^{-1}$ comparing to 170.67 cm^2 $seedling^{-1}$ for control interaction S0 × H0, and increased by 80.34%.

Table 4: *Effect of agricultural sulfur application and humic acid foliar spray on leaf area per seedling (cm^2 $seedling^{-1}$)*

Agricultural sulfur	Humic acid (mL L^{-1})			Average
Kg h-1	H0	H1	H2	
S0	170.67	182.1	188.67	170.67
S1	186.33	201.33	224.67	186.33
S2	206.67	270.33	307.8	206.67
Average	187.89	217.92	240.38	187.89

Effect of agricultural sulfur and humic acid on the mean increase in main stem diameter (mm)

The results presented in Table 5 indicate a significant effect of agricultural sulfur application on the mean increase in main stem diameter of fig seedlings. The S2 treatment recorded the highest increase in stem diameter (10.30 mm), compared with the control treatment (S0), which recorded 6.87 mm, corresponding to an increase of 49.92%.

Similarly, foliar application of humic acid significantly enhanced the mean increase in stem diameter. The H2 treatment achieved an increase of 9.91 mm, whereas the control treatment (H0) recorded 6.79 mm, representing an increase of 45.94%.

With regard to the interaction effect between agricultural sulfur application and humic acid foliar spraying, the combined treatment S2 × H2 exhibited the greatest significant increase in main stem diameter, reaching 12.67 mm, compared with 5.80 mm for the control interaction S0 × H0, which reflects a pronounced increase of 118.44%.

Table 5: *Effect of agricultural sulfur application and humic acid foliar spray on the mean increase in main stem diameter (mm)*

Agricultural sulfur	Humic acid (mL L^{-1})			Average
Kg h-1	H0	H1	H2	
S0	5.8	6.83	7.97	170.67
S1	6.67	8.27	9.1	186.33
S2	7.9	10.33	12.67	206.67
Average	6.79	8.48	9.91	187.89

Effect of farm sulphur and humic acid on average fresh leaf weight (g)

Results of the experiments, mean fresh leaf weight of fig seedling as influenced by sulfur application to agricultural soil were presented in Table 6. The fresh leaf weight of S2 was 29.32g, that is significantly different from the S0 (20.12g) and increased by 45.72%.

Spray application on the leaves with humic acid resulted in an increase of fresh weight of leaves. Fresh leaf weight Weight of saplings had the highest fresh leaf weight (34.77%) in control treatment (H0) and reached up to 20.99 g, but its maximum average value was observed for H2 (28.29 g).

For the interaction between agricultural sulfur and humic acid/-foliar application, combined treatment of S2 × H2 was remarkably superior (fresh leaf weight;

31.50 g) than that of S0 × H0 control combination (fresh leaf weight; 15.07 g), showing a significant difference of 109.02%.

Table 6: *Effect of agricultural sulfur application and foliar spraying with humic acid on fresh leaf weight (g)*

Agricultural sulfur	Humic acid (mL L^{-1})			Average
Kg h-1	H0	H1	H2	
S0	15.07	20.93	24.37	20.12
S1	20.33	27.42	29	25.58
S2	27.57	28.88	31.5	29.32
Average	20.99	25.75	28.29	

Mean dry weight of seedling leaves (g)

The results presented in Table 7 showed that the treatment with agricultural sulfur application (S2) resulted in a significant increase in leaf dry weight, reaching 9.46 g, compared with the control treatment (S0), which recorded 4.99 g, representing an increase of 89.57%. Similarly, foliar spraying with humic acid (H2) caused a significant increase in leaf dry weight, reaching 8.56 g, compared with the control treatment (H0), which recorded 5.92 g, with an increase of 44.59%. Regarding the interaction between agricultural sulfur application and humic acid spraying, the S2 × H2 treatment showed a significant superiority, recording the highest leaf dry weight of 10.43 g, compared with the S0 × H0 treatment, which recorded 3.90 g, achieving an increase of 167.43%.

Table 7: *Effect of agricultural sulfur application and foliar spraying with humic acid on leaf dry weight (g)*

Agricultural sulfur	Humic acid (mL L^{-1})			Average
Kg h-1	H0	H1	H2	
S0	3.9	5.17	5.9	4.99
S1	5.2	6.83	9.33	7.12
S2	8.67	9.27	10.43	9.46
Average	5.92	7.09	8.56	

Leaf chlorophyll content (SPAD)

The results reported in Table 8 show that the use of agricultural sulfur (S2), gave rise to a significant increase in the leaf chlorophyll content, which attained 48.62 SPAD units against only 41.63 SPAD unit found for the control treatment S0 with an increment of 16.79%. Also, application of humic acid in foliar manner (H2) led to an enhance on leaf chlorophyll content up to 47.48 SPAD units compared with the control treatment (H0), which recorded 41.75 SPAD units showing an increase of 13.72 %.

The interaction effect between agricultural sulfur application and humic acid spraying was significant, the S2 × H2 treatment was significantly better than other treatments, and the maximum seedling chlorophyll content reached 50.09 SPAD units, which was 42.42% that of S0 × H0 (35.17~SPAD units).

Table 8: *Impact of agricultural sulfur application and spraying plants with humic acid on leaf chlorophyll index (SPAD)*

Agricultural Sulfur	Humic acid (mL L^{-1})			Average
Kg h-1	H0	H1	H2	
S0	35.17	44.47	45.25	41.63
S1	42.7	46.02	47.1	45.27
S2	47.38	48.4	50.09	48.62
Average	41.75	46.3	47.48	

Discussion

The data represented in Table 2, Table 3, Table 4, Table 5, Table 6, Table 7 and Table 8) manifestly prove the substantial influence of agricultural sulfur on statistical significant improvement to be limited to all studied characters. This phenomenon may be due to higher requirement of sulfur by plants in the vegetative growth period. Sulfur containing compounds are necessary for amino acids such as Methionine and Cystine, an important part of glutathione, Vitamins A and B1, as well as Chlorophyll. Sulfur is also involved in the creation of disulfide bonds in proteins, enzyme regulation, and redox reaction modulation. Furthermore, iron–sulfur proteins are involved in many important biological activities such as photosynthesis, energy generation and metabolism (Zenda *et al*., 2021; Shah *et al*., 2022; Narayan *et al*., 2023, ; Hamid and Almaeakh, 2024; Al-Khafagi *et al*., 2023; Al-Khafagi *et al*., 2025).

In addition, application of cultured sulfur to the soil fills up the niche of nutrient supply increased and that leads to an increased in the uptake amount of nutrients by plants. This is essentially the result accomplished with oxidation of sulfur, which creates sulfuric acid and lowers soil pH to enhance nutrient solubility and availability. This improvement also was directly reflected on fig seedling growth traits (Abdul-Kadhim and Oleiwi, 2025).

According to the same tables, foliar application of humic acid concentration at 4 and 6 mL L^{-1} showed increased significant differences in all the characteristics studied. This could be due to the stimulating effect of HS on plant through organic matter, mineral elements and amino acids. Humic acid increases cell membrane permeability, improves nutrient uptake and is also involved in metabolic processes whereby chlorophyll, sugars and enzymes are synthesized. Moreover, utilization of humic acid increases the tolerance of the plant to abiotic stress in a way that this aspect contributes favorable for the ongoing of important physiological processes in the plant (Hamid and Kadhim, 2022; Shahad and Hamid, 2025).

Moreover, chlorophyll contents are also increased by humic acid leading to higher amounts of carbohydrates used for all physiological processes. It eventually results in the improvement of all vegetative structures and photosynthesis components that are found in fig seedlings, thereby allowing them to uptake increased levels of nutrients from the soil. These results are in line with those of Sekhi *et al.* (2021), Kelly and Khalaf (2022), Ali and Al-Dolaimi (2023) and Rahim and Hamid (2025).

It may be concluded from the results of this study that applying agricultural sulfur along with foliar application of humic acid has a significant role in enhancing some growth characters of fig seedlings (*Ficus carica* L.) cv. White Adriatic.

Conclusions and Recommendations

The findings of this trial suggest that the exogenous application of agricultural sulfur could enhance comprehensive growth traits of fig seedlings, which is probably related to its involvement in the synthesis of amino acids, vitamins and chlorophyll, and metabolism regulation. Sulfur improved nutrient access through acidification and nutrient uptake. Humic acid foliar application at 4-6 mL Land[1] also demonstrated better growth promotion by enhancing cell membrane permeability, metabolic activity, chlorophyll and carbohydrate content. Hence, application of agricultural sulphur combined with humic acid was very efficient on increasing vegetative growth and physiological activities of Ficus carica L. cv. White Adriatic seedlings.

Acknowledgments

The authors are thankful to the staff of the Horticulture and Forestry Station, Al-Mahawil District, Babil Governorate, Iraq, for their valuable technical support and assistance. Appreciation is also extended to the Soil and Water Technologies laboratories at Al-Musayyib Technical College for facilitating soil analysis.

Novelty Statement

This study provides the first comprehensive evaluation of the combined application of agricultural sulfur and humic acid on vegetative growth of fig seedlings (White Adriatic cultivar) under Iraqi agro-ecological conditions, demonstrating a significant synergistic effect compared to individual applications

Generative AI and AI-assisted technology statement
The authors declare that no generative AI and AI assisted technology was used in the creation of this manuscript.

Conflict of interest
The authors have declared no conflict of interest.

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