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Response of growth hydroponic forages to different nutrient types and seeding rates under optimum conditions

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I. Abstract.

A laboratory experiment was performed in the Aquaculture Unit at the College of Agriculture, University of Basra, to assess the impact of various nutrient solutions and seed rates on the productivity of hydroponically cultivated barley fodder, aiming to generate cost-effective and sustainable aquatic fodder year-round. The experiment encompassed two variables: the first variable comprised three categories of nutrient solutions alongside a control treatment, which included (N0) a control treatment devoid of fertilization, (N1) humic acid (12%), (N2) humic acid (20%) supplemented with nitrogen (15%), phosphorus (8%), and potassium (14%), and (N3) fulvic acid (70%). The second component consisted of three seed rates: 2 kg m-2 (S1), 2.5 kg m-2 (S2), and 3 kg m-2 (S3), each with three repetitions. The experiment used a fully randomized block design (CRBD). The averages were analyzed using the LSD test at a significance level of $P \leq 0.01$ to evaluate the differences among the treatments regarding plant height, total fresh weight, total dry weight, protein percentage, and total ash content. The findings indicated that fulvic acid fertilizer (N3) excelled in all examined characteristics. While the seed rate of 3 kg m-2 (S3) excelled in all measured parameters (plant height, total fresh weight, and total dry weight), it did not significantly influence the protein % or total ash content. The interaction between fertilizer type and seeding rate was insignificant for all features, except for total ash content, in which the N2S2 treatment surpassed the other treatments.

Key words: Barley, *Hordeum vulgare* L, fodder, hydroponic, nutrient solution, seed rate

II. INTRODUCTION

The world population is projected to reach 9.7 billion by 2050, necessitating a 70-100% increase in global food production to satisfy their dietary requirements (Safi et al. 2023; Safi et al. 2024). Mechanical tillage and agricultural machinery traffic adversely affect soil and its production (Nassir et al. 2024; Ashour et al. 2024).

Barley is ranked sixth in terms of productivity (Alsudays et al. 2024). Iraq has inadequate water management, desertification, soil deterioration, overuse of fertilizers and pesticides, poor productivity per unit area, and excessive water use (Al-Rukabi et al. 2021), all of which exacerbate soil degradation (Rukabi et al., 2021; Liu et al., 2019). The agriculture industry in Iraq utilizes around 70-80% of freshwater (Elmulthum et al. 2023).

Hydroponics is a contemporary technique embraced by several livestock producers globally because to its high yield, efficient spatial utilization, and absence of pesticides and chemicals. Hydroponics are economically and ecologically efficient in fertilizer and water use (Taghreed et al. 2023; Yang et al., 2020). Hydroponics technology diminishes labor requirements and optimizes spatial use (Rahman et al. 2024), relying on technologies that facilitate the regulation of lighting, temperature, and sensors to enhance production (Kaleel and Ali 2024; Farghaly et al. 2019; Ali et al. 2021). Hydroponic meals possess increased energy, digestibility, and protein levels (El-Morsy et al. 2013). Hydroponic fodder is organic, abundant in minerals, proteins, essential nutrients, and amino acids, and devoid of pesticides and pesticide residues (Kishore et al. 2023).

The use of hydroponic fodder production methods is crucial for the agricultural industry due to the significant disparity between fodder demand and worldwide fodder supply. Green fodder is a vital element in livestock productivity. Green fodder must be provided to support animal output. Due to its scarcity year-round, much agricultural land has degraded, resulting in water issues. Hydroponic farming methods for fodder production in Iraq provide continuous animal feeding and address the deficiency in local green fodder production (Kaleel and Ali 2024).

Barley is a crucial green fodder for animal feed because to its beneficial effects on livestock health and its capacity to provide high-quality, sustained output at minimal costs, along with its effective application in these domains (Kaleel and Ali 2024). Hydroponic fodder significantly enhances animal immunity and reproduction, while also aiding the digesting process (Grigas et al. 2019). Barley yields 6-10 kg of sustainable green fodder for every 1 kilogram of hydroponic barley grain (Soder et al. 2018). This significantly exceeds the production of barley fodder in traditional agriculture (Elmulthum et al. 2023).

Delivering a nutrient solution in suitable ratios is crucial for plant growth and development, and is a fundamental aspect of hydroponic methods (Ashpreet et al. 2023). Formulating techniques for generating local organic nutrient solutions is essential for incorporating hydroponics into a sustainability framework and will facilitate the advancement of hydroponics. Consequently, the use of liquid organic fertilizers instead than chemical fertilizers is essential. A primary difficulty is to provide locally produced nutrient solutions that include all needed elements in adequate amounts and are devoid of harmful plant compounds, since these solutions are crucial for delivering nutrients to plants (Mahmoud 2015).

Organic fertilizers may be derived from agricultural byproducts, including animal manure, plant leftovers, abattoir waste, home trash, agricultural industry waste, and algae (Szekely and Jijakli 2022). By administering nutritional solutions that directly penetrate the plant, we may achieve a high plant density within a constrained area (Rahman et al. 2024). An ideal mix of the three nutrients, nitrogen, phosphorus, and potassium, exists (Hou et al. 2024).

Hydroponics may effectively address the challenges encountered by the Iraqi agriculture industry (Al-Rukabi et al. 2021). The increase in global animal feed costs necessitates the introduction of alternative cost-effective feed. This research aimed to assess the impact of various nutrient solutions and seed numbers on the productivity and development of barley fodder germinated under hydroponic circumstances.

III. MATERIALS AND METHODS

Research region

A laboratory experiment was performed at the aquaculture laboratory of the College of Agriculture at the University of Basrah (47°45'00" E, 30°33'48" N) to investigate the impact of nutrient solutions (Table 1) and seed rates on the productivity of hydroponically cultivated barley fodder. The experiment had two variables: the first variable consisted of three nutrient solution types: (N0) a control treatment without fertilizer, (N1) a treatment with 12% humic acid, (N2) a treatment with 20% humic acid, 15% nitrogen, 8% phosphorus, and 14% potassium, and (N3) a treatment with 70% fulvic acid. The second element consisted of three seed rates: 2 (S1), 2.5 (S2), and 3 (S3) kg m⁻². The experiment was performed three times.

Seed germination

Germination assays were performed with local barley seeds (Buhoth 244). The germination rate was 93 percent. The barley grains were purified to eliminate contaminants, thoroughly rinsed with distilled water, then immersed for 24 hours in distilled water. The sanitized grains were subjected to sterilization by immersion for 30 minutes in a 20% sodium hypochlorite solution to prevent fungal infection. The grains were then rinsed with distilled water to eliminate sodium hypochlorite residues, placed in a perforated cork container, and covered with a damp towel for 24 hours to provide an optimal environment for germination. The grains were distributed on circular plastic germination plates (diameter: 15.5 cm, area: 188.77 cm²) at seed rates of 37.8, 47.2, and 56.6 g per plate, respectively. The meals were categorized into four groups of nine, with each group allocated a certain kind of nutritional solution**.**

Nutrient formulations

The nutritional solutions (Table 1) were formulated in four 15-liter containers. The first contained simply water, the second included humic acid at a concentration of 1 cm3 L-1, and the third contained humic acid supplemented with NPK (1 cm3 L-1) and phosphoric acid (1 cm3 L-1). The solutions were properly mixed to guarantee uniformity. For the first two days, plants received irrigation just with water; thereafter, they were watered with various nutrient solutions in accordance with the research methodology..

Table (1) Nutrient solution specifications

Nutrient solution type	pH	Ec
Water only	7	1.1
Humic acid	6.3	1.7
Humic acid with NPK	9.2	2.6
Fulvic acid	3.7	2.9

System manufacturing

The hydroponic system (Fig. 1) used four irrigation lines for barley. Each line consisted of a small pump that delivered nutrients from a 120 cm high and 15-liter capacity independent reservoir. The solution was supplied in a flexible tube (diameter: 0.7 cm). The flexible tube was branched through nine vertical T-connectors in the dish to ensure that the nutrient solution was evenly and regularly distributed across all parts of the dish. The nozzles were placed 25 cm apart from each other. This provided a uniform distribution of solutions in agricultural containers containing barley. Each agricultural container had a length of 30 cm, width of 20 cm, and depth of 5 cm, which provided adequate space for root growth and nutrient absorption. The system also contained two air pumps, each with two outlets for pumping oxygen through a flexible tube with a 0.3 cm diameter into the nutrient reservoir, preventing solution stagnation and improving nutrient absorption. In each reservoir, underwater heating rods with adjustable temperature control were used to maintain a constant solution temperature of 24 ± 1 °C, which improved the nutrient absorption. The system operated through a single electric regulator and activated four pumps four times a day, each of which took a minute to activate, thereby ensuring a consistent distribution of the solution. This system allowed the study of the effects of different treatments, such as water alone, humic acid, humic acid, NPK, and fulvic acid, on barley growth, providing an ideal environment for comparing plant responses and developing effective water-based farming methods.

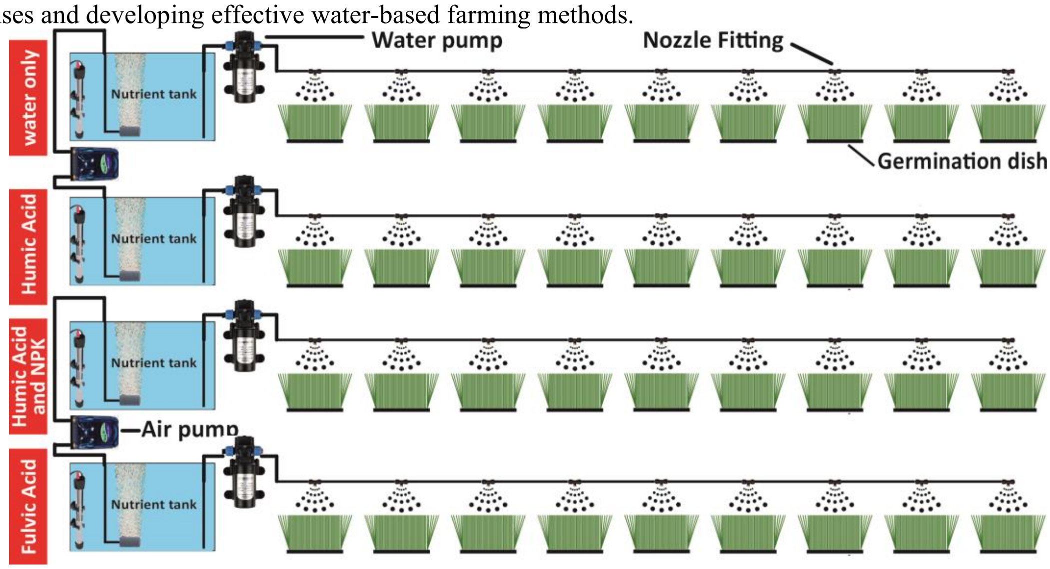

Figure 1. System Manufacturing.

Electrical connection

The main power supply was connected to an inverter and a 150-amp battery to maintain continuous DC power. An electrical timer was set to turn on the pumps every 6 h (four times per day) at a rate of 1 min. Before starting the experiment, the system was calibrated in the laboratory to pump the nutrient solution at a flow rate of 15 ml min^{-1} four times per day for each dish (Fig. 2).

The room was lit with electric and natural lights throughout the germination period. An electronic thermostat was used to operate the fan air vent when the temperature reached 27 °C. When the temperature dropped to 20 °C, an infrared heating and sterilization lamp was used to maintain the temperature at 20-27 °C. An electronic thermostat was connected, as shown in Figure 3. The thermostat was programmed as shown in Table 2.

The experiment was completed 14 d after spreading the grains as they were ready for harvest. The green fodder was air-dried for 72 h and then oven-dried at 70 °C for 72 h. The characteristics of each plate were measured (plant height, green fodder weight, dry fodder weight, protein content of the green and root parts, and total straw estimation).

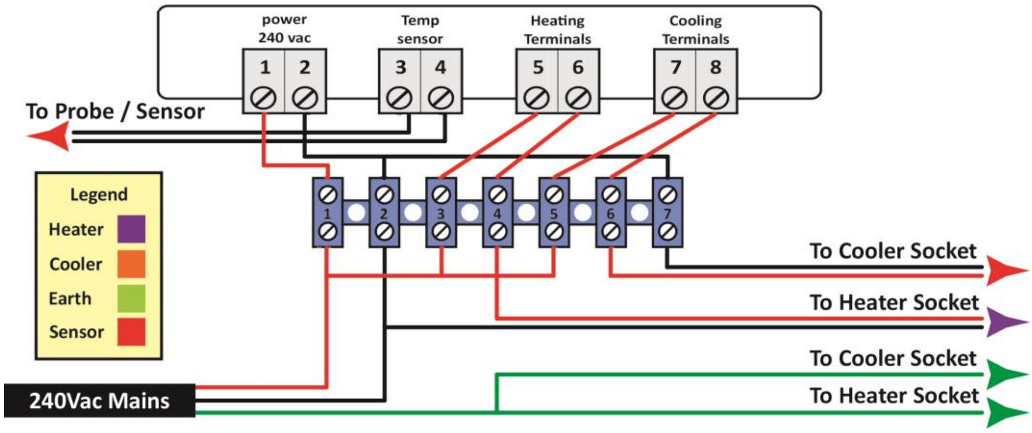

Figure 2. Digital Temperature PID Controller Thermostat 220 V STC-1000.

Table (2) Programming and adjusting digital temperature controller

Controller buttons	Definition of variables	Controller operation range	Controller range selected
F1	Temperature set value	- 50.0 ~ 99.9 °C	20.0 - 27.0 °C
F2	Difference set value	0.3 ~ 10.0 °C	0.5 °C
F3	Compressor delay time	1 ~ 10 min	3 min
F4	Temperature calibration value	- 10.0 ~ 10.0 °C	0 °C

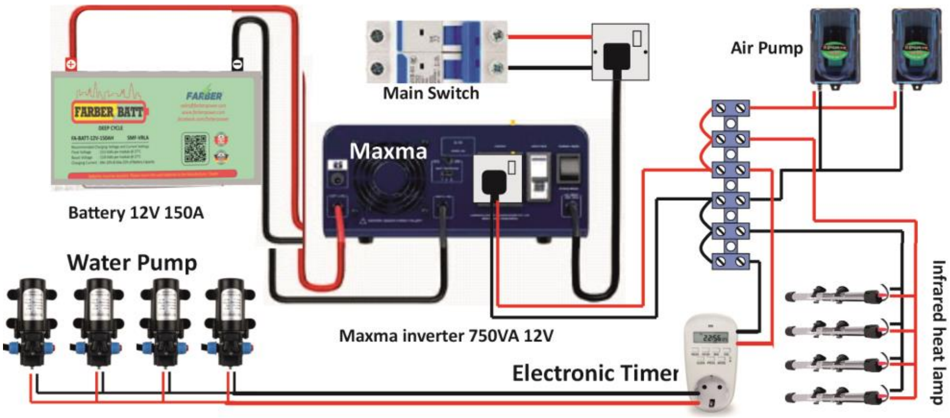

Figure 3. Power supply diagram.

Measurement of qualities

Plant height was measured using a graduated ruler. Wet and dry weights were measured using a precision balance. Protein content was calculated by estimating nitrogen content using a MicroKjeldahl device (An Automatic Kjeldahl nitrogen analyzer was used to analyze the content of protein and nitrogen compounds in nature, which is widely used for rapid protein analysis in the fields of food, milk, meat, drink, medicine, soil, and feed). Crude protein (CP) content was calculated according to the following equation: N × 6.25. Total ash was estimated by burning the samples in a muffle furnace at 520 °C and weighing the samples before and after incineration to measure the ash concentration on a dry weight basis.

Measurement of plant characteristics

The height of the plant was measured using a graduated right angle placed next to the plant dish such that it was straight and perpendicular to the surface of the table containing the germinated barley. Distance was measured from the bottom of the root to the top of the plant. The process was replicated five times for each plate at different locations, and the average was used to express the plant height of the dish (experimental unit). At the end of the experiment (14 d after spreading the grains), random samples of germinated barley plants were harvested from each plate (experimental unit). The samples were weighed using a sensitive balance to measure the wet weight. To determine dry weights, the plants were air-dried for 72 h after harvest, placed in A4 paper bags, and dried in an oven at 70 °C for 72 h. The dry weight was measured using a precision balance. For protein percentage, 0.2 g of dry grain plant sample powder was taken. After passing through a 1 mm sieve, the sample was digested by adding a mixture of concentrated sulfuric acid and perchloric acid with heating until a clear solution was obtained, according to the method described by Cresser and Parsons (1979). The digestion product was transferred to 50 cm³ volumetric bottles, and the nitrogen content was estimated using a MicroKjeldahl device in the laboratories of the Aquaculture Unit of the College of Agriculture at the University of Basra. The percentage of N was calculated according to the equation described by Agrawal et al. (1980).

$$N\% = \frac{V_m * HCL\ stander * V_d}{V_s * W_D * 100} * 100 \qquad (1)$$

Where: $N\%$: Nitrogen percentage; V_m: The volume of acid consumed in the burette; V_d: Volume of dilutions; V_s: Volume of sample taken during distillation; W_D: Weight of digested sample

The crude protein content was calculated using the following equation:

$$\text{CP} = N * 6.25 \qquad (2).$$

The total ash content was estimated by burning the samples in a muffle furnace at 520 °C for some time and weighing them before and after incineration to measure the ash concentration on a dry-weight basis.

Statistical analyses

The experiment was a randomized complete block design (RCBD). The data were analyzed using the SPSS statistical program, and the means were compared using the LSD test with a probability level of $P \leq 0.01$ to compare the means between the treatments. The experimental units were distributed as listed in Table 3.

Table (3) Distribution of the experimental units

	R1			***R2***			***R3***		
	S1	*S2*	*S3*	*S1*	*S2*	*S3*	*S1*	*S2*	*S3*
N0	*N0S1R1*	*N0S2R1*	*N0S3R1*	*N0S1R2*	*N0S2R2*	*N0S3R2*	*N0S1R3*	*N0S2R3*	*N0S3R3*
N1	*N1S1R1*	*N1S2R1*	*N1S3R1*	*N1S1R2*	*N1S2R2*	*N1S3R2*	*N1S1R3*	*N1S2R3*	*N1S3R3*
N2	*N2S1R1*	*N2S2R1*	*N2S3R1*	*N2S1R2*	*N2S2R2*	*N2S3R2*	*N2S1R3*	*N2S2R3*	*N2S3R3*
N3	*N3S1R1*	*N3S2R1*	*N3S3R1*	*N3S1R2*	*N3S2R2*	*N3S3R2*	*N3S1R3*	*N3S2R3*	*N3S3R3*

S1, S2, and S3 are the seed rates of 2, 2.5, and 3 kg m^{-2}, respectively. N0, N1, N2, and N3 are the nutrient solutions without nutrients, humic acid, humic acid with NPK, and Fulvic acid, respectively. R1, R2, and R3 represent replicates of experiments.

Table (4) Specifications of supplies

Supplies image	No.	Supplier Name	Description
	4	Solution tank	Dimension: 30 cm, H: 310 cm, Vol.: 15 L
	4	Air dispersion stone	Dimension: 25 ×15 mm^2
	4	Heating rod	230 V, 50 HZ, AC/16 A/3600 W, Length: 12.5 cm Temperature: 20~34 °C (68~93 °F)
	36	YS Brass Mist Nozzle	Sprinkler: 0.3 mm
	2	Air pump	5 W, OUTPUT: 3.5 L/min, 220 V, 2 output, SIZE: 137 × 83 × 50 mm^3
	1	Digital Plastic Electronic Timer	POWER TYPE: AC 220-240 V 50/60 HZ 13 A 1000 W
	4	Water pump	Pressure max: 0.75 Mpa Flow Max: 4 L/Min, 110 V AC

	1	Infrared heat lamp	Dimension: W x H: 19 cm x 12.5 cm 220 V-200 W
	1	Digital Temperature Controller	16 A-50 to +99 °C STC 1000 - 2 K/Watts
	1	Air vacuum fan	D: (120 × 120 × 48) mm^3, AC 220/240 V, 30 W 50 Hz, RPM: 3000 RPM, air volume: 3 m^3/min, fan noise : 47 dB

IV. RESULTS AND DISCUSSION

Hydroponic Barley Height (cm)

Table (5) shows the significant effects of the fertilizer type on plant height. Treatment N3 (fulvic acid) significantly surpassed the other treatments. The heights of N3 compared with N0, N1, and N2 increased by 28%, 26.80%, and 20.37%, respectively. This may be attributed to fulvic acid, which contributes to cell elongation and increased division, improving the average plant height by adequately expanding the cell wall required for division and growth (Alsudays et al. 2024). This is consistent with Roozbahani (2015), who reported that the addition of humic acid and fulvic acid had a positive effect on improving the growth and productivity of barley plants, which led to an increased growth rate of the stems resulting from the use of humic acid and fulvic acid, leading to an increased allocation of nutrients to vegetative organs.

Seed rates

Table (5) shows the significant effects of seed rate on plant height. Treatment S3 (3 kg m^{-2}) significantly outperformed the other treatments, as plant height increased by 7.7% and 3.1% for treatment S3 compared to treatments S1 and S2, respectively. The reason may be attributed to the fact that increasing the seed rate leads to an increase in plant density, which increases competition between plants for light to obtain taller plants (Adinew 2019). This is consistent with the findings of Adinew (2019), who found a significant effect of seed rate on plant height, as increasing seed density caused an increase in the number of plants and increased competition for light, thereby increasing plant height.

Table (5) Effects of fertilizer type, seeding rate, and their interaction on barley height (cm)

Seed rates S	**Fertilizer type N**				**Mean (seed rates)**
	N0	N1	N2	N3	
S1	19.33	19.33	19.67	24.00	20.58
S2	19.33	19.67	21.33	25.67	21.50
S3	20.33	20.67	21.67	26.00	22.17
Mean (fertilizer type)	19.66	19.89	20.89	25.22	
$LSD_{0.01}$	N		S		N × S
	0.821		0.711		ns

Wet weight (kg m^{-2})

As shown in Table (6), the fertilizer type had a significant effect on fresh weight, as treatment N3 (fulvic acid) significantly outperformed the other treatments, and the fresh weight of treatment N3 increased compared to treatments N0, N1, and N2 by 21%, 15%, and 0.2%, respectively. This may be attributed to fulvic acid, which contributes to better absorption of nutrients from the leaves, enhances chlorophyll production, and increases branching growth, as well as to the contribution of the acid to increasing the absorption of nutrients (Afzalinia & Karimi 2020). This is consistent with the findings of Alrubaiee and Al-Sulaiman (2023), who reported that spraying with humic acid increases the production of green fodder.

Seed rates

Table (6) shows the significant effects of seed rate on plant fresh weight. Treatment S3 (3 kg m^{-2}) significantly outperformed the other treatments, as the fresh weight of the plants for treatment S3 increased compared to treatments S1 and S2 by 19% and 2.9%, respectively. This may be attributed to the fact that increasing plant density and plant height resulted in a higher green weight (Adinew 2019). This agrees with the findings of Paudel et al. (2021) and Hayawi et al. (2021), who reported that green weight increased with increasing seed rates.

Table (6) Effects of fertilizer type, seeding rate, and their interaction on barley wet weight (kg m^{-2})

Seed rates S	Fertilizer type N N0	N1	N2	N3	Mean (seed rates)
S1	249.2	250.3	317.8	322.0	284.83
S2	290.6	326.1	330.8	378.3	331.45
S3	315.5	320.8	389.0	339.6	341.23
Mean (fertilizer type)	285.10	299.07	345.87	346.63	
$LSD_{0.01}$	N		S		N × S
	45.54		39.44		Ns

Dry weight (kg m^{-2})

As shown in Table (7), the fertilizer type had a significant effect on dry weight, as treatment N3 (fulvic acid) significantly outperformed the other treatments, and the dry weight of treatment N3 increased compared with treatments N0, N1, and N2 by 13%, 8.3%, and 5.2%, respectively. This may be attributed to the fact that fulvic acid contributes to increasing plant height, in addition to increasing the size of the root system and wet weight, which contributes to increasing the total dry weight of the plant (Alsudays et al. 2024). This is consistent with Roozbahani (2015), who reported that humic and fulvic acids have a significant effect on the dry weight of stems, leaves, and spikes.

Seed rates

Table (7) shows the significant effect of seeding rate on plant dry weight, as treatment S3 (3 kg m^{-2}) significantly outperformed the other treatments, and the dry weight of the plants for treatment S3 increased compared to treatments S1 and S2 by 5.3% and 2.5%, respectively. This may be attributed to an increase in the number of plants per unit area, fresh weight, and plant height, which in turn led to an increase in dry weight (Hayawi, et al. 2021). This is in agreement with Afzalinia et al. (2020) and Afzalinia and Karimi (2020), who reported an increase in dry weight with increasing seeding rate.

Table (7) Effects of fertilizer type, seeding rate, and their interaction on barley dry weight (kg m^{-2})

Seed rates S	Fertilizer type N N0	N1	N2	N3	Mean (seed rates)
S1	27.1	27.4	27.9	30.7	28.3
S2	32.2	34.3	35.2	37.4	34.7
S3	41.0	43.0	44.5	45.4	43.5
Mean (fertilizer type)	33.4	34.9	35.9	37.8	
$LSD_{0.01}$	N		S		N × S
	1.491		1.292		ns

Crude protein (CP) (%)

Table (8) shows the significant effect of fertilizer type on the protein percentage. Treatment N3 (fulvic acid) significantly outperformed the other treatments as the protein percentage of treatment N3 increased compared to treatments N0, N1, and N2 by 14%, 10%, and 9.5%, respectively. It facilitates the transport of nutrients to plants and improves the use and absorption of essential nutrients such as nitrogen, phosphorus, and potassium by plants. Fulvic acid also increases root growth, which in turn increases mineral absorption and facilitates nitrate absorption and the metabolism of nitrogenous compounds that increase carbohydrate reserves, thus increasing crude protein levels (Alsudays et al. 2024). This is consistent with the results of Naik et al. (2012), who found an increase in the protein percentage with chemical treatment.

Table (8) Effects of fertilizer type, seeding rate, and their interactions on barley crude protein (%)

Seed rates S	Fertilizer type N N0	N1	N2	N3	Mean (seed rates)
S1	14.2	14.0	13.8	16.2	14.6
S2	13.7	15.3	14.7	15.7	14.9
S3	14.3	14.3	15.5	16.3	15.1
Mean (fertilizer type)	14.1	14.6	14.7	16.1	
$LSD_{0.01}$	N		S		N × S
	0.765		Ns		ns

Total ash content (%)

Table (5) shows the significant effect of fertilizer type on total ash content: Treatment N3 (fulvic acid) significantly outperformed the other treatments, as the total ash content of treatment N3 increased compared to treatments N0, N1, and N2 by 42%, 36%, and 12%, respectively. This may be attributed to fulvic acid, which promotes growth and increases the concentration of minerals in plants (Sneath and McIntosh 2003). This is consistent with the findings of Naik et al. (2012), who observed an increase in the total ash content of hydroponic fodder corn when chemically fertilized.

Contribution of fertilizer and seeding rates

Table (9) shows the significant effect of the interaction between fertilizer type and seeding rate on the total ash content, as N2 (humic acid with NPK) with the seed rate S2 (2.5 kg m^{-2}) significantly outperformed N0 (the comparison treatment without fertilization) with the seed rate S1 (2.5 kg m^{-2}), as the total ash content increased by 56%.

Conclude from the study that fulvic acid is an important organic fertilizer, as fulvic acid significantly improved most of the studied barley crop characteristics, such as plant height, dry weight, fresh weight, crude protein percentage, and total ash content, compared with other treatments. This improvement is due to the ability of fulvic acid to increase the availability of nutrients, photosynthetic efficiency, and root growth. Moreover, increasing the seeding rate to 3 kg m^{-2} increased the vegetative growth and biological production of the barley crop. This is because increasing plant density and competition for light led to increased elongation of the barley stems, and thus increased water and dry matter content. Many characteristics, including total ash content, were significantly affected by the interaction treatment between seeding rate and fertilizer type, which highlights the need to combine different agricultural treatments to achieve maximum plant quality and productivity under conditions similar to this study. According to this study, growth can be increased. Barley and its productivity in a similar agricultural environment using fulvic acid with a relatively high seed rate.

Table (9) Effects of fertilizer type, seeding rate, and their interaction on the total ash content in barley

Seed rates S	Fertilizer type N N0	N1	N2	N3	Mean (seed rates)
S1	4.8	5.2	5.2	9.2	6.1
S2	5.0	5.2	7.5	5.6	5.8
S3	5.2	5.2	6.0	6.5	5.7
Mean (fertilizer type)	5.0	5.2	6.3	7.1	
$LSD_{0.01}$	N		S		N × S
	1.197		ns		2.074

V. ACKNOWLEDGEMENTS

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