Effect of Humic Acid-Fortified Compound Fertilizer, Organic Amendment, and Biofertilization on Selected Growth Traits and Leaf Nitrogen, Phosphorus, and Potassium Concentrations in Barley.

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Abstract

This study aimed to assess the effects of a humic acid–enriched compound fertilizer, in combination with organic and biological amendments, on growth traits and foliar nutrient concentrations in barley. The field work took place on farmland affiliated with the College of Agriculture at the University of Diyala during the 2024–2025 season, using a randomized complete block design laid out as a factorial experiment with three replicates. The three experimental factors comprised a humic acid-fortified compound fertilizer at four application levels (0, 33, 66, and 100% of the recommended dose), an organic amendment at three levels (0, 2, and 4% of soil volume), and biofertilization with *Pseudomonas fluorescens* at two levels (with and without inoculation).

The recorded measurements included plant height, leaf area, number of spikes per plant, grain yield per plant, and the concentrations of nitrogen, phosphorus, and potassium in the leaves at the booting stage. A clear superiority of the A4B3C2 interaction was observed across nearly all traits. This combination gave the tallest plants at 91.96 cm, the largest leaf area reaching 30.67 cm^2, the highest spike count of 4.66 spikes per plant, and the greatest per-plant yield of 5.055 g. Compared with the A1B1C1 control, the increases amounted to 98.06% for plant height, 380.72% for leaf area, 366.00% for spike number per plant, and 494.01% for individual plant yield. Leaf nutrient levels at booting also peaked under this treatment, registering 4.66% nitrogen, 0.70% phosphorus, and 5.62% potassium—representing gains of 130.69%, 366.67%, and 73.46% respectively over the control values.

It can be concluded from these findings that an integrated fertilization strategy blending a humic acid-augmented compound fertilizer with organic matter and bacterial inoculants offers a sound, efficient approach for stimulating barley growth and improving its mineral nutrition. The underlying mechanisms likely involve a more balanced delivery of nutrients from the soil to the plant, enhanced fertilizer recovery efficiency, and broader improvements in those soil characteristics that

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govern nutrient release, including shifts in pH and greater rooting depth and root density, all of which feedback positively onto the traits examined here.

Keywords: Barley, humic acids, organic fertilizer, biofertilization, *Pseudomonas fluorescens*, NPK

Introduction

Barley (Hordeum vulgare L.) stands among the major cereal crops cultivated in arid and semi-arid regions, owing to its adaptability to a wide range of environmental conditions, its value as food and feed, and its versatility in various industrial applications. Growth efficiency and grain yield in barley are, to a considerable degree, shaped by soil fertility and the availability of essential nutrients particularly nitrogen, phosphorus, and potassium given their central roles in canopy development, photosynthetic capacity, and the formation of yield components.

Integrated nutrient management has emerged as a contemporary paradigm for boosting crop productivity. Relying on a single fertilizer source may fail to elicit optimal plant response under variable soil conditions and differential nutrient uptake efficiencies. Compound fertilizers provide an immediate and balanced supply of macronutrients, whereas humic acids promote an enhanced rhizosphere environment and improve nutrient availability, enhanced uptake efficiency, and positive shifts in key biological and chemical properties of the soil. Recent studies have demonstrated that combining humic acids with mineral fertilizers can promote growth attributes, raise yields, and improve plant nutrient utilization [2, 15, 16].

Organic amendments, for their part, fulfill a vital function in soil structure improvement, organic matter accumulation, and the soil's capacity to retain water and nutrients. Biofertilization, on the other hand, stimulates beneficial microbial communities in the root zone, thereby increasing the accessibility of certain nutrients and triggering plant growth promotion. An expanding body of evidence suggests that the integration of chemical, organic, and biological fertilization can elicit superior plant responses, reflected in improved vegetative growth, enhanced yield components, and greater efficiency of mineral nutrient utilization [5, 13, 14].

For barley, the relevance of such combined treatments lies in their anticipated impact on growth and productivity traits. Indicators such as plant height, leaf area, spike number per plant, grain yield per individual plant, and the nitrogen, phosphorus, and potassium content of the leaves serve as valuable benchmarks for gauging fertilizer treatment efficacy.

Accordingly, the present work was undertaken to investigate the effects of a humic acid-enriched compound fertilizer applied in concert with organic and biological amendments on selected growth parameters of barley, and to elucidate how these treatments translate into improved plant performance and nutritional status.

Materials and Methods

A field experiment was conducted during the 2024–2025 growing season at a site belonging to the College of Agriculture, University of Diyala. The soil at the location had a clay texture. Composite samples were collected from the surface layer (0–30 cm), air-dried, and passed through a 2-mm sieve. Selected physical and chemical properties were then determined to characterize the soil prior to planting, as summarized in Table 1. Physical analyses covered particle size distribution, bulk density, and field capacity following the procedures outlined by [3], while chemical analyses included pH, electrical conductivity, organic matter, and available nutrients according to [12]; available soil nitrogen was measured by the [4] method cited in [3].

The experiment was laid out in a randomized complete block design with a factorial arrangement and three replications. Three factors were studied. The first factor, a humic acid-enriched compound fertilizer, comprised four levels: no addition (A1), 33% of the recommended dose (A2), 66% of the recommended dose (A3), and 100% of the recommended dose (A4). The second factor, an organic fertilizer derived from decomposed buffalo manure, was applied at three levels: no addition (B1), 2% of soil volume (B2), and 4% of soil volume (B3). The third factor involved biofertilization with *Pseudomonas fluorescens* at two levels: without inoculation (C1) and with inoculation (C2). The treatments and their corresponding codes are detailed in Table 2. Altogether, 24 treatment combinations were randomly assigned within each block, giving a total of 72 experimental units, each measuring 5 m².

Land preparation began with leaching to reduce salt levels, after which the soil was plowed in two perpendicular directions, harrowed, and leveled. The field was subsequently divided into three blocks, each containing 24 experimental units with dimensions of 2.5 × 2 m; 0.5-m alleyways were left between plots and between blocks. Sprinklers were installed to ensure uniform water distribution across the experimental units. Barley seeds were broadcast-sown on 15 November 2024 at a rate of 40 kg ha^{-1}, equivalent to 80 g per experimental unit.

The humic acid-fortified compound fertilizer, manufactured by the Kufa

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Agricultural Fertilizer Plant / College of Agriculture, University of Kufa, was applied two weeks before sowing. According to the product label, it contained 16.5% nitrogen, 45.4% phosphorus, 2.14% potassium, along with humic and fulvic acids and certain micronutrients. It was added at the four levels specified above, corresponding to 0, 33, 66, and 100% of the recommended fertilizer rate. The organic amendment—decomposed buffalo manure—was incorporated at 0, 2, and 4% of the soil volume of each plot. The biofertilizer carrying *Pseudomonas fluorescens* was prepared by culturing the inoculum and determining its density, then used to treat the seeds immediately before sowing.

Data were collected on plant height, leaf area, number of spikes per plant, grain yield per individual plant, and the concentrations of nitrogen, phosphorus, and potassium in the leaves, as outlined in Table 3. At full maturity, plant height was recorded from ten randomly selected plants within each experimental unit, from the soil surface to the tip of the spike. Leaf area was estimated for ten randomly chosen leaves per unit using the formula: leaf length × maximum width × 0.7. Spike number per plant and per-plant grain yield were also recorded from ten randomly selected plants in each unit. For leaf nutrient determination, plant samples were oven-dried at 65°C to constant weight, ground, and subjected to wet digestion. Nitrogen was determined using a micro-Kjeldahl apparatus as described by [7]. Phosphorus was measured by the ammonium molybdate–ascorbic acid method according to Olsen and Sommers (1982) in [12], and potassium was quantified using a flame photometer following [7].

All data were subjected to statistical analysis with the SAS software package, applying the randomized complete block model for a factorial experiment. Treatment means were compared using Duncan's multiple range test at the 0.05 probability level.

Table 1. Selected physical and chemical properties of the experimental soil prior to planting.

Property	Value	Unit
Electrical conductivity (1:1)	32.88	$dS\ m^{-1}$
pH (1:1)	7.31	—
Organic matter	0.50	%
Available nitrogen	15.11	$mg\ kg^{-1}$
Available phosphorus	10.70	$mg\ kg^{-1}$

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Property	Value	Unit
Available potassium	190.00	mg kg^{-1}
Bulk density	1.50	g cm^{-3}
Clay	48.24	%
Silt	27.76	%
Sand	24.00	%
Soil texture	Clay	—

Table 2. Experimental factors, treatment codes, and their descriptions.

Factor	Code	Description
Humic acid-enriched compound fertilizer (A)	A1	No addition
	A2	33% of the recommended dose
	A3	66% of the recommended dose
	A4	100% of the recommended dose
Organic fertilizer—buffalo manure (B)	B1	No addition
	B2	2% of soil volume
	B3	4% of soil volume
Biofertilizer—Pseudomonas fluorescens (C)	C1	Without inoculation
	C2	With inoculation

Table 3. Traits measured, growth stages at which they were assessed, units, and estimation methods.

Trait	Assessment stage	Unit	Method of estimation
Leaf nitrogen concentration	Booting	%	Determined after wet digestion using a micro-Kjeldahl apparatus according to Haynes (1980)
Leaf phosphorus concentration	Booting	%	Determined after wet digestion by the ammonium molybdate–ascorbic acid method using a spectrophotometer at 620 nm
Leaf potassium concentration	Booting	%	Determined after wet digestion using a flame photometer

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Trait	Assessment stage	Unit	Method of estimation
Plant height	Full maturity	cm	Measured from the soil surface to the tip of the spike on ten randomly selected plants per experimental unit, then averaged
Leaf area	Booting	cm^2	Estimated on ten randomly selected leaves per experimental unit using the formula: leaf length × maximum width × 0.7
Number of spikes per plant	Full maturity	spike $plant^{-1}$	Counted on ten randomly selected plants per experimental unit, then averaged
Grain yield per plant	Harvest	g $plant^{-1}$	Determined from ten randomly selected plants per experimental unit after threshing and weighing the grains, then averaged

Results and Discussion

3-1. Effect of Humic Acid-Enriched Compound Fertilizer, Organic Amendment, and Biofertilization on Plant Height in Barley.

Table 4 shows a significant influence of the humic acid–enriched compound fertilizer, the organic amendment, and the bio- fertilizer on barley plant height . The A4 level produced the tallest plants, averaging 85.30 cm, compared with 71.77 cm recorded for the A1 control. The intermediate levels A2 and A3 gave mean heights of 76.87 and 75.90 cm, respectively. For the organic factor, the B3 level yielded the highest value at 83.73 cm, whereas B1 registered 71.41 cm. The biofertilizer also exerted a marked influence, with C2 reaching 81.09 cm relative to 73.83 cm under C1. Among the interactions, the combination A4B3C2 stood out, delivering a maximum plant height of 91.96 cm, while A1B1C1 gave the poorest result at 46.43 cm.

These outcomes can be attributed to the capacity of the humic acid-supplemented compound fertilizer to enhance nutrient availability and

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uptake. Complementing this, the organic amendment improved soil physical and chemical characteristics, and the bacterial inoculant stimulated root development and nutrient-use efficiency, together promoting more vigorous vegetative growth and greater stature. The increased nitrogen absorption likely facilitated greater phosphorus uptake, which in turn supported deeper, more extensive root systems. A more robust root network improved water and nutrient acquisition, feeding back positively into shoot growth and final plant height. These findings align with observations reported by [2, 5].

Table 4. Effect of humic acid-enriched compound fertilizer, organic fertilization, and biofertilization on barley plant height (cm).

Factor A	**Factor B**	**Factor C**		**Interaction between A*B**	**Means of the factor A**	**Means of the factor B**
		C1	C2			
A1	B1	g 46.43	ef 66.00	f 56.21		
	B2	de 74.20	cd 78.40	cd 76.30		
	B3	bcd 82.40	a–d 83.20	a 82.80		
A2	B1	f 61.26	abc 84.23	de 72.75		
	B2	ef 67.36	abc 85.96	bcd 76.66		
	B3	bcd 81.43	bcd 80.96	abc 81.20		
A3	B1	ef 67.46	bcd 81.20	de 74.33		
	B2	cd 79.06	f 59.36	e 69.21		
	B3	bcd 82.03	abc 86.30	a 84.16		
A4	B1	cd 77.70	abc 87.00	ab 82.35		
	B2	abc 85.00	ab 88.53	a 86.76		
	B3	bcd 81.60	a 91.96	a 86.78		
A	A1	d 67.67	c 75.86		71.77 C	
	A2	d 70.02	b 83.72		76.87 B	
	A3	c 76.18	c 75.62		75.90 B	
	A4	b 81.43	a 89.16		85.30 A	
B	B1	d 63.21	bc 79.60			C 71.41
	B2	c 76.40	bc 78.06			B 77.23
	B3	ab 81.86	a 85.60			A 83.73
Means of the factor C		B 73.83	A 81.09			

Means within each factor or interaction sharing the same letter are not significantly different (P ≤ 0.05) according to Duncan's multiple range test.

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3-2. Effect of Humic Acid-Enriched Compound Fertilizer, Organic Amendment, and Biofertilization on Leaf Area in Barley

Leaf area in barley was significantly influenced by the humic acid-fortified compound fertilizer, the organic amendment, and the biofertilizer, as shown in Table 5. The A4 level recorded the highest mean leaf area of 23.21 cm², surpassing the A1 control, which measured 12.53 cm². Intermediate values of 19.20 and 18.25 cm² were obtained at A2 and A3, respectively. For the organic factor, the B3 treatment achieved the greatest leaf area at 20.34 cm², compared with 15.73 cm² under B1. The biofertilizer also produced a notable effect, with C2 yielding 18.95 cm² relative to 17.64 cm² for C1. The strongest response was observed with the A4B3C2 combination, which gave a peak leaf area of 30.67 cm², whereas the A1B1C1 treatment produced the lowest value at just 6.38 cm².

This enhancement can be traced to the role of the humic acid-enriched compound fertilizer in boosting nutrient availability and improving uptake, which fueled vegetative expansion and greater leaf surface development. The organic amendment further contributed by improving soil structure and increasing the retention of water and nutrients. Heightened nitrogen absorption, in particular, directly promoted canopy growth and, consequently, leaf area. Conversely, the bacterial inoculant promoted root development and improved nutrient uptake efficiency. It is also plausible that certain organic acids taken up by the plant exerted an indirect positive influence on growth indices, reinforcing the expansion of leaf area. These findings are in line with those reported by [2, 5].

Table 5. Effect of humic acid-enriched compound fertilizer, organic fertilization, and biofertilization on barley leaf area (cm²).

Factor A	Factor B	Factor C		Interaction between A*B	Means of the factor A	Means of the factor B
		C1	C2			
A1	B1	k 6.38	j 9.33	h 7.86		
	B2	i 12.81	hi 15.10	g 13.95		
	B3	hi 15.43	gh 16.15	fg 15.79		
A2	B1	fgh 17.05	e–h 18.12	ef 17.58		
	B2	d–g 19.18	c–f 19.52	cde 19.35		
	B3	bcd 21.80	c–f 19.55	c 20.67		
A3	B1	gh 16.28	d–g	def 17.75		

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Factor A	Factor B	Factor C		Interaction between A*B	Means of the factor A	Means of the factor B
		C1	C2			
			19.22			
	B2	gh 16.12	b–e 20.87	de 18.50		
	B3	c–f 19.64	fgh 17.39	de 18.51		
A4	B1	fgh 16.98	bc 22.50	cd 19.74		
	B2	b 23.17	b 23.79	b 23.48		
	B3	bcd 22.14	a 30.67	a 26.40		
A	A1	f 11.54	e 13.53		12.53 C	
	A2	bc 19.34	cd 19.06		19.20 B	
	A3	cd 18.93	d 17.57		18.25 B	
	A4	b 20.76	a 25.65		23.21 A	
B	B1	d 14.17	c 17.29			C 15.73
	B2	b 19.01	b 18.63			B 18.82
	B3	ab 19.75	a 20.94			A 20.34
Means of the factor C		B 17.64	A 18.95			

Means within each factor or interaction sharing the same letter are not significantly different (P ≤ 0.05) according to Duncan's multiple range test.

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3-3. Effect of Humic Acid-Enriched Compound Fertilizer, Organic Amendment, and Biofertilization on Spike Number per Plant

Data presented in Table 6 demonstrate that spike number per plant was significantly affected by the humic acid-fortified compound fertilizer, the organic amendment, and the biofertilizer. The A4 level produced the highest mean of 3.94 spikes per plant, compared with 2.11 spikes per plant recorded for the A1 control. The intermediate levels A2 and A3 registered means of 2.44 and 2.61 spikes per plant, respectively. For the organic factor, the B3 treatment achieved the greatest spike count at 3.20 spikes per plant, relative to 2.29 spikes per plant under B1. The biofertilizer also exerted a significant effect, with C2 yielding 3.00 spikes per plant compared with 2.55 spikes per plant for C1. The interaction A4B3C2 gave the highest value of 4.66 spikes per plant, whereas the A1B1C1 combination resulted in the lowest value of only 1.00 spike per plant.

These results can be attributed to the humic acid-supplemented mineral fertilizer improving plant growth and nutritional efficiency, which translated into more fertile tillers and a greater spike count. Enhanced uptake of N, P, and K—nutrients directly tied to canopy development—played a decisive role, particularly potassium, which is known to be instrumental in increasing spike number. The organic amendment further contributed by creating a more favorable soil environment and delivering nutrients more effectively through accelerated mineralization and improved nutrient availability, with clear benefits for vegetative growth and spike formation. Meanwhile, the bacterial inoculant boosted root activity and nutrient utilization efficiency, further promoting spike production per plant. These outcomes align with the findings of [11, 6].

Table 6. Effect of humic acid-enriched compound fertilizer, organic fertilization, and biofertilization on spike number per plant in barley.

Factor A	Factor B	Factor C		Interaction between A*B	Means of the factor A	Means of the factor B
		C1	C2			
A1	B1	f 1.00	def 1.66	f 1.33		
	B2	cde 2.33	bcd 2.66	de 2.50		
	B3	cde 2.33	bcd 2.66	de 2.50		
A2	B1	ef 1.33	cde 2.33	ef 1.83		
	B2	def 1.66	ab 3.66	d 2.66		

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Factor A	Factor B	Factor C		Interaction between A*B	Means of the factor A	Means of the factor B
		C1	C2			
	B3	bc 3.00	bcd 2.66	cd 2.83		
A3	B1	cde 2.33	bcd 2.66	de 2.50		
	B2	bcd 2.66	cde 2.33	de 2.50		
	B3	bc 3.00	bcd 2.66	cd 2.83		
A4	B1	bcd 2.66	a 4.33	bc 3.50		
	B2	ab 3.66	ab 3.66	b 3.66		
	B3	a 4.66	a 4.66	a 4.66		
A	A1	e 1.88	cde 2.33		2.11 C	
	A2	de 2.00	c 2.88		2.44 BC	
	A3	c 2.66	cd 2.55		2.61 B	
	A4	b 3.66	a 4.22		3.94 A	
B	B1	c 1.83	ab 2.75			C 2.29
	B2	b 2.58	a 3.08			B 2.83
	B3	a 3.25	a 3.16			A 3.20
Means of the factor C		B 2.55	A 3.00			

Means within each factor or interaction sharing the same letter are not significantly different (P ≤ 0.05) according to Duncan's multiple range test.

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3-4. Effect of Humic Acid-Enriched Compound Fertilizer, Organic Amendment, and Biofertilization on Grain Yield per Plant (g).

Grain yield per plant responded significantly to the humic acid-enriched compound fertilizer, organic amendment, and biofertilizer applications, as presented in Table 7. The A4 treatment registered the highest mean yield of 3.795 g, exceeding the A1 control, which recorded 1.921 g. The A2 and A3 levels yielded intermediate means of 2.303 and 2.734 g, respectively. Among organic treatments, B3 attained the highest mean at 3.247 g, compared with 2.120 g obtained under B1. The biofertilizer factor also produced a clear effect, with C2 reaching 3.041 g relative to 2.335 g for C1. The combined A4B3C2 treatment delivered the greatest per-plant yield of 5.055 g, whereas A1B1C1 gave the lowest value at 0.851 g.

These findings can be explained by the fact that applying the humic acid-fortified compound fertilizer, particularly at the highest rate, enhanced nutrient availability and uptake efficiency. Such improvements had a pronounced impact on vegetative growth indicators, which in turn drove higher grain yield and biological yield. The organic amendment contributed by improving soil physical and chemical properties, creating a more favorable rooting environment, and supporting greater canopy development and yield attributes. The bacterial inoculant further boosted nutrient utilization, leading to improved growth, enhanced yield components, and a substantial increase in per-plant grain yield. These results are consistent with those reported by [6, 8].

Table 7. Effect of humic acid-enriched compound fertilizer, organic fertilization, and biofertilization on grain yield per plant (g).

Factor A	Factor B	Factor C		Interaction between A*B	Means of the factor A	Means of the factor B
		C1	C2			
A1	B1	0.851 i	1.518 ghi	1.184 e		
	B2	2.078 fgh	2.506 efg	2.292 cd		
	B3	2.066 fgh	2.506 efg	2.286 cd		
A2	B1	1.195 hi	2.122 fgh	1.659 de		
	B2	1.535 ghi	3.551 bcd	2.543 c		
	B3	2.838 c-f	2.574 d-g	2.706 c		
A3	B1	2.074 fgh	2.512 efg	2.293 cd		
	B2	2.529 efg	2.316 fg	2.422 c		

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Factor A	Factor B	Factor C		Interaction between A*B	Means of the factor A	Means of the factor B
		C1	C2			
	B3	2.924 c-f	4.050 b	3.487 b		
A4	B1	2.514 efg	4.177 ab	3.346 b		
	B2	3.455 b-e	3.607 bc	3.531 b		
	B3	3.963 b	5.055 a	4.509 a		
A	A1	1.665 d	2.177 d		1.921 D	
	A2	1.856 d	2.749 c		2.303 C	
	A3	2.509 c	2.959 bc		2.734 B	
	A4	3.311 b	4.280 a		3.795 A	
B	B1	1.659 d	2.582 bc			2.120 C
	B2	2.399 c	2.995 b			2.697 B
	B3	2.948 b	3.546 a			3.247 A
Means of the factor C		2.335 B	3.041 A			

Means within each factor or interaction sharing the same letter are not significantly different ($P \leq 0.05$) according to Duncan's multiple range test.

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3-5. Effect of Humic Acid-Enriched Compound Fertilizer, Organic Amendment, and Biofertilization on Leaf Nitrogen Concentration in Barley at the Booting Stage

The A4 level recorded the highest mean nitrogen concentration of 3.61%, compared with 2.84% for the A1 control. The A2 and A3 treatments gave intermediate values of 3.22% and 3.41%, respectively. For the organic factor, the B3 and B2 levels yielded the highest means at 3.53% and 3.29%, respectively, relative to 2.99% under B1. The biofertilizer did not produce a pronounced significant difference between its two levels, with C2 reaching 3.35% and C1 recording 3.19%. The interaction A4B3C2 delivered the highest leaf nitrogen concentration of 4.66%, whereas A1B1C1 produced the lowest value of 2.02%.

This result can be attributed to the combined application of the humic acid–enriched compound fertilizer and the organic amendment, which markedly enhanced nitrogen availability, uptake efficiency, and its translocation to the leaves. Consequently, this led to increased leaf nitrogen concentrations during the vegetative growth stage. The results consist with by [9] and [5].

Table 8. Effect of humic acid-enriched compound fertilizer, organic fertilization, and biofertilization on leaf nitrogen concentration at the booting stage (%).

Factor A	Factor B	Factor C		Interaction between A*B	Means of the factor A	Means of the factor B
		C1	C2			
A1	B1	e 2.02	de 2.32	d 2.17		
	B2	bcd 3.24	bc 3.50	bc 3.37		
	B3	cde 2.81	bcd 3.16	c 2.98		
A2	B1	bcd 3.22	bc 3.33	bc 3.27		
	B2	bc 3.37	bcd 3.12	bc 3.25		
	B3	bcd 3.19	cd 3.08	c 3.14		
A3	B1	bcd 3.13	cd 3.05	c 3.09		
	B2	bcd 3.18	cde 2.89	c 3.04		
	B3	ab 4.08	ab 4.11	a 4.10		
A4	B1	bcd 3.28	bc 3.60	bc 3.44		
	B2	bc 3.68	bc 3.35	abc 3.51		
	B3	bcd 3.13	a 4.66	ab 3.90		
A	A1	c 2.69	bc 2.99		2.84 C	
	A2	b 3.26	bc 3.18		3.22 B	

Factor A	**Factor B**	**Factor C**		**Interaction between A*B**	**Means of the factor A**	**Means of the factor B**
		C1	C2			
	A3	ab 3.46	b 3.35		3.41 AB	
	A4	b 3.36	a 3.87		3.61 A	
B	B1	c 2.91	bc 3.07			B 2.99
	B2	ab 3.37	bc 3.21			A 3.29
	B3	bc 3.30	a 3.75			A 3.53
Means of the factor C		A 3.19	A 3.35			

Means within each factor or interaction sharing the same letter are not significantly different (P ≤ 0.05) according to Duncan's multiple range test.

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3-6. Effect of Humic Acid-Enriched Compound Fertilizer, Organic Amendment, and Biofertilization on Leaf Phosphorus Concentration in Barley at the Booting Stage (%) .

Leaf phosphorus concentration at the booting stage was significantly affected by the humic acid-enriched compound fertilizer, organic amendment, and biofertilizer, as detailed in Table 9. The A4 level produced the highest mean phosphorus concentration of 0.58%, compared with 0.30% recorded for the A1 control. The A2 and A3 treatments yielded intermediate values of 0.37% and 0.45%, respectively. Among organic treatments, B3 achieved the highest mean at 0.49%, relative to 0.37% and 0.41% for B1 and B2. The biofertilizer did not generate a clearly significant difference between its two levels; C2 recorded 0.44%, while C1 registered 0.40%. The interaction A4B3C2 delivered the maximum leaf phosphorus concentration of 0.70%, whereas A1B1C1 gave the lowest value at 0.15%.

These results stem from the capacity of the humic acid-supplemented compound fertilizer, working in concert with the organic amendment, to increase phosphorus availability and release, accelerate the mineralization of organic phosphorus contained in the organic matter, and improve its uptake and translocation to the leaves during vegetative development. Soil microorganisms also played an important role in mobilizing adsorbed and organically bound phosphorus through the formation of complexes with microbial exudates, further contributing to plant-available pools. This interpretation is consistent with the findings of [2, 5].

Table 9. Effect of humic acid-enriched compound fertilizer, organic fertilization, and biofertilization on leaf phosphorus concentration at the booting stage (%).

Factor A	Factor B	Factor C		Interaction between A*B	Means of the factor A	Means of the factor B
		C1	C2			
A1	B1	f 0.15	de 0.35	f 0.25		
	B2	ef 0.26	de 0.33	ef 0.29		
	B3	de 0.36	de 0.35	cde 0.36		
A2	B1	de 0.37	bc 0.49	c 0.43		
	B2	de 0.31	ef 0.27	ef 0.29		
	B3	cd 0.41	de 0.34	cde 0.38		
A3	B1	de 0.33	bc 0.51	cd 0.42		
	B2	de 0.36	de 0.31	def 0.33		

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Factor A	Factor B	Factor C		Interaction between A*B	Means of the factor A	Means of the factor B
		C1	C2			
	B3	ab 0.61	ab 0.58	ab 0.60		
A4	B1	b 0.56	bc 0.51	b 0.54		
	B2	bc 0.54	b 0.57	b 0.55		
	B3	ab 0.60	a 0.70	a 0.65		
A	A1	e 0.26	d 0.34		0.30 D	
	A2	cd 0.36	cd 0.37		0.37 C	
	A3	bc 0.43	b 0.47		0.45 B	
	A4	a 0.57	a 0.59		0.58 A	
B	B1	b 0.35	a 0.46			B 0.37
	B2	b 0.37	b 0.37			B 0.41
	B3	a 0.50	a 0.49			A 0.49
Means of the factor C		B 0.40	A 0.44			

Means within each factor or interaction sharing the same letter are not significantly different ($P \leq 0.05$) according to Duncan's multiple range test.

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3-7. Effect of Humic Acid-Enriched Compound Fertilizer, Organic Amendment, and Biofertilization on Leaf Potassium Concentration in Barley at the Booting Stage (%)

Leaf potassium concentration at the booting stage was significantly influenced by the humic acid-enriched compound fertilizer, organic amendment, and biofertilizer, as presented in Table 10. The A4 and A3 levels recorded the highest means of 4.56% and 4.44%, respectively, compared with 3.72% for the A1 control, while A2 registered 4.21%. For the organic factor, B3 achieved the highest mean at 4.53%, relative to 3.89% under B1. The biofertilizer also produced a notable difference, with C2 yielding 4.40% compared with 4.06% for C1. The interaction A4B3C2 delivered the maximum leaf potassium concentration of 5.62%, whereas A1B2C1 gave the lowest value at 3.04%.

This enhancement can be attributed to the humic acid-fortified compound fertilizer and the organic amendment working together to improve potassium availability, uptake, and translocation to the leaves. The bacterial inoculant further contributed by raising nutrient utilization efficiency. These observations align with [9], who reported that potassium concentrations in barley leaves respond to the fertilization regime and that fertilizer use efficiency and nutrient availability can be substantially improved. They are also consistent with [2], who documented better nutrition and growth in barley following the application of humic and fulvic acids.

Table 10. Effect of humic acid-enriched compound fertilizer, organic fertilization, and biofertilization on leaf potassium concentration at the booting stage (%).

Factor A	Factor B	Factor C		Interaction between A*B	Means of the factor A	Means of the factor B
		C1	C2			
A1	B1	g 3.24	g 3.34	f 3.29		
	B2	g 3.04	bcd 4.65	e 3.84		
	B3	ef 4.19	f 3.84	de 4.02		
A2	B1	g 3.42	ef 4.15	e 3.78		
	B2	cde 4.39	cde 4.44	c 4.42		
	B3	cde 4.46	cde 4.39	c 4.42		
A3	B1	de 4.30	ef 4.16	cd 4.23		
	B2	de 4.28	cde 4.43	c 4.36		
	B3	b–e 4.55	b 4.92	ab 4.73		

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Factor A	**Factor B**	**Factor C**		**Interaction between A*B**	**Means of the factor A**	**Means of the factor B**
		C1	C2			
A4	B1	cde 4.35	ef 4.16	cd 4.25		
	B2	de 4.24	bc 4.73	bc 4.49		
	B3	de 4.27	a 5.62	a 4.94		
A	A1	e 3.49	d 3.94		3.72 C	
	A2	cd 4.09	b 4.32		4.21 B	
	A3	b 4.37	b 4.50		4.44 A	
	A4	bc 4.28	a 4.84		4.56 A	
B	B1	c 3.82	c 3.95			C 3.89
	B2	c 3.99	a 4.56			B 4.28
	B3	b 4.37	a 4.69			A 4.53
Means of the factor C		B 4.06	A 4.40			

Means within each factor or interaction sharing the same letter are not significantly different (P ≤ 0.05) according to Duncan's multiple range test.

The collective findings point toward a synergistic rather than an isolated role for each experimental factor in improving growth traits, yield, and leaf nutrient content. The data tables consistently show that the higher-level combinations—particularly A4 with B3, and in most cases with C2—delivered the greatest plant height, leaf area, spike number, and per-plant grain yield, accompanied by elevated concentrations of nitrogen, phosphorus, and potassium in the leaves at booting. In contrast, the lowest values almost invariably appeared under the no-addition treatments.

This pattern can be explained by the fact that the compound fertilizer supplied essential nutrients in a readily available and balanced form. Humic acids, meanwhile, enhanced the availability and uptake of these nutrients while stimulating root development. The organic amendment improved overall soil properties and increased its water and nutrient retention capacity, and the bacterial inoculant boosted biological activity in the rhizosphere and raised nutrient-use efficiency. As a result, the nutritional status of the plants improved, reflected in higher leaf N, P, and K concentrations. This, in turn, promoted more vigorous vegetative growth—evidenced by taller plants and larger leaf area—which subsequently translated into a greater number of spikes and higher grain yield per plant.

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These observations are in line with [2], who reported improved barley growth, yield, and nutrient uptake following the application of humic and fulvic acids. They also concur with [5], who found that organic fertilization enhanced growth and nutrient acquisition in barley, and with [9], who documented the influence of fertilization regime on barley growth and leaf nutrient concentrations. The overall trend further matches studies demonstrating that integrating humic acids with mineral or organic fertilizers boosts growth and nutrient uptake in barley and other crops. Additionally, the results agree with [15, 16], who observed that applying a compound fertilizer together with humic acids improved NPK availability in the soil and raised N, P, and K concentrations in cabbage leaves when chemical fertilizers and humic acids were combined.

Conclusions

It can be concluded from this study that the humic acid-enriched compound fertilizer, in combination with organic and biological amendments, improved barley growth traits and leaf nutrient content. The best responses were generally obtained at the higher levels of the compound fertilizer together with the organic amendment, particularly at the B3 level, and in most cases with the addition of the biofertilizer. The findings also demonstrated that the interaction among these factors proved more effective than applying any of them alone, as reflected in greater plant height, larger leaf area, higher spike number, increased grain yield per plant, and elevated concentrations of nitrogen, phosphorus, and potassium in the leaves at the booting stage. This underscores the value of adopting an integrated fertilization approach to enhance barley growth and its nutritional status.

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