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MAIZE RESPONSE TO MINERAL FERTILIZERS AND SEAWEED EXTRACT FOR GROWTH AND YIELD-RELATED TRAITS

M.M. FATIMA* and M.N.H. AL-YASARI

Department of Field Crops, College of Agriculture, University of Kerbala, Kerbala, Iraq
*Corresponding author's email: sabraoassociateeditors@gmail.com, calmcharming@gmail.com
Email address of co-author: mahmood.n@uokerbala.edu.iq

SUMMARY

The presented maize experiment commenced in autumn 2022 at the Al-Hussainiya, Kerbala, Iraq. The experiment comprised two factors: the first included nitrogen (0, 150, and 300 kg N ha^{-1}) and phosphorus (0, 50, and 100 kg P ha^{-1}), and the second was the seaweed extract (2 and 4 ml L^{-1}) used as a foliar application. The seaweed extracts (Algazone Mx30) were treatments applied in the main plots, while the subplots received mineral fertilizer combinations. A randomized complete block design (RCBD) consisted of a factorial arrangement and three replications to evaluate the maize cultivar 'Maha's' response in clay loam soil. In most growth and yield parameters, applying nitrogen-phosphorous fertilizer combinations and the foliar application of seaweed extract (4 ml L^{-1}) had a substantial effect. The interaction between the seaweed extract and nitrogen and phosphate fertilizers significantly improved leaf area, stem diameter, chlorophyll index in leaves, 500-grain weight, and biological and grain yields. The treatments with seaweed extract (4 ml L^{-1}) and the combination of 150 N + 50 P performed better for leaf area (55.48 cm^2 plant^{-1}), stem diameter (23.10 mm), chlorophyll index (48.54 SPAD), 500-grain weight (141.17 g), biological yield (357.56 g plant^{-1}), and grain yield (201.46 g plant^{-1}).

Keywords: Maize (*Zea mays* L.), seaweed extract, nitrogen and phosphorus fertilizers, growth and yield traits, chlorophyll index

Key findings: A significant improvement in growth and yield traits of maize resulted from the foliar application of seaweed extract (4 ml L^{-1}) in combination with nitrogen and phosphorus fertilizers.

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INTRODUCTION

Maize (*Zea mays* L.) belongs to the grass family Poaceae and is one of the cereal grain crops of great value. Maize, a widely grown crop worldwide, is also one of the multi-purpose crops cultivated for obtaining grains, oil, and fodder. In addition, a strategic crop of increasing importance in the food industries, it provides the basics of human food security and fodder for livestock. Despite the valuable relevance of this crop, its productivity per unit area in Iraq is still lower than the global production.

Maize requires highly fertile soil to reach the best vegetative growth and highest grain yield due to its absorption of large amounts of nutrients at different stages of development, especially nitrogen, phosphorus, and potassium, requiring fertilization at appropriate times and quantities (Desa, 2017; Ahmed *et al.,* 2020). Mineral fertilizers are crucial in increasing crops' growth and yields, especially when needing a balance in applying fertilizers. The insufficient addition of fertilizers leads to delayed maturity, affecting the yield, and high and unbalanced quantities can also negatively influence the plant and its yield while contaminating the cultivated soil, causing deterioration.

The health damage in humans, especially in irrigated agriculture, regardless of any considerations since the irrational use of fertilizer is uneconomical and negatively affects the environment (Yahaya *et al*., 2023). Crops, including maize, need various balanced nutrients for their growth and development. Nitrogen is an essential nutrient required in relatively immense quantities during growth stages. Adding nitrogen is necessary, especially if the nitrogen concentration falls below a particular limit in plant tissues. In crop plants, the vital processes necessitate protein; thus, the optimal nitrogen concentration increases the leaf area and photosynthesis, which leads to considerable enhancement in vegetative growth, dry matter, and grain yield (Iqbal *et al.,* 2015).

Phosphate fertilizers differ from nitrogen fertilizers, as these slowly move in the soil and, therefore, do not wash off the soil layer easily. However, in the system of dense cultivation and continuous irrigation of soils in dry and desert areas, phosphorus deficiency symptoms appear faster due to the low phosphorus content available to crop plants. Therefore, it is necessary to add phosphorus to soils to raise its content. Phosphorus' value lies in its prominent role in completing vital and physiological processes in plants. Phosphorus works to increase the number of branches and strengthen the root structure, accelerate ripening, and improve fruit quality traits (Menzies and Lucia, 2009; Ali *et al.,* 2014). The results by Affendi *et al.* (2023) indicated the positive role of NPK combinations on the growth and yield of maize when they studied several combinations of NPK (100, 200, and 300 kg ha^{-1}). They observed that the combination of 300 kg ha^{-1} was excellent for plant height, weight of 100 grains, and total grain yield (113.62 cm, 22.39 g, and 5.07 t ha^{-1}, respectively).

The trend worldwide diverts to using natural alternatives to mineral fertilizers as complementary materials and not as their substitute. The use of seaweed extract is becoming popular due to being non-polluting to the environment, non-toxic, and low cost. Seaweed extracts have also become materials that encourage plant growth and considerably contribute to various physiological functions in plants. They also contain several macro- and micro-nutrients, auxins, gibberellins, and cytokinins, stimulating cell division and elongation in plant tissues. Thus, increasing the leaf area and improving the photosynthesis process reflects positively on the crops' vegetative and root growth indicators (Abbas, 2017; Begum *et al*., 2018).

Seaweed extract is also a rich source of free amino acids, making it a vital source of easy plant food. Adding it compensates for insufficient nutrients and accelerates the plant's vegetative growth. Likewise, it is rich in vitamins, which contribute to activating photosynthesis and participate in the transfer of electrons, control the redox processes, and activate natural auxin formation within plants (Kumawat and Kumawat, 2023). A study by Jader *et al.* (2019) determined the effect of several concentrations of spraying with marine algae extracts (0, 3, 6, and 9 ml L^{-1}) on the growth characteristics and yield of four maize genotypes. The results showed the excellence of the concentration of 6 ml L^{-1} in leaf area, the number of grains in ear, and grain productivity per plant (5241.9 and 5250.8 cm^2, 443.42 and 448.58 grain ear^{-1}, 160.92 and 165.67 g $plant^{-1}$ in 2017 and 2018, respectively).

Therefore, adding appropriate amounts of balanced fertilization (N, P, and K) and its integration with foliar application of organic nutrients may be a successful strategy to obtain high productivity and quality products, rationalizing the use of mineral fertilizers, and reducing environmental pollution (Al-Yasari and Al-Hilli, 2018, 2019). The presented study determined the best fertilizer combination of nitrogen and phosphorus in integration with seaweed extract added to the soil and plants, respectively, and their effects on growth and yield-related traits in maize due to increased demand for high-quality foods.

MATERIALS AND METHODS

Experimental site and procedure

The latest maize experiment commenced in the fall crop season 2022 at the District Al-Hussainiya, Kerbala, Iraq. The experiment comprised two factors: the first included combinations of different nitrogen (0, 150, and 300 kg N ha^{-1}) and phosphorus (0, 50, and 100 kg P ha^{-1}) fertilizer levels. The second factor was the foliar application of seaweed extract (Algazone Mx30) with two concentrations (2 and 4 ml L^{-1}). The seaweed extract application occupied the main plots, while the mineral fertilizer combination treatments were in the subplots. The experiment utilized a local maize cultivar 'Maha' in clay loam soil using a randomized complete block design (RCBD) with a factorial arrangement and three replications. Analysis of the chemical and physical properties of the study soil at a depth of 0–30 cm before maize planting transpired (Table 1).

For the experiment, the soil preparation comprised plowing, smoothing, and leveling operations, and later, dividing the soil into three replications, with each replication having 18 experimental units. Thus, the total number of experimental units was 54 with a 3-m^2 × 3- m^2 dimension each, and maintaining a one-meter space between the experimental units within one replicate. Three to five maize seeds contained per hill had a planting depth of 5 cm, with the row and plant spacing kept at 75 cm and 25 cm, respectively, and a plant density of 53,333.33 plants ha^{-1}. Irrigation proceeded immediately after planting, and the crop continued to receive watering during the growing season according to the need. Manual weeding occurs whenever necessary during the season to remove weeds. Fertilization used the mono-superphosphate fertilizer (19% P_2O_5) as a source of phosphorus, and the addition ensued in one batch during the maize planting. The fertilizer combinations of nitrogen and potassium (urea fertilizer - 46% N and potassium sulfate - 50% K_2O) were sources of nitrogen and potassium.

Table 1. Chemical and physical properties of the study soil at a depth of 0–30 cm before Maize planting.

Properties		Values
pH		7.2
EC (1:1)		2.18 ds m^{-1}
OM		1.21 g kg^{-1}
N available		28.34 mg kg^{-1}
P available		10.8 mg kg^{-1}
K available		65.27 mg kg^{-1}
Soil separators	Sand	250 G kg^{-1}
	Silt	360 G kg^{-1}
	Clay	390 G kg^{-1}
Texture		Clay loam

Fertilization with potassium sulfate (50% K_2O) as a source of potassium also occurred, with the addition applied in one batch during planting. The first factor included fertilizer combinations of nitrogen and phosphorus. Three nitrogen levels (0, 150, and 300 kg N ha^{-1}) received symbols as N_0, N_1, and N_2, respectively. Three levels of phosphorus (0, 50. and 100 kg P ha^{-1}) incurred labels as P_0, P_1, and P_2, respectively, with the added Urea fertilizer (46% N) as nitrogen sources in the two batches. The first batch of urea application transpired just a week to 10 days after germination, and the second dose was at the beginning of the formation of silk threads. The mono-super phosphate fertilizer (19% P_2O_5) treatment emerged all at once during planting as a source of phosphorus.

The second factor was seaweed extract (Algazone Mx30) treatment as a foliar application to plants with two concentrations (2 and 4 ml L^{-1}). The foliar application also proceeded in two stages, with the first spray made at the 6-8 true leaf stage and the second at the appearance of male inflorescence. The foliar application of seaweed extract used the manual sprayer with a dorsal capacity of 16 l. Spraying transpired in the early morning with complete wetness of plants and to avoid high temperature. Spraying the control treatment (with water only) used a diffuser (bright cleaning solution) to reduce the surface tension of the water and ensure complete wetness of leaves to increase the spray solution's efficacy.

Data recorded

The data recorded for various traits came from an average of 10 randomly taken maize plants in each experimental unit. Measurements comprised leaf area (dm^2 $plant^{-1}$), stem diameter (mm), chlorophyll index in leaves (SPAD), 500-grain weight (g), biological yield (g $plant^{-1}$), and grain yield (g $plant^{-1}$) following the methodology of Al-Mohammadi (1990).

Statistical analysis

All the recorded data for various parameters underwent evaluation according to the analysis of variance (ANOVA) per randomized complete block design with factorial experiments arrangement (Gomez and Gomez, 1984). The least significant difference ($LSD_{0.05}$) test helped compare and separate the mean differences. The study used the statistics software GenStat12 for the analysis.

RESULTS

According to the analysis of variance, fertilizer combinations, seaweed extract concentrations, and their interactions revealed significant ($p \leq 0.05$) differences for most growth and yield-related traits in maize (Table 2).

Leaf area

The results showed the superiority of the fertilizer combination 300 and 100 kg NP ha^{-1} - N_2P_2 by providing the highest leaf area in maize plants (52.10 dm^2 $plant^{-1}$) compared with the control treatment (N_0P_0) (44.54 dm^2 $plant^{-1}$), with a 17.00% increase rate (Table 3). Following the promising treatment were nonsignificant differences from fertilizer combinations (N_1P_1, N_2P_1, and N_1P_2), which

Table 2. Analysis of variance with two factors: seaweed extract (Algazone Mx30) and combination of nitrogen and phosphorus fertilizers and their interaction for various traits in maize.

Source of variation	d.f.	Leaf area (dm^2 $plant^{-1}$)	Stem diameter (mm)	Chlorophyll index in leaves	500-grain weight (g)	Biological yield (g $plant^{-1}$))	Grain yield (g $plant^{-1}$)	Harvest Index (%)
Replications	2	21.2554	20.15915	83.0006	832.909	11444.68	772.602	57.712
Seaweed extract	1	270.7264*	7.16498*	38.8452*	642.735*	4445.16*	8289.344*	324.509*
Error A	2	0.2060	0.03107	0.0986	0.588	207.86	3.088	5.369
Fertilizer Combination	8	60.3736*	11.96603*	56.4347*	655.284*	5426.41*	4674.978*	116.104*
SE × FC	8	8.0554*	0.08839*	0.4638*	24.236*	164.62*	316.181*	9.008 *
Error B	32	0.1181	0.03885	0.1468	1.241	44.21	3.737	1.419

Table 3. Effect of foliar application of seaweed extract (Algazone Mx30) and nitrogen and phosphorus fertilizers combination on the leaf area.

Fertilizer combinations	Seaweed extract concentration (ml L^{-1})		Means (dm^2 $plant^{-1}$)
	F_1	F_2	
N_0P_0	44.11	44.96	44.54
N_0P_1	44.63	47.50	46.06
N_0P_2	44.92	47.85	46.38
N_1P_0	45.01	47.93	46.47
N_1P_1	48.44	55.48	51.96
N_1P_2	48.48	55.21	51.85
N_2P_0	45.06	48.61	46.84
N_2P_1	48.48	55.33	51.90
N_2P_2	48.83	55.38	52.10
Means (dm^2 $plant^{-1}$)	46.44	50.92	
$LSD_{0.05}$ Fertilizers: 0.40, Seaweed extract: 0.53, F × SE: 0.59			

amounted to 51.96, 51.90, and 51.85 dm2 $plant^{-1}$, respectively. In turn, these significantly outperformed the rest of the fertilizer combinations with an increased rate of 16.66%, 16.54%, and 16.41%, respectively, compared with the control treatment showing the lowest average for this trait. The seaweed extract (4 ml L^{-1}) foliar application was significantly superior by giving a higher average for leaf area (50.92 dm^2 $plant^{-1}$) than its lower concentration (2 ml L^{-1}), recording with the minimum average for the said trait (46.44 dm^2 $plant^{-1}$), exhibiting a 9.64% increased rate.

According to the interaction effects, the two factors also indicated significant differences in leaf area (Table 3). The treatments, F_2 N_1P_1, F_2 N_2P_2, F_2 N_2P_1, and F_2 $N_1P_{2,}$ appeared with nonsignificant differences; however, they achieved the highest leaf area with an average of 55.48, 55.38, 55.33, and 55.21 dm^2 $plant^{-1}$, respectively. These promising interactions were significantly superior over other combinations with an increased rate of 25.77%, 25.54%, 25.44%, and 25.17%, respectively, compared with the control treatment, with the minimum leaf area in maize plants (44.11 dm^2 $plant^{-1}$).

Stem diameter

The outcomes revealed that the fertilizer combination N_2P_1 was superior by giving the highest stem diameter (22.90 mm), with an increased rate of 19.76% compared with the control treatment in maize plants (19.12 mm) (Table 4). Trailing the promising combination were fertilizer combinations, N_1P_1, N_1P_2, N_2P_0, and N_2P_2 with nonsignificant differences (22.84, 22.86, 22.01, and 22.88 mm), respectively. They, in turn, significantly outperformed other combinations, with an increased rate of 20.76%, 20.45%, and 20.45%, respectively, compared with the control treatment showing the lowest average for the said trait. For the stem diameter, the seaweed extract foliar application 4 ml L^{-1} was notably better by giving a higher average for the said trait (22.03 mm), with an increased rate of 3.42%, than its lower concentration (2 ml L^{-1}) (21.30 mm).

The interaction between the two factors revealed significant differences in stem diameter in maize (Table 4). The interaction treatments, F_2 N_2P_2, F_2 N_1P_1, F_2 N_2P_1, and F_2 N_1P_2), with no significant differences, achieved a higher stem diameter (23.15, 23.10, 23.22, and 23.12 mm, respectively). These interactions emerged remarkably superior over other treatment combinations, with an increased rate of 22.22%, 21.96%, 22.59%, and 22.06%, respectively, compared with the check treatment (F_1 N_0P_0), recording the tiniest stem diameter (18.94 mm).

Chlorophyll index

For the chlorophyll index in leaves, the significant differences resulted from fertilizer combinations N_1P_1, N_2P_2, $N_2P_1$and N_1P_2, achieving the highest values for leaf chlorophyll index, with an average of 47.78,

Table 4. Effect of foliar application of seaweed extract (Algazone Mx30) and nitrogen and phosphorus fertilizers combination on the stem diameter.

Fertilizer combinations	Seaweed extract concentration (ml L^{-1})		Means (mm)
	F_1	F_2	
N_0P_0	18.94	19.30	19.12
N_0P_1	20.01	20.30	20.15
N_0P_2	20.94	21.53	21.24
N_1P_0	21.01	21.67	21.34
N_1P_1	22.58	23.10	22.84
N_1P_2	22.61	23.12	22.86
N_2P_0	21.21	22.81	22.01
N_2P_1	22.58	23.22	22.90
N_2P_2	22.61	23.15	22.88
Means (mm)	21.39	22.02	
$LSD_{0.05}$ Fertilizers: 0.14, Seaweed extract: 0.12, F × SE: 0.19			

Table 5. Effect of foliar application of seaweed extract (Algazone Mx30) and nitrogen and phosphorus fertilizers combination on the chlorophyll index in the leaves.

Fertilizer combinations	Seaweed extract concentration (ml L^{-1})		Means (SPAD)
	F_1	F_2	
N_0P_0	39.80	41.79	40.80
N_0P_1	39.61	42.22	40.92
N_0P_2	40.36	42.08	41.22
N_1P_0	44.44	45.75	45.09
N_1P_1	47.02	48.54	47.78
N_1P_2	46.37	48.22	47.29
N_2P_0	45.61	46.20	45.90
N_2P_1	46.43	48.44	47.44
N_2P_2	46.79	48.47	47.63
Means (SPAD)	44.05	45.74	
$LSD_{0.05}$ Fertilizers: 0.45, Seaweed extract: 0.36, F × SE: 0.62			

47.63, 47.44, and 47.29 SPAD, sequentially, in maize (Table 5). These promising fertilizer combinations significantly outperformed other combinations, with an increased rate of 17.10%, 16.74%, 16.27%, and 15.90%, respectively, compared with the control treatment with the minimum average (40.80 SPAD). A significant difference in the average index of chlorophyll in the leaves by spraying with seaweed extract also occurred. Its higher concentration (4 ml L^{-1}) significantly exceeded by giving the optimum average for the said trait (45.74 SPAD), with an increase of 3.83% compared with the seaweed's lower concentration (2 ml L^{-1}) at 44.05 SPAD.

The interaction effects between the fertilizer combinations and spraying of seaweed extract were also meaningful for the chlorophyll index in maize leaves (Table 5). Results indicated superiority of the interaction treatment F_2 N_1P_1 by giving the highest average (48.54 SPAD) with an increase of 21.95% compared with the control treatment recording with the lowest average (39.80 SPAD), followed by the coefficients (F_2 N_2P_2, F_2 N_2P_1 and F_2 N_1P_2), not differing significantly, with an average of 48.47, 48.44, and 48.22 SPAD, respectively. They, in turn, outperformed the rest of the treatment interactions.

500-grain weight

For 500-grain weight, the fertilizer combinations enunciated significant differences (Table 6). The fertilizer combinations N_2P_1, N_2P_2, N_1P_2, and N_1P_1 revealed nonsignificant differences; however, these achieved higher 500-grain weights in maize (135.73, 135.64, 135.18, and 135.06 g, respectively). These

Table 6. Effect of foliar application of seaweed extract (Algazone Mx30) and nitrogen and phosphorus fertilizers combination on the 500-grain weight.

Fertilizer combinations	Seaweed extract concentration (ml L^{-1})		Means (g)
	F_1	F_2	
N_0P_0	109.23	112.23	110.73
N_0P_1	112.12	115.48	113.80
N_0P_2	115.48	118.78	117.13
N_1P_0	116.93	119.38	118.16
N_1P_1	128.94	141.17	135.06
N_1P_2	129.68	140.68	135.18
N_2P_0	120.15	126.65	123.40
N_2P_1	130.11	141.36	135.73
N_2P_2	131.14	140.15	135.64
Means (g)	121.53	128.43	
$LSD_{0.05}$ Fertilizers: 1.31, Seaweed extract: 0.89, F × SE: 1.79			

Table 7. Effect of foliar application of seaweed extract (Algazone Mx30) and nitrogen and phosphorus fertilizers combination on the biological yield.

Fertilizer combinations	Seaweed extract concentration (ml L^{-1})		Means (g $plant^{-1}$)
	F_1	F_2	
N_0P_0	263.63	270.38	267.00
N_0P_1	280.31	290.81	285.56
N_0P_2	287.25	294.94	291.09
N_1P_0	292.13	297.00	294.56
N_1P_1	326.81	357.56	342.19
N_1P_2	327.75	355.88	341.81
N_2P_0	301.13	323.44	312.28
N_2P_1	330.19	356.44	343.31
N_2P_2	330.75	356.81	343.78
Means (g $plant^{-1}$)	304.44	322.58	
$LSD_{0.05}$ Fertilizers: 1.31, Seaweed extract: 0.89, F × SE: 1.79			

combinations significantly outperformed most fertilizer combinations, with an increased rate of 22.57%, 22.49%, 22.08%, and 21.97%, respectively, compared with the control treatment, with the lowest 500-grain weight (110.73 g). For 500-seed weight, the spraying with seaweed extract (4 ml L^{-1}) was significantly higher (128.43 g) than its lower concentration (2 ml L^{-1}), which amounted to 121.53 g with an increase of 5.67%.

The interaction effects between the two factors indicated substantial differences for 500-grain weight in maize (Table 6). The treatment combinations F_2 N_1P_1, F_2 N_2P_1, F_2 N_1P_2, and F_2 N_2P_2 were nonsignificantly different; however, they achieved the highest grain weight (141.17, 141.36, 140.68, and 140.15 g, sequentially). These interactions were significantly superior over other treatment combinations, with an increased rate of 49.24%, 29.41%, 28.79%, and 28.30%, respectively, versus the control treatment, showing the lowest 500-grain weight (109.23 g).

Biological yield

The fertilizer combination 300 and 100 kg NP ha^{-1} provided the highest biological yield in maize (343.78 g $plant^{-1}$), with an increase of 28.72% compared with the control treatment (267.00 g $plant^{-1}$) (Table 7). Following the said fertilizer combination were fertilizer mixtures N_2P_1, N_1P_1, and N_1P_2, with an average of 343.31, 342.19, and 341.81 g $plant^{-1}$, respectively. They significantly outperformed the rest of the combinations, with an increased rate of 28.58%, 28.16%, and 20.01%, respectively, compared with the control combination, giving the lowest average for the said trait. The foliar application of seaweed extract (4 ml L^{-1}) also significantly enhanced the biological yield (322.58 g $plant^{-1}$), with an increased rate of 5.97% compared with its lower concentration (2 ml L^{-1}) (304.44 g $plant^{-1}$).

