



Effect of mineral fertilization (NPK) and foliar spraying with organic silicon on some growth traits and yield of maize

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Abstract

A factorial experiment using a randomized complete block design (RCBD) was conducted in the spring of 2024 in clay loam soil at Ibn Al-Bitar Vocational Preparatory School/Al-Husainiya District, Holy Karbala, to study the effect of adding mineral fertilizers (NPK) and spraying with silicon on some growth and yield traits of maize. The experiment included two factors: mineral fertilizers (N, P, and K) at three levels: without fertilization, symbolized by M_0 , adding 50% of the fertilizer recommendation (150 kg N ha^{-1} , 50 kg P ha^{-1} , and 80 kg K ha^{-1}) and symbolized by M_1 , and adding 100% of the fertilizer recommendation (300 kg N ha^{-1} , 100 kg P ha^{-1} , and 160 kg K ha^{-1}) and symbolized by M_2 , and the second factor is foliar feeding with Organic silicon (80%) at three concentrations (0, 3 and 6 ml L^{-1}), the results of the study showed the significant superiority of adding mineral fertilizers individually in most of the studied traits. Adding the full fertilizer recommendation 100% achieved the highest averages in the trait of number of leaves ($11.884 \text{ leaf plant}^{-1}$), leaf area ($6220.60 \text{ cm}^2 \text{ plant}^{-1}$), chlorophyll index (53.82 SPAD), biological yield ($16.418 \text{ tons' ha}^{-1}$), and grain yield ($7.827 \text{ tons' ha}^{-1}$). The increase in the concentration of silicon added as a spray on the vegetative group of maize led to a significant increase in the averages of the studied traits. The concentration (6 ml L^{-1}) achieved a significant superiority in the trait of leaf area ($5917.30 \text{ cm}^2 \text{ plant}^{-1}$), chlorophyll index (52.55 SPAD), biological yield ($16.418 \text{ tons' ha}^{-1}$), and grain yield ($7.112 \text{ tons' ha}^{-1}$). The results also showed the response of maize to the two-way interaction between the two study factors. The treatment ($M_2\text{Si}_2$) was significantly superior in the number of leaves ($12.013 \text{ leaf plant}^{-1}$), leaf area ($6303.80 \text{ cm}^2 \text{ plant}^{-1}$), chlorophyll index (55.78 SPAD), biological yield ($17.045 \text{ tons' ha}^{-1}$), and grain yield ($8.250 \text{ tons' ha}^{-1}$) compared to the comparison treatment without fertilization.

Keywords: Mineral fertilizers, Organic silicon, spraying, maize.

Introduction

Maize (*Zea mays* L), belonging to the grass family (Poaceae), is one of the important cereal crops and is widely cultivated around the world. It ranks third globally in terms of importance, cultivated area, and production, following wheat and rice. Annual maize

production in Iraq is estimated to be around 600,000 tons, spanning an area of about 150,000 hectares [1]. It is considered an important crop in Iraq for its use in nutrition, as its grains contain starches, calories, amino acids, and dietary fibers that promote digestive health. Its oil is also used in food and medicine due to its digestibility and health benefits, and it is recommended for patients with high cholesterol levels [2].

Additionally, its use as animal feed includes incorporating its grains into poultry diets because they contain carotene, as well as feeding livestock. Therefore, it is essential to follow a good management system for this crop to achieve higher productivity per unit area [3]. Corn crops require a diverse and balanced range of essential nutrients for the growth and development of the plant. Nitrogen, phosphorus, and potassium are among the most important nutrients for its nutrition, as the plant needs them in relatively large quantities. A deficiency in these nutrients has a detrimental effect on growth and productivity. Therefore, there is a focus on their presence in fertilizers, whether they are simple or compound. When the levels of these essential nutrients in the soil decrease, or their availability is reduced due to depletion by the plant, fixation in the soil, leaching outside the root zone, or any other reasons, these nutrients must be added to the soil to achieve good growth, development, and production [4]. These nutrients are crucial for plants as they are required in large amounts for vital functions such as building proteins, nucleic acids, various membranes, and energy production, as well as regulating water absorption and activating enzymes (5). While mineral fertilizers are efficient and play a significant role in boosting agricultural production and enhancing crop quality, they can be costly and may have detrimental effects on the environment. Therefore, reducing their usage by transitioning to nutritional supplements that help optimize the use of mineral fertilizers, particularly those containing nitrogen, phosphorus, and potassium.

This approach includes the use of natural alternatives, including organic silicon fertilizer [6]. Silicon is a valuable nutrient for plants that has been increasingly used in recent years to mitigate the harmful effects of salinity and drought, as well as reduce the toxicity of heavy metals. It plays several important roles in various physiological processes, including improving the efficiency of photosynthesis and enhancing the roots' ability to absorb essential nutrients for plant growth and development. Additionally, silicon helps to lessen the toxicity of sodium ions and boosts the effectiveness of antioxidant enzymes. It also fortifies cell walls, providing mechanical support to the plant's above-ground structures. [7].

This study was conducted with the aim of knowing the effect of foliar spraying with different concentrations of organic silicon and adding different levels of mineral fertilizer (NPK) and their interaction on the growth and yield of yellow corn in Iraq.

Materials and Methods

Executing the experiment

A factorial experiment was conducted in a clay loam soil in an agricultural field belonging to Ibn Al-Bitar Vocational Preparatory School/Al-Husainiya District in Holy



Karbala during the spring season (2024 AD) to study the effect of adding mineral fertilizers (NPK) and foliar spraying with silicon on some growth and yield traits of maize. A Randomized Complete Block Design (RCBD) was used.

Table (1): Chemical and physical properties of the study soil at a depth of 0 –30 cm before maize planting

Properties		Values
pH		7.1
EC (1:1)		2.11 ds m ⁻¹
OM		1.31 g kg ⁻¹
N available		29.65 mg kg ⁻¹
K available		72.78 mg kg ⁻¹
P available		14.5 mg kg ⁻¹
Soil separators	Sand	250 G kg ⁻¹
	Silt	360 G kg ⁻¹
	Clay	390 G kg ⁻¹
Texture		Clay loam

Field preparation and agricultural operations

The experiment included two factors: levels of mineral fertilization (N, P, and K), which are: no fertilization, denoted as M₀; the addition of 50% of the recommended fertilization (150 kg N, 50 kg P, and 80 kg K) ha⁻¹, denoted as M₁; and the addition of 100% of the recommended fertilization (300 kg N, 100 kg P, and 160 kg K) ha⁻¹, denoted as M₂. The second factor was foliar feeding with Organic silicon (80%) at three concentrations (0, 3, and 6 ml L⁻¹). The soil was prepared through processes that included plowing with a moldboard plow, leveling with disc harrows, and finally dividing it into experimental units, each with an area of 6 m². Seeds were planted on March 21, 2024, in rows spaced 75 cm apart, with 25 cm between each hole to achieve a plant density of 53,333.33 plants ha⁻¹. The field was fertilized with urea (46% N), triple superphosphate (21% P), and potassium sulfate (41.5% K) as sources of mineral fertilizer (N, P, and K) applied to the soil by banding at a distance of 10 cm from the planting line and at a depth of 5 cm. The phosphorus fertilizer was applied in one dose at planting, while the nitrogen and potassium fertilizers were applied in two equal doses: one at planting and the second 45 days after the first application. The following traits were measured:

- Number of leaves (leaf plant⁻¹): The number of leaves was counted for the main stem and for ten protected plants, and then the average was taken.
- Leaf area (cm² plant⁻¹): Calculated by multiplying the square of the leaf length under the main cob leaf × 0.75. The area was measured during the flowering stage for ten protected plants [8].

- Chlorophyll content (SPAD) was measured during the male flowering stage using a Chlorophyll SPAD-Meter. Readings were taken from five leaves per plant, averaged, and then the average was calculated across five plants [9].
- Biological yield ($Mg\ ha^{-1}$): After the drying process of the sample is completed until weight stability is achieved, the average biological yield per plant is then calculated, multiplied by the plant density [10].
- Total grain yield ($Mg\ ha^{-1}$): Calculated by multiplying the average grain weight per plant by the plant density [10].

Statistical analysis

The data were collected from the field experiment, and the results were statistically analyzed according to the analysis of variance (ANOVA) as per the split-plot design [11]. The least significant difference ($LSD_{0.05}$) test was used to compare and separate the mean differences. The statistics software GenStat12 was employed.

Results and Discussion

Number of leaves (leaf plant⁻¹)

The results in Table 2. show that the addition of mineral fertilizers (NPK) at a level of 100% M_2 of the fertilizer recommendation significantly affected the increase in the average number of leaves per plant, which reached 11.884 (leaf plant⁻¹), with an increase of 14.40% compared to the treatment without the addition of mineral fertilizers M_0 , which reached 10.388 (leaf plant⁻¹). As for the addition of mineral fertilizers (NPK) at a level of 50% M_1 of the fertilizer recommendation, it reached 11.792 (leaf plant⁻¹). A plant can benefit from nutrients (N, P, and K) in an integrated manner, leading to an increase in the number of leaves and improved health and productivity. Nitrogen helps increase leaf growth and chlorophyll formation, which enhances photosynthesis. With increased chlorophyll, the plant can produce more energy, contributing to a greater number of leaves. Phosphorus, on the other hand, promotes strong root development and increases the plant's ability to absorb nutrients. It is an important element in the energy process (ATP), helping the plant generate the energy needed for leaf growth. Phosphorus also contributes to the reