AMERICAN JOURNAL OF BOTANY AND BIOENGINEERING
https://biojournals.us/index.php/AJBB
ISSN: 2997-9331

Article

Interactive Effects of Phosphorus Fertilization and Atonic Application on Growth, Productivity, and Phosphorus-Use Efficiency Roselle (Hibiscus sabdariffa L.)

Heba M. M. Al-Hamdany
Dept. Medicinal and Industrial Plants, College of Medicinal and Industrial Plants, University of Kirkuk, Iraq

Citation: Al-Hamdanym, H. M. M. Interactive Effects of Phosphorus Fertilization and Atonic Application on Growth, Productivity, and Phosphorus-Use Efficiency Roselle (Hibiscus sabdariffa L.). American Journal Of Botany And Bioengineering 2026, 3(1), 90-103.

Received: 05th Dec 2025
Revised: 30th Dec 2025
Accepted: 15th Jan 2026
Published: 31th Jan 2026

Abstract: A pot experiment was conducted during the 2023-2024 growing season at the College of Medicinal and Industrial Plants, Kirkuk University, in the Ronaki area of the Kirkuk Governorate, to study the interaction between phosphorus levels and the growth regulator Atonic on the growth, productivity, and phosphorus use efficiency of the Roselle plant. The experiment was carried out according to a randomized complete block design with three replications. The treatments consisted of four phosphorus fertilizer rates (0, 25, 50, and 75 kg P_2O_5 ha^{-1}) and three Atonic levels (0, 100, and 150 mg L^{-1}). The traits studied included plant height, number of branches $plant^{-1}$, chlorophyll content, leaf area, dry weight, nitrogen, phosphorus, and potassium concentrations, total yield, and phosphorus use efficiency. The results showed that phosphate fertilization had a significant effect on most of the studied traits. The 50 kg P_2O_5 ha^{-1} level achieved the highest values in plant height (78. 10 cm), number of branches/plant (9.2), chlorophyll content (8. 81 mg g^{-1}), leaf area Plant (1. 80 m^2), plant dry weight (218. 00 g $plant^{-1}$), nitrogen concentration (2.70%), phosphorus concentration (0. 32%), potassium concentration (2. 65%), yield (3330. 95 kg ha^{-1}), and phosphorus – use efficiency (198. 64%). The highest phosphorus rate (75 kg P_2O_5 ha^{-1}) adversely affected all the studied traits. As for the Atonic effect, the 150 mg L^{-1} level had a significant effect on all the studied traits. It produced plant height (77. 07 cm), number of branches/plant (8.9), chlorophyll content (8. 98 mg g^{-1} fresh weight), leaf area index (2.07 m^2), dry weight (227. 26 g $plant^{-1}$), nitrogen concentration (3. 09%), phosphorus concentration (0. 30%), potassium concentration (2.59%), yield (2973. 80 kg ha^{-1}), and fertilization efficiency (166. 62%), the interaction effect showed that the A_2B_2 combination gave the highest growth and yield indicators for the Roselle plant. Accordingly, the study recommends using phosphate fertilization at a rate of 50 kg P_2O_5 ha^{-1} and spraying with Atonic at a concentration of 150 mg L^{-1} to achieve optimal growth and productivity of the roselle plant under calcareous soil conditions.

Keywords: Roselle (Hibiscus Sabdariffa L.), Phosphorus Fertilization, Atonic Growth Regulator, Phosphorus Use Efficiency, Yield and Growth Performance

Introduction

Medicinal and aromatic plants are important agricultural resources position in the agricultural and industrial sectors as a primary source of active compounds used in the pharmaceutical and food industries. The World Health Organization has confirmed that approximately 80% of the world's population uses medicinal plants to treat various diseases, psychological disorders, and bacterial infections. Treatment with medicinal plants, including *Hibiscus sabdariffa L.*, Medicinal plants are valuable sources of bioactive compounds and may provhde affordable complementary resources for pharmaceutical , food and traditional medicine applications [1]. *Hibiscus sabdariffa L.* is a widespread medicinal plant belonging to the Malvaceae family. Two distinct varieties of this plant can be differentiated morphologically and chemically: *Hibiscus sabdariffa* var. altissima Wester and Hibiscus sabdariffa var. sabdariffa [2]. Roselle (Hibiscus sabdariffa L.) is a medicinal-aromatic crop with increasing economic and nutritional importance, due to the active compounds in its fleshy calyces, such as anthocyanins, organic acids, and vitamin C, in addition to its wide-ranging uses in medicinal plants in the pharmaceutical and food industries [3]. There has been growing interest in improving this plant's productivity and the quality of its active components through integrated fertilization management and the use of growth regulators, with the aim of maximizing productivity while maintaining soil fertility and the sustainability of the agricultural system. Phosphorus is an essential element for plants, as it is a component of energy compounds (ATP), phospholipids, and nucleic acids. It also plays a vital role in cell division, root formation, and improving fruit quality and quantity. Furthermore, it directly influences the timing of flowering. Despite its crucial importance to plants, its utilization is limited due to fixation, precipitation, and adsorption processes, particularly in calcareous soils prevalent in arid and semi-arid regions. Calcareous soils added phosphate fertilizers may react with calcium carbonate and calcium ions, leading to the formation of sparingly soluble calcium phosphate compounds and reducing phosphorus availability to plant. When all these fertilizers are added to calcareous soils, they undergo a reaction that results in the volatilization of CO2 and the formation of poorly soluble phosphate compounds that are not readily available to the plant. This necessitates studying the optimal application levels to achieve the highest physiological and productive response [4]. Many studies have shown that growth regulators, including atonic, a growth stimulant easily absorbed by the plant's vegetative parts, increase sap translocation, photosynthesis, and root growth and branching. They also provide additional strength and vitality to plant cells, increase seed germination rates when seeds are soaked in them, reduce flower drop, and enhance nutrient and mineral absorption by plants, thereby increasing yield. Patal et al. (2020) found that adding growth regulators to potted roselle plants significantly increased several growth indicators, such as plant height, leaf area, number of leaves per plant, number of stems per plant, chlorophyll content, and other traits, when measured after 30, 60, and 90 days of the study. The interaction between phosphorus fertilizer rates and the fertilizer rates of atonic provides a scientific approach to understanding how mineral nutrition and growth regulators interact in roselle plants. It is expected that the stimulatory and positive effects of phosphorus and atonic will lead to increased absorption of phosphorus and other nutrients, increased dry matter accumulation, improved vegetative and root growth characteristics, increased sepal production, and improved content of active compounds [5], [6]

Although numerous studies have examined the effects of phosphate fertilization or growth promoters individually on various crops, research investigating the interaction between phosphorus levels and the growth regulator tonic in sedges under calcareous soil conditions remains limited. Therefore, this study aims to evaluate the effects of different phosphorus levels, tonic concentrations, and their interaction on vegetative growth characteristics, total yield, and macronutrient concentrations, and to assess the yield increase resulting from phosphate fertilizer application compared to a control treatment.