For biological yield, the interaction effects between fertilizer combinations and seaweed extract demonstrated significant differences (Table 7). The results indicated the superiority of the interaction treatment F_2 N_1P_1 by giving the maximum average of biological yield (357.56 g $plant^{-1}$) with an increase of 35.63% compared with the control treatment, providing the lowest average (263.63 g $plant^{-1}$). Trailing the promising interaction were coefficients F_2 N_2P_2, F_2 N_2P_1, and F_2 N_1P_2, with an average of 356.81, 356.44, and 355.88 g $plant^{-1}$, respectively, which, in turn, excelled the rest of the interactions in maize crop.

Grain yield

The results showed the superiority of the fertilizer combination 300 and 100 kg NP ha^{-1} by boasting the highest grain yield (180.91 g $plant^{-1}$), with an increase of 49.92%, compared with the control treatment in maize crops (120.62 g $plant^{-1}$) (Table 8). Tailing the promising fertilizer combination were nonsignificant differences from three other fertilizer combinations (N_1P_2, N_1P_1, and N_2P_1) with an average grain yield of 180.33, 180.20, and 180.23 g $plant^{-1}$, respectively. These combinations appeared significantly superior to other combinations, with an increased rate of 49.61%, 49.45%, and 49.45%, respectively, compared with the control combination displaying the lowest grain yield in maize. The foliar application of seaweed extract (4 ml L^{-1}) proved significantly superior by showing the highest grain yield (163.85 g $plant^{-1}$), with an increased rate of 17.81% compared with its lower concentration (2 ml L^{-1}) (139.07 g $plant^{-1}$).

For grain yield per plant, the interaction effects between fertilizer combinations and seaweed extract indicated the dominance of the treatment F_2 N_1P_1 by showing the higher average grain yield (201.46 g $plant^{-1}$) with an increased rate of 74.06% in maize crops (Table 8). Compared with the control, it gave the lowest average grain yield (115.69 g $plant^{-1}$), preceded by treatment interactions F_2 N_1P_2, F_2 N_2P_2, and F_2 N_2P_1), which were not different significantly with an average grain yield of 200.25, 200.04, and 199.40 g $plant^{-1}$, respectively. These interactions notably excelled the rest of the combinations.

DISCUSSION

The promising results showed that adding nitrogen and phosphorus fertilizer combinations to the soil and seaweed extract foliar application remarkably affected improving plant growth indicators. The reason may be due to the role of nitrogen and phosphorus in increasing their content in plant tissues, which manifested in increasing growth

Table 8. Effect of foliar application of seaweed extract (Algazone Mx30) and nitrogen and phosphorus fertilizers combination on the grain yield.

Fertilizer combinations	Seaweed extract concentration (ml L^{-1})		Means (g $plant^{-1}$)
	F_1	F_2	
N_0P_0	115.69	125.54	120.62
N_0P_1	117.56	129.94	123.75
N_0P_2	122.56	133.68	128.12
N_1P_0	124.60	135.59	130.10
N_1P_1	158.94	201.46	180.20
N_1P_2	160.41	200.25	180.33
N_2P_0	129.00	148.71	138.85
N_2P_1	161.06	199.40	180.23
N_2P_2	161.78	200.04	180.91
Means (g $plant^{-1}$)	139.07	163.85	
$LSD_{0.05}$ Fertilizers: 2.27, Seaweed extract: 2.05, F × SE: 3.17			

parameters (Kudaibergenova *et al*., 2023; Al-Yasari and Al-Jbwry, 2024). Nitrogen is crucial in cell division and expansion, increasing the length of the internodes and the number of nodes in the stem that carry the leaves and forming the amino acid (tryptophan), the primary substance for building auxins. It, then, enhances plant cell division and elongation and causes an increase in the leaf area. Nitrogen and phosphorus also contribute to forming plant hormones that activate the cells involved in leaf development. Phosphorus also participates in energy compound buildup, increasing the number and size of cells and their division and elongation, positively increasing plant growth indicators (Lestari *et al.,* 2016; Anwar *et al.,* 2017).

In crop plants, the increased leaf area positively influences plant performance because the leaves are the chief food source for plants, and nitrogen and phosphorus are essential in enlarging the plant's leaf area. The broader the leaf area, the higher the rate of light interception and chlorophyll formation, enhancing the efficiency of photosynthesis in the leaves and providing the opportunity for accumulating nutrients and materials produced in the process, such as carbohydrates and proteins, which in plant tissues are necessary dry matter components; thus, their concentration increases. In addition, nitrogen and phosphorus are vital in cell membrane formation and contribute to transporting sugars from their formation sites in the leaves and other parts of the plants, enhancing plant growth indicators, as reflected in an increased stem diameter (Ali *et al.,* 2014; Iqbal *et al.*, 2014).

The foliar application of seaweed extract may augment plant biological activities and nutrient absorption. It may also have a hormonal effect contributing to an increase in cell division and elongation, activating the leaf tissue cell division and expansion, leading to an increased leaf area in crop plants; hence, the dry matter accumulation, improved growth, and increased fertilization as a result of reducing the rate of ovarian abortion (White and Brown, 2010; Amare *et al.,* 2022). Increased leaf area in maize led to enhanced efficiency of photosynthesis and the transfer of its products to the grains. Seaweed extract application, as a result of its nutrient content and plant valuable compounds, also regulates hormones that control the performance of auxins in developing apical dominance of the cob and cytokinins to prevent the transfer of auxins from old grains to newer ones; it increases the rate of seed setting in cobs positively raising grain yield (Al-Hilfy and Al-Temimi, 2017; Abbas, 2017).

The grain filling depends on the efficiency of the source, which, in turn, depends on the leaf area of the plants, how long it remains green, and the rate of photosynthesis. The grain-filling rate also relies on the strength of the downstream, represented by its ability to withdraw the maximum possible amount of metabolic materials and give an immense number with larger grains (Bindraban *et al.,* 2020). Fertilizer combinations and seaweed extract application improved the process of photosynthesis and synthesis. Bio-chlorophyll and metabolism increasing the leaf area and total chlorophyll content eventually manifested in an upsurge in yield components. Additionally, the seaweed extract is vital in raising the efficiency of photosynthesis and the division process occurring in the cells responsible for grain formation, which leads to an increased grain weight (Abbas, 2017; Nigussie, 2021).

The increased biological yield may refer to the simultaneous addition of nitrogen, phosphorus, and organic nutrients, contributing to the formation of nucleic acids and energy compounds (ATP) capable of providing plants with energy. Similarly, their entry into the synthesis of enzymatic accompaniments, such as NADP and NAD, also depends upon their activity in metabolic processes. In addition to their vital role in cell division and the development of roots, they also encourage forming a dense and deep root system, which helps to absorb more water and nutrients (Halvin *et al.,* 2005; Al-Yasari and Al-Hilli, 2018, 2019).

Quality increases associated with yield components positively appeared in grain yield enhancement with the buildup in traits, which can be due to the positive role of nitrogen and phosphorus fertilizer combinations and foliar application of organic nutrient seaweed extracts. These raise the efficiency of photosynthesis and boost the formation of chlorophyll, proteins, enzymes, and most growth regulators that had a primary role in amplifying grain yield. The maize plants' response to mineral fertilization and seaweed extract on the plant's growth traits could point to achieving a better nutritional balance of these nutrients within the plant, thus promoting plant growth and the plant's ability to develop better and produce more grain yield (Ragheb, 2016; Bashir *et al.,* 2021).

CONCLUSIONS

The latest results revealed that foliar application of seaweed extract and the nitrogen and phosphorus fertilizer combinations significantly enhanced vegetative growth, enriching photosynthesis, eventually improving yield components, and enhancing maize grain yield. The interaction between the fertilizer combinations and foliar application of seaweed extract (4 ml L^{-1}) proved most responsive in augmenting the maize growth and grain yield.

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