Materials and Methods

A pot experiment was conducted at the College of Medicinal and Industrial Plants, University of Kirkuk (Ronaki area/Kirkuk Governorate), during the 2023-2024 growing season to study the effect of the interaction between phosphate fertilizer levels and the growth regulator Atonic on the growth and productivity of *Hibiscus sabdariffa L.* soil. A soil sample was taken from the study area before planting. It was air-dried and sieved through a 2 mm sieve. The preliminary analyses mentioned in Table 1 were performed on it, where electrical conductivity (EC), soil pH, cation exchange capacity (CEC), available phosphorus, available potassium, and organic matter were estimated as described in [7], and available nitrogen according to the method of Bremner and Edwards [8].

Table 1. Some physical and chemical properties of the soil under study.

Characteristic	Unit	Value
Sand		459
silt	$g.kg^{-1}$	308
Clay		233
Soil Texture		Loam
PH	-	7.34
EC	dS/m	2.25
CEC	cmol.kg-1	19.31
Organic matter	$g.kg^{-1}$ soil	9.32
CO_3	$g.kg^{-1}$ soil	364.66
Available Potassium		187.98
Available Nitrogen	$mg.kg^{-1}$	29.34
Available Phosphorus		7.23

The experiment was designed as a randomized complete block design (RCBD) with three replicates per treatment and included two factors:

- Factor 1: Four levels of phosphate fertilizer (0, 25, 50, and 75 kg P_2O_5 ha^{-1}).
- Factor 2: Three concentrations of the growth regulator Atonic (0, 100, and 150 mg L^{-1}).

Therefore, there were 12 treatments, totaling 36 experimental units. The soil was placed in 15-cm-high, 9-cm-diameter plastic pots, and the seeds of the roselle plant were sown on April 18, 2024. With 5 plants in each pot, and after germination, the thinning process was carried out, and only two plants were left in each pot to ensure uniformity of plant density for all treatments. Urea fertilizer (46% N) was added at a rate of 1 gram per pot in two doses, the first at planting and the second at the flowering stage, and potassium fertilizer in the form of potassium sulfate in two doses, the first at planting and the second when adding the second dose of nitrogen [9]. Phosphate fertilizer in the form of triple superphosphate was added at four levels (0, 25, 50, 75 kg P_2O_5 ha^{-1}). Phosphate fertilizer in the form of triple superphosphate (TSP) was added at a rate of 46% P_2O_5 at four levels (0, 25, 50, 75 kg P_2O_5 ha^{-1}).

These levels were converted to the equivalent amount per pot, based on the pot's soil weight (4 kg) and the standard soil weight per hectare (2,000,000 kg/ha). The fertilizer amounts applied per pot were 0.109, 0.217, and 0.326 g TSP pot^{-1} for P_2O_5 rates of 25, 50, and 75 kg ha^{-1}, respectively. The fertilizer was thoroughly mixed with the soil before planting to ensure even distribution. Nitrogen fertilizer in the form of urea (46% N) was applied at a rate of 1 g pot^{-1} in two applications: the first at planting and the second at the flowering stage. Potassium fertilizer in the form of potassium sulfate (K_2SO_4) was also applied in two applications: the first at planting and the second concurrently with nitrogen [9]. Phosphate fertilizer in the form of triple superphosphate was added at four levels (0, 25, 50, and 75 kg P_2O_5 ha^{-1}). The phosphate fertilizer in the form of triple superphosphate (TSP) was added at a rate of 46% P_2O_5 at four levels (0, 25, 50, and 75 kg P_2O ha^{-1}). These levels were converted to the equivalent amount per pot, based on the pot's soil weight (4 kg) and the standard soil weight per hectare (2,000,000 kg/hectare). Thus, the amounts of fertilizer added per pot were: 0.109, 0.217, and 0.326 g TSP pot^{-1} for the 25, 50, and 75 kg P_2O ha^{-1} levels, respectively.

The fertilizer was thoroughly mixed with the soil before planting to ensure even distribution. Nitrogen fertilizer in the form of urea (46% N) was added at a rate of 1 g/pot in two applications: the first at planting and the second at the flowering stage. Potassium fertilizer in the form of potassium sulfate (K_2SO_4) was also added in two applications: the first at planting and the second concurrently with the nitrogen application [9], at a rate of 1.5 g pot^{-1}. One month after germination, the plants were sprayed with the growth regulator Atonic at concentrations of 0, 100, and 150 mg L^{-1} once a month. The spraying was done in the morning to avoid evaporation loss. Then following traits were measured, which are: Plant height (cm): The height of the plant was measured from the soil surface to the longest point of the plant using a measuring tape, then the average of one plant was extracted from it, Number of branches/plant: The main branches of each plant were counted at the end of the season and the average was calculated, Leaf area (m^2): The total leaf area of the plant was estimated through the following equation: **Leaf area(cm) = Maximum length of leaf × Maximum width of leaf × 0.75, Chlorophyll content (mg g^{-1})**: The chlorophyll content in the leaves was estimated according to the Arnon method (1949) using 80% acetone. Absorbance was measured at wavelengths of 645 and 663 nm using a spectrophotometer, and total chlorophyll was calculated in mg g^{-1}. Dry weight was determined by collecting and cleaning the plants, then drying them in an electric oven at 65-70 °C until a constant weight was reached. The concentrations of nitrogen, phosphorus, and potassium in the dry weight of the plants were calculated, and fertilization efficiency was calculated using the following equation proposed by Yduvanshi [10]:

Fertilization Efficiency = (Production of the fertilized treatment - Production of the control treatment) / (Production of the control treatment) × 100

The data were statistically analyzed using an LSD design, with the least significant difference (LSD) test at the 5% significance level [11].

Results and Discussion

Plant Height

The results in Table 2 show that adding different levels of phosphorus and concentrations of the growth regulator Atonin led to a clear increase in the height of the roselle plants grown in calcareous soil poor in nutrients. Adding phosphorus levels led to a significant increase of 11.47%, 20.48%, and 15.73% for levels (A1, A2, A3), respectively, compared to the treatment without addition (A0). This clear response to the addition of phosphate fertilizer is due to the low level of available phosphorus in the study soil (Table 1). It also indicates the importance of phosphate fertilizer in plant growth, as phosphorus participates in chlorophyll formation, increases photosynthetic activity, and stimulates cell division [12]. The results also show that level A2 yields the highest plant height index, while at level A3 the indices begin to decrease. This may be due to the fact that the high levels of phosphorus affected the absorption and translocation of a number of micronutrients (Zn, Fe, Cu), which led to a decrease in plant height [13]. This is consistent with what was found by Yadav et al. [14]. As for the effect of spraying with Atonic, the results show that increasing the concentration of Atonic led to a significant increase in plant height, with increases of (6.85%, 13.40%) for levels (B1, B2), respectively. This indicates that increasing the concentration of Atonic increased vegetative mass by activating physiological processes [15]. As for the effect of the interaction, it was found that the combination (A2B2) gave the highest plant height, which reached (84.61) cm, compared to the combination without addition (A0B0), which gave the lowest plant height, which reached (54.60) cm.

Table 2. Effect of phosphate and atonic fertilizer on plant height (cm).

Phosphorus levels (A) kgP_2O_5 ha^{-1}	Atonic levels (B) mg L^{-1}			Mean
	0	100	150	
0	54.60	68.60	71.27	**64.82**
25	71.40	70.77	74.63	**72.26**
50	72.90	76.80	84.61	**78.10**
75	72.96	74.31	77.80	**75.02**
Mean	**67.96**	**72.62**	**77.07**	
L.S.D	(A) =5.687	(B) =4.925	A×B=9.850	

Number of Branches/Plant

The results in Table (3) show that phosphate fertilization has a significant effect on the number of branches per plant in the jujube plant. The application levels significantly outperformed the no-application level, yielding an average of 8.4, 9.2, and 9.0 branches per plant for levels A1, A2, and A3, respectively. In contrast, the no-application level resulted in an average of 7.3 branches per plant, representing increases of 15.06%, 26.02%, and 23.69% for the three levels, respectively. The superiority of the fertilization points is attributed to phosphorus's role in increasing metabolic processes, enhancing plant selection, and stimulating selective bud development [16]. Furthermore, phosphorus promotes increased growth and nutrient uptake, leading to more branches per plant [17]. Despite this response, the results show that the number of kiwi plant branches has begun to decrease. This means that the A2 level has become excessive for the plant, as the overuse of phosphate fertilizers leads to a reduction in the absorption of some micronutrients, such as iron, zinc, and manganese, due to their precipitation and the formation of compounds not available to the plant. This weakens vegetative growth and reduces photosynthetic efficiency, leading to fewer branches per plant. Studies have indicated that the accumulation of phosphorus in the soil can hinder the absorption of iron and zinc through the formation of insoluble compounds or by changing the metabolic balance within the plant, which leads to a disruption of physiological processes and a decrease in growth efficiency and productivity [18]. This is consistent with what was found by Alam et al. [17]. Moderate levels of phosphorus significantly increased growth characteristics such as plant height and number of branches/plant, while higher levels did not achieve additional growth or production. As for the effect of atonic concentrations, the results show that increasing the concentration of atonic led to a significant increase in the number of branches/plant, with increases of 7.59% and 12.65%, compared to the treatment without addition, which gave the lowest number of branches/plant, amounting to 7.9 branches/plant. This is attributed to the presence of nitrophenolic compounds in atonic, which activate metabolic processes in plant cells, leading to increased cell division and elongation and thus improving vegetative growth characteristics. This is consistent with what Abood and Mirare found [15]. Moderate levels of phosphorus significantly increased growth characteristics such as plant height and number of branches/plant, while higher levels did not achieve additional growth or production. As for the effect of atonic concentrations, the results show that increasing the concentration of atonic led to a significant increase in the number of branches/plant, with increases of 7.59% and 12.65%, compared to the treatment without addition, which gave the lowest number of branches/plant, amounting to 7.9 branches/plant. This is attributed to the presence of nitrophenolic compounds in atonic, which activate metabolic processes in plant cells, leading to increased cell division and elongation and thus improving vegetative growth characteristics. This is consistent with what Abood and Mirare found [15]. As for the effect of the interaction, the combination (A2B2) gave the highest number of branches/plant, reaching 10.9 branches/plant, with an increase of 62.68% compared to the control treatment (A0B0), which gave the lowest number of branches/plant, amounting to 6.7 branches/plant.

Table 3. Effect of adding phosphate and anionic fertilizer on the number of branches in the plant (branch/plant).

Phosphorus levels (A) kgP/ha	Atonic levels (B) mg/L			Mean
	0	100	150	
0	6.7	7.5	7.7	**7.3**
25	7.5	8.9	8.8	**8.4**
50	8.18	8.6	10.9	**9.2**
75	9.4	9.2	8.5	**9.0**
Mean	**7.9**	**8.5**	**8.9**	
L.S.D	(A) =0.937	(B) =0.812	A×B=1.624	

Chlorophyll Content

Table (4) shows that there is a significant effect on chlorophyll content when different levels of phosphorus are added. Levels (A1, A2, and A3) gave chlorophyll content of (7.77, 8.81, and 8.15) mg/g for all levels respectively, with increases of 8.21%, 22.70%, and 13.50% compared to the no-phosphorus treatment, which gave the lowest chlorophyll content of 7.18 mg/g. This response may be attributed to phosphorus contributing to the formation of high-energy compounds such as ATP, which are involved in photosynthesis and energy transfer within the plant cell, thereby increasing the efficiency of photosynthesis, including chlorophyll [19]. The results show that high phosphorus levels began to reduce chlorophyll concentration in the leaves of the kojrat plant. This may be due to a nutrient imbalance, as high levels of phosphorus can precipitate certain nutrients, especially iron, which is essential for chloroplast formation and the activity of enzymes involved in chlorophyll synthesis. Therefore, its deficiency leads to a decrease in chlorophyll content and the appearance of yellowing symptoms (Chlorosis) in the leaves. This is consistent with what was found by In-Nam et al. [20].As for the effect of atonic acid, the results showed that there was a significant increase in chlorophyll content with increasing atonic acid concentration, as concentrations (B1 and B2) gave chlorophyll content of 7.65 and 8.98 mg/g, respectively, with increases of 4.93% and 23.18%, compared to the non-added treatment (B0), which gave the lowest chlorophyll content of 7.29 mg/g. This may be attributed to the fact that atonic acid enhanced the absorption of essential nutrients such as iron, magnesium, and nitrogen, thereby improving iron availability within cellular organelles. This enhanced nutrient absorption helped alleviate iron deficiency, which is crucial for maintaining chlorophyll concentration [21]. As for the interaction, the results showed that the combination (A2B2) yielded the highest chlorophyll content in the kojrat plant, at 10.47 mg/g, while the combination (A0B0) yielded the lowest, at 7.08 mg/g.

Table 4. Effect of adding phosphate and anionic fertilizer on chlorophyll (mg/g).

Phosphorus levels (A) kgP/ha	**Atonic levels (B) mg/L**			**Mean**
	0	**100**	**150**	
0	7.08	7.17	7.31	**7.18**
25	7.39	7.55	8.37	**7.77**
50	7.75	8.21	10.47	**8.81**
75	6.96	7.69	9.80	**8.15**
Mean	**7.29**	**7.65**	**8.98**	
L.S.D	(A) =0.531	(B) =0.460	A×B=0.920	

Leaf Area

The results in Table (5) show that phosphate fertilization levels have a highly significant effect on the leaf area of the squill plant. Level (A2) outperformed the other levels, yielding the highest leaf area at 1.80 m², while the lowest leaf area was at level (A0), at 0.96 m². This may be attributed to the important role of phosphorus in stimulating cell division, forming plant tissues, and increasing leaf growth and number, which in turn increases the plant's total leaf area. Phosphorus also participates in the formation of energy compounds such as ATP, which are involved in photosynthesis and carbohydrate transport within the plant, leading to increased leaf growth and expansion, and consequently, a larger leaf area. A study on phytoplankton showed that the addition of phosphorus led to a significant increase in vegetative growth characteristics, including leaf area. Plants treated with a level of approximately 40 kg of phosphorus/hectare recorded the highest leaf area of about 148 cm² per leaf compared to the control treatment, indicating the importance of phosphorus in promoting plant leaf growth [17]. As for level A3, the results clearly indicate that leaf area has begun to decrease significantly. This means that at the level (75 kg p/ha), symptoms of toxicity begin to appear on the plant, and it becomes weak. The reason is also attributed to the fact that high levels of phosphorus cause an imbalance in the nutritional balance within the plant, as an excessive increase in phosphorus may reduce the absorption of some important micronutrients such as iron and zinc, which are necessary for leaf growth and chlorophyll formation, leading to a decrease in the efficiency of photosynthesis and a reduction in leaf growth and area. A recent study on the response of plants to mineral fertilization demonstrated that vegetative growth characteristics such as leaf area and number of leaves gradually increase with increasing fertilization levels until they reach an optimal level. However, higher levels may not achieve further increases in these characteristics due to the plant's limited response beyond a certain fertilization threshold [22]. Regarding the effect of atonic acid, the results showed a significant increase in the leaf area index as atonic acid concentration increased. Concentrations B1 and B2 resulted in leaf areas of 1.14 and 2.07 m², respectively, representing increases of 5.55% and 91.66% compared to the control treatment (B0). The lowest leaf area was 1.08 m². The effect of atonic on increasing the leaf area index is attributed to its stimulation of cell division and elongation in meristematic tissues, as well as to its promotion of leaf formation and increased leaf size by enhancing physiological activity within the plant. Atonic also contributes to increasing the efficiency of photosynthesis by improving chlorophyll formation and activating enzymes associated with photosynthesis, leading to an increased accumulation of carbohydrates necessary for leaf growth and expansion. Recent studies have indicated that treating plants with the growth regulator atonic resulted in a significant increase in vegetative growth characteristics such as leaf area and number of leaves, due to its role in improving nutrient absorption and activating metabolic processes within the plant [15]. Regarding the interaction, the results showed that the combination (A2B2) produced the highest leaf area in the kojrat plant, at 2.74 m², while the combination (A0B0) produced the lowest area, at 0.89 m².

Table 5. Effect of adding phosphate and anionic fertilizers on the leaf area index (m²).

Phosphorus levels (A) kgP/ha	**Atonic levels (B) mg/L**			**Mean**
	0	**100**	**150**	
0	0.89	0.97	1.04	**0.96**
25	0.99	1.09	1.94	**1.34**
50	1.40	1.27	2.74	**1.80**
75	1.07	1.25	2.58	**1.63**
Mean	**1.07**	**1.14**	**2.07**	
L.S.D	(A) =0.273	(B) =0.236	A×B=0.473	

Dry weight

The results in Table (6) show that the phosphate fertilization factor has a significant effect on the dry weight of the kojrat plant, as the levels of addition were significantly superior to the control treatment and gave an average dry weight of 186.61, 218.00 and 196.25 g/plant for levels (A1, A2 and A3) respectively, compared to the non-addition treatment which gave an average of 161.50 g/plant, with percentage increases of 15.54%, 34.98% and 21.51% for the three levels respectively. The reason for the superiority of the phosphate fertilization levels is attributed to the vital role of phosphorus in regulating photosynthesis and electron transport within chloroplasts, which leads to increased CO2 fixation and the production of carbohydrates that are subsequently converted into dry matter in the plant [23]. In addition to its contribution to increasing the absorption of other nutrients such as nitrogen and potassium, according to the apparent positive or stimulatory interaction, which leads to an increase in the vegetative part and thus an increase in dry weight [24]. the results also showed that high levels of phosphorus led to a decrease in the percentage of dry weight, as it decreased from the A2 level by 7.00%. This decrease is attributed to the fact that high levels of phosphorus cause disturbances in the absorption of other nutrients, which lead to a physiological disturbance in plants, such as a decrease in the efficiency of photosynthesis and an acceleration of leaf aging, which reduces the effective leaf area and is considered a dry matter production. This is consistent with what was found by Melo et al. (2023). As for the effect of the concentrations of atonic acid, the results show that increasing the concentration of atonic acid led to a significant increase in the dry weight of the kojrat plant, with increases of 7.15% and 36.65%, compared to the treatment without addition, which gave the lowest dry weight of 166.30 g/plant. The reason for this increase is attributed to the fact that atonic directly affects the improvement of the efficiency of photosynthesis by increasing the chlorophyll content (Table 4) and improving the absorption of nutrients, which leads to an increase in the formation of carbohydrates and their transfer to the growing tissues, which leads to an increase in the accumulation of dry matter [25]. This is consistent with what was shown by Apriyatna et al. (2024). As for the interaction effect, the combination

(A2B2) yielded the highest dry weight of 284.58 g/plant, an increase of 106.59% over the control treatment (A0B0), which had the lowest dry weight of 137.75 g/plant.

Table 6. Effect of adding phosphate and atonic fertilizer on the dry weight of the Roselle plant (g/plant)

Phosphorus levels (A) kgP/ha	Atonic levels (B) mg/L			Mean
	0	100	150	
0	137.75	161.17	185.58	**161.50**
25	167.29	179.94	212.60	**186.61**
50	182.27	187.15	284.58	**218.00**
75	177.90	184.56	226.29	**196.25**
Mean	**166.30**	**178.20**	**227.26**	
L.S.D	(A) =20.859	(B) =18.065	A×B=36.129	

Nitrogen Concentration in Dry Matter

The results in Table (7) show that phosphate fertilization levels have a highly significant effect on the percentage of nitrogen in the vegetative part. Level (A2) outperformed the other levels, giving the highest percentage of nitrogen in dry matter, reaching (2.70%), while the lowest percentage of nitrogen was at level (A0), reaching (2.14%). This high response to the addition of phosphorus fertilizer may be related to the low content of available phosphorus, as shown in Table 1, which is below the critical limit for phosphorus. This also shows that the addition of phosphorus increased the concentration of phosphorus in the soil solution, which was clearly and significantly reflected in the amount of nitrogen absorbed. This may be due to the positive or catalytic effect between the two elements []. In addition to the effect of nitrogen on increasing the growth of the root part of the plant, which leads to an increase in the efficiency of the absorption of nutrients, especially nitrogen, it also increases the activity of enzymes responsible for nitrogen metabolism, such as nitrate reductase, which leads to an increase in the formation of amino acids and proteins and a rise in the concentration of nitrogen in plant tissues (Tang et al., 2025). The results also show that the nitrogen concentration began to decrease at level (A3). This is attributed to the fact that high levels of phosphorus lead to an increase in vegetative growth and plant biomass, which leads to a decrease in the concentration of nitrogen in plant tissues as a result of what is known as the phenomenon of nutrient dilution, where the bioweight of the plant increases at a faster rate than nitrogen absorption. Hence, its concentration appears lower in plant tissues. This is consistent with what Gu et al. [26]. indicated: that adding phosphorus can affect nitrogen stores in plants and ecosystems by influencing the dynamics of nitrogen uptake and conversion in soil and plants. Regarding the effect of atonicity, the results showed a significant increase in nitrogen concentration with increasing atonicity concentration. Concentrations (B1 and B2) yielded nitrogen concentrations of 2.27% and 3.09%, respectively, representing increases of 22.70% and 67.02% compared to the non-additional treatment (B0), which yielded the lowest concentration of 1.85%. This suggests that this regulator activates nutrient uptake, improves plant metabolic activity, and increases protein synthesis, leading to higher nitrogen concentrations in plant tissues and improved plant nutritional status. This aligns with the findings of Tavallali and Darvishzadeh [6].

Table 7. Effect of adding phosphate and atonic fertilizer on nitrogen concentration in the dry weight of the kojrat plant (%)

Phosphorus levels (A) kgP/ha	Atonic levels (B) mg/L			Mean
	0	100	150	
0	1.46	2.22	2.75	**2.14**
25	1.51	2.30	2.83	**2.21**
50	2.33	2.36	3.43	**2.70**
75	2.12	2.23	3.37	**2.57**

Mean	**1.85**	**2.27**	**3.09**	
L.S.D	(A) =0.210	(B) =0.182	A×B=0.365	

Phosphorus Concentration in Dry Matter

The results in Table (8) show that the levels of phosphate fertilization have a significant effect on the percentage of phosphorus in the dry matter of the vegetative part of the succulent plant. Levels (A1, A2, and A3) gave phosphorus concentrations of (0.24, 0.32, and 0.26)% for the three levels, respectively, with increases of (50.00, 100.00, and 62.50)% compared to the no-fertilization treatment, which gave the lowest phosphorus concentration of (0.16)%. This response is attributed to the low phosphorus content of the soil, which is an important element for plant growth, as well as its contribution to increased vegetative growth, which in turn increases the absorption of nutrients, especially phosphorus [4]. The results also indicate that nitrogen concentration begins to decrease at level (A3). This is attributed to the fact that high phosphorus levels lead to increased vegetative growth and plant biomass, which in turn leads to a decrease in nitrogen concentration in plant tissues due to the phenomenon known as nutrient dilution. In this phenomenon, the plant's biomass increases at a faster rate than nitrogen absorption, resulting in a lower nitrogen concentration in plant tissues. This is consistent with the findings of Gu et al. [26]. The addition of phosphorus may affect nitrogen stores in plants and ecosystems through its impact on the dynamics of nitrogen uptake and conversion in the soil and plants. Regarding the effect of atonicity, the results showed a significant increase in nitrogen concentration with increasing atonicity concentration. Concentrations (B1 and B2) yielded nitrogen concentrations of 2.27% and 3.09%, respectively, representing increases of 22.70% and 67.02% compared to the non-additional treatment (B0), which yielded the lowest concentration of 1.85%. This suggests that this regulator activates nutrient uptake, improves plant metabolic activity, and increases protein synthesis, leading to higher nitrogen concentrations in plant tissues and improved plant nutritional status. This aligns with the findings of Tavallali and Darvishzadeh [6].

Table 7. Effect of adding phosphate and atonic fertilizer on nitrogen concentration in the dry weight of the kojrat plant (%)

Phosphorus levels (A) kgP/ha	Atonic levels (B) mg/L			Mean
	0	100	150	
0	1.46	2.22	2.75	**2.14**
25	1.51	2.30	2.83	**2.21**
50	2.33	2.36	3.43	**2.70**
75	2.12	2.23	3.37	**2.57**
Mean	**1.85**	**2.27**	**3.09**	
L.S.D	(A) =0.210	(B) =0.182	A×B=0.365	

Phosphorus Concentration in Dry Matter

Table (8) shows that phosphate fertilization levels have a significant effect on the percentage of phosphorus in the dry matter of the vegetative parts of the succulent plant. Levels (A1, A2, and A3) yielded phosphorus concentrations of (0.24, 0.32, and 0.26)%, respectively, with increases of (50.00, 100.00, and 62.50)% compared to the no-fertilization treatment, which yielded the lowest phosphorus concentration of (0.16)%. This response is attributed to the low phosphorus content in the soil, an element essential for plant growth and contributing to increased vegetative growth, which in turn enhances nutrient absorption, particularly phosphorus [4]. The table also shows that at level (A3), the phosphorus concentration index in the kojrat plant begins to decrease. This indicates that high phosphorus levels have weakened the plant and reduced its ability to absorb nutrients, and have caused nutritional interactions with other elements, particularly zinc, leading to decreased efficiency of processes related to phosphorus metabolism within the plant. This is consistent with the findings of [27]. As for the effect of atonic acid, the results show a significant increase in phosphorus concentration as atonic acid concentration increases. Concentrations (B1 and B2) yielded phosphorus concentrations of (0.24 and 0.30)%, respectively, with increases of (26.31 and 57.89)%, compared to the non-additional treatment (B0), which yielded the lowest concentration of (0.19)% This may be attributed to the role of atonic fertilizer in strengthening the root system, which increases the efficiency of nutrient absorption, including phosphorus. Furthermore, it stimulates microbial activity in the root zone, thereby increasing phosphorus availability and its conversion into absorbable forms. This aligns with the findings of [28]. Regarding the interaction, the results showed that the combination (A2B2) yielded the highest phosphorus concentration in the succulent plant (0.38%), while the combination (A0B0) yielded the lowest concentration (0.09%).

Table 8. Effect of adding phosphate fertilizer and atonic fertilizer on the phosphorus concentration in the dry matter of the succulent plant (%)

Phosphorus levels (A) kgP/ha	Atonic levels (B) mg/L			Mean
	0	**100**	**150**	
0	0.09	0.18	0.21	**0.16**
25	0.21	0.22	0.29	**0.24**
50	0.28	0.31	0.38	**0.32**
75	0.30	0.27	0.32	**0.26**
Mean	**0.19**	**0.24**	**0.30**	
L.S.D	(A) =0.052	(B) =0.026	A×B=0.365	

Potassium concentration in dry matter

Table (9) shows that adding different levels of phosphorus and concentrations of phosphorus significantly increased potassium concentration in the kojrat plant. Adding levels (A1, A2, A3) increased the plant's potassium content by (2.04, 2.65, 2.38)% for the three levels, respectively, representing increases of (20.00, 55.88, 40.00)%, respectively, compared to the control treatment (A0). This is attributed to the fact that an abundance of potassium stimulates root growth by increasing root mass and enzymatic activity, thereby enhancing the roots' ability to absorb potassium from the soil solution [29]. The table also shows that at level A3, the potassium concentration begins to decrease. This indicates that at this level, symptoms of toxicity begin to appear, meaning it is above the plant's critical limit, resulting in plant weakness. This is attributed to excessive phosphate fertilization in calcareous soils, which transforms phosphate into complex, poorly soluble compounds, thereby reducing the phosphorus concentration in the plant and consequently weakening plant growth and reducing nutrient absorption from the soil [4]. As for the effect of spraying with Atonic, the results show that increasing its concentration significantly increased the potassium concentration. Concentrations (B1 and B2) gave a significant increase of (2.18 and 2.59)%, respectively. The increase was (21.11 and 43.88)%, indicating that increasing the concentration of atonic acid led to a significant increase in the growth of the succulent plant, both in its vegetative and root parts. This was reflected positively in nutrient absorption, particularly of potassium, and in an increase in their concentration in the plant. Regarding the interaction effect, it was found that the combination (A2B2) gave the highest potassium concentration of (3.25%) compared to the combination (A0B0), which resulted in a low infection rate of (1.41%).

Table 9. Effect of adding phosphate and atonic fertilizers on potassium concentration in the dry matter of the succulent plant (%)

Phosphorus levels (A) kgP/ha	Atonic levels (B) mg/L			Mean
	0	**100**	**150**	
0	1.41	1.80	1.93	**2.14**
25	1.70	2.15	2.27	**2.21**
50	2.21	2.49	3.25	**2.70**
75	1.91	2.30	2.94	**2.57**

Mean	**1.80**	**2.18**	**2.59**	
L.S.D	(A) =0.152	(B) =0.132	A×B=0.264	

Total Yield

The results in Table (10) show that phosphate fertilization has a significant effect on the total yield of the kojrat plant, as the application levels significantly outperformed the control treatment, giving an average total yield of 5.77, 6.65, and 6.19 g/pot for levels (A1, A2, and A3) respectively, compared to the non-application treatment, which gave a yield of 5.02 g/pot, with increases of 14.94%, 32.47%, and 23.30% for the three levels respectively. The reason for the superiority of the phosphate fertilization levels is attributed to the role of phosphorus in promoting root growth, which increases the absorption of water and nutrients, which in turn contributes to increased vegetative growth and flowering, and this is reflected in increased productivity. This is consistent with what was found by [23]. Phosphorus improves the quality characteristics of the yield by increasing the efficiency of nutrient absorption and the accumulation of dry matter. The results also showed that high levels of phosphorus (A3) led to a decrease in the total yield, as it decreased by 7.43% compared to level A2. This decrease is attributed to the fact that high levels of phosphorus cause an impediment to the absorption of micronutrients such as iron and zinc, which leads to weak vegetative growth and flowering, and consequently a decrease in the quantity and quality of the calyxes, which represent the economic part of the plant [19]. This is consistent with what was found by Melo et al. (2023). Regarding the effect of atonic acid concentration, the results show that increasing the atonic acid concentration significantly increased the total yield of the kojrat plant, with increases of 7.05% and 16.45% compared to the control treatment, which yielded the lowest yield of 5.53 g/pot. This increase is attributed to the fact that atonic acid improves growth and increases tolerance to salt stress, thus contributing to higher plant productivity under harsh environmental conditions [30]. As for the interaction effect, the combination (A2B2) gave the highest yield of 7.83 g/pot, representing an increase of 64.84%, compared to the control treatment (A0B0), which yielded the lowest yield of 4.75 g/pot.

Table 10. Effect of adding phosphate and atonic fertilizer on the total yield of the kojrat plant (g/pot)

Phosphorus levels (A) kgP/ha	Atonic levels (B) mg/L			Mean
	0	100	150	
0	4.75	5.02	5.29	**5.02**
25	5.44	5.77	6.09	**5.77**
50	6.13	6.65	7.83	**6.65**
75	5.81	6.23	6.53	**6.19**
Mean	**5.53**	**5.92**	**6.44**	
L.S.D	(A) =0.515	(B) =0.446	A×B=0.893	

This was reflected in the fertilization efficiency, as treatment A2B2 gave the highest fertilization efficiency value of 64.84%, as shown in Table (11). Fertilization efficiency represents the percentage increase in yield compared to the control treatment. Adding phosphorus at level A2 (50 kg P2O5/hectare) and Atonic B2 (150 mg/L) resulted in the best interaction between the two levels, and this was reflected in the highest total yield in treatment A2B2. From Table (11), significant differences are observed in the effect of the added phosphorus levels on the fertilization efficiency of the crop yield. Level A2 showed the highest fertilization efficiency of 44.63%, and the lowest efficiency was in the control treatment A0 at 5.68%. However, when the phosphorus fertilization level was raised from level A2 to A3, the fertilization efficiency decreased to 30.31%. This aligns with the findings of Liu et al. [29], who concluded that excessive fertilization leads to phosphorus fixation in the soil and a decline in plant response. The study also demonstrated that excessive fertilization can disrupt the soil nutrient balance, leading to deficiencies in other elements such as iron and zinc, thereby hindering their absorption and negatively impacting growth and productivity. Furthermore, excessive phosphorus fertilization can increase agricultural costs without yielding a significant increase in overall yield. As for the effect of Atonic on fertilization efficiency, Table 11 shows that Atonic has a positive effect on raising or increasing fertilization efficiency for the grain yield. The addition of Atonic led to a significant increase in fertilization efficiency, with level B2 achieving the highest average of 35.47%. This indicates that the addition of Atonic played a major role in increasing the quantity of grain yield by increasing the absorption and concentration of phosphorus. As Tavallali and Darvishzadeh indicated, spraying with Atonic increased nutrient absorption, including phosphorus, and improved nutrient utilization efficiency [6]. As for the interaction effect, the combination (A2B2) gave the highest fertilization efficiency of 64.84%, compared to the control treatment (A0B0), which gave the lowest fertilization efficiency of 0%.

Table 11. Effect of adding phosphate and atonic fertilizer on fertilization efficiency (%) of the yield of the kojrat plant

Phosphorus levels (A) kgP/ha	**Atonic levels (B) mg/L**			**Mean**
	0	**100**	**150**	
0	0	5.68	11.36	**5.68**
25	14.52	21.47	28.21	**21.40**
50	29.05	40.00	64.84	**44.63**
75	22.31	31.15	37.47	**30.31**
Mean	**16.47**	**24.57**	**35.47**	
L.S.D	(A) =0.210	(B) =0.182	A×B=0.365	

Conclusion

The study results showed that phosphate fertilization significantly improved most vegetative growth characteristics and total yield of the jujube plant. The 50 kg P_2O_5 ha^{-1} level was optimal, achieving the highest values for plant height, number of branches, chlorophyll content, leaf area, and dry weight, in addition to increasing the concentrations of nitrogen, phosphorus, and potassium in the dry matter compared to the control treatment. Spraying the plants with the growth regulator Atonic also significantly increased all studied characteristics, with a concentration of 150 mg L^{-1} being the most effective in improving growth and yield. The interaction between the two factors showed that the treatment (50 kg P_2O_5 ha^{-1} + 150 mg L^{-1} Atonic) was the most effective. The study achieved the highest overall yield and best indicators of growth and mineral nutrition. Therefore, it recommends applying phosphate fertilization at a rate of 50 kg P_2O_5 $hectare^{-1}$ and spraying to improve the growth and productivity of the kojrat plant under calcareous soil conditions.

REFERENCES

[1] B. Ahirwar and D. Ahirwar, "In vivo and in vitro investigation of cytotoxic and antitumor activities of polyphenolic leaf extract of Hibiscus sabdariffa against breast cancer cell lines," Res. J. Pharm. Tech., vol. 13, no. 2, pp. 615–620, 2020.

[2] C. I. Oyewole and M. Mera, "Response of Roselle (Hibiscus sabdariffa L.) to rates of inorganic and farmyard fertilizers in the Sudan savanna ecological zone of Nigeria," Afr. J. Agric. Res., vol. 5, no. 17, pp. 2305–2309, 2010.

[3] M. J. Villalobos-Vega, G. Rodríguez-Rodríguez, O. Armijo-Montes, P. Jiménez-Bonilla, and V. Álvarez-Valverde, "Optimization of the extraction of antioxidant compounds from roselle Hibiscus calyxes (Hibiscus sabdariffa), as a source of nutraceutical beverages," Molecules, vol. 28, no. 6, Art. no. 2628, 2023.

[4] A. M. T. Al-Maeni, Soil Fertility and Fertilization under Arid and Semi-Arid Region Conditions. Mosul, Iraq, 2024.

[5] A. Przybysz, H. Gawrońska, and J. Gajc, "Biological mode of action of a nitrophenolates-based biostimulant: Case study," Front. Plant Sci., vol. 5, Art. no. 713, 2014.

[6] M. Tavallali and A. Darvishzadeh, "Synergistic effects of Fe nanocomplex and nitrophenolate-based biostimulant on tomato," BMC Plant Biol., 2025.
[7] A. L. Page, R. H. Miller, and D. R. Keeney, Eds., Methods of Soil Analysis. Madison, WI, USA: American Society of Agronomy, 1982.
[8] J. M. Bremner, "Total nitrogen," in Methods of Soil Analysis, C. A. Black, Ed. Madison, WI, USA: ASA, 1965.
[9] M. Dahmardeh, "Effects of sowing date on the growth and yield of maize cultivars (Zea mays L.) and the growth temperature requirements," Afr. J. Biotechnol., vol. 11, no. 61, pp. 12450–12453, 2012.
[10] H. S. Yduvanshi, "Transformation of native and applied phosphorus in soil as affected by moisture regime under black gram," J. Indian Soc. Soil Sci., vol. 32, pp. 97–99, 1984.
[11] K. M. D. Al-Zubaidi and K. K. A. Al-Jubouri, Design and Analysis of Genetic Experiments. Baghdad, Iraq: Dar Al-Wadah for Publishing and Dijlah Library for Printing and Publishing, 2016.
[12] M. Arun Raj, D. Vasanthi, and M. D. I. Mansingh, "Effect of sulphur on growth and yield of greengram (Vigna radiata L.)," Int. J. Sci. Environ. Technol., vol. 7, no. 5, pp. 1861–1867, 2018.
[13] J. L. Havlin, S. L. Tisdale, W. L. Nelson, and J. D. Beaton, Soil Fertility and Fertilizers: An Introduction to Nutrient Management, 8th ed. Upper Saddle River, NJ, USA: Pearson, 2014.
[14] B. Yadav, S. Singh, S. Sharma, A. Pandey, A. Yadav, S. Jaiswal, and S. Singh, "Influence of liming and phosphorus application on growth of soybean in acidic soil of Chandauli, Uttar Pradesh, India," Int. J. Plant Soil Sci., vol. 36, no. 9, pp. 158–166, 2024.
[15] N. M. Abood and S. S. Mirare, "Effect of seed soaking with a growth regulator (Atonik) and seeding dates on the vegetative growth characteristics of Sorghum bicolor L.," Iraqi J. Agric. Sci., 2024.
[16] A. A. S. Abdel-Kader and F. E. M. Saleh, "Improvement of yield and quality of roselle (Hibiscus sabdariffa L.) plant by using natural sources of phosphorus and potassium in calcareous sandy soils," Sci. J. Flowers Ornam. Plants, 2017.
[17] H. Alam, "Effect of organic and inorganic phosphorus on growth of Roselle (Hibiscus sabdariffa L.)," J. Northeast Agric. Univ., 2016.
[18] X. Xie, W. Hu, X. Fan, H. Chen, and M. Tang, "Interactions between phosphorus, zinc, and iron homeostasis in nonmycorrhizal and mycorrhizal plants," Front. Plant Sci., vol. 10, Art. no. 1172, 2019.
[19] R. Rashid, "Phosphorus nutrition and chlorophyll formation in crop plants," 2022.
[20] H. I. Nam et al., "Interdependent iron and phosphorus availability controls chloroplast retrograde signaling and photosynthesis," Nat. Commun., vol. 12, Art. no. 27548, 2021.
[21] G. Z. K. Al-Rikabi, L. T. Fadalah, and A. S. Jewar, "Management of cucumber (Cucumis sativus L.) in integration with biostimulant atonik based on physical and biochemical properties," SABRAO J. Breed. Genet., vol. 57, pp. 1510–1517, 2025.
[22] N. M. Inuwa, "Effect of stand densities and NPK fertilizer on growth and calyx yield of Hibiscus sabdariffa L. in Sudan savanna zone of Nigeria: An approach towards growth characters," J. Exp. Agric. Int., vol. 44, no. 10, 2022.
[23] A. Carstensen, A. Herdean, S. B. Schmidt, A. Sharma, C. Spetea, M. Pribil, and S. Husted, "The impacts of phosphorus deficiency on the photosynthetic electron transport chain," Plant Physiol., vol. 177, no. 1, pp. 271–284, 2018.
[24] A. M. Al-Ma'moun, Soil Fertility and Plant Nutrition under Calcareous Soil Conditions. Iraq, 2024.
[25] D. R. Nurhayati and W. Prayoga, "Study on the effect of growth regulators and the concentration of coconut water on the growth and yield of garlic shallots (Allium ascalonicum L.)," World J. Adv. Res. Rev., vol. 19, no. 2, pp. 392–395, 2023.
[26] X. Gu, F. Zhang, X. Xie, Y. Cheng, and X. Xu, "Effects of N and P addition on nutrient and stoichiometry of rhizosphere and non-rhizosphere soils of alfalfa in alkaline soil," Sci. Rep., vol. 13, Art. no. 12119, 2023.
[27] M. Shi, C. Liu, X. Wang, Z. Guo, Z. Wang, J. Lin, K. H. M. Siddique, and Z. Wang, "High phosphorus fertilization increases manganese accumulation in wheat: Absorption and transport mechanisms," J. Agric. Food Chem., vol. 73, no. 30, pp. 19084–19093, 2025.

[28] Y. Xia et al., “Phosphorus-solubilizing bacteria improve the growth of Nicotiana benthamiana on lunar regolith simulant by dissociating insoluble inorganic phosphorus,” Commun. Biol., vol. 6, Art. no. 1039, 2023.

[29] Y. Liu, J. Gao, Y. Zhao, Y. Fu, B. Yan, X. Wan, and G. Cheng, “Effects of different phosphorus and potassium supply on the root architecture, phosphorus and potassium uptake, and utilization efficiency of hydroponic rice,” Agronomy College, Shenyang Agricultural University, Shenyang, China.

[30] M. Haghighi, M. Jalali, and M. Mozafarian, “The effect of Atonik biostimulant on greenhouse pepper under salinity stress,” BMC Plant Biol., vol. 25, Art. no. 1778, 2018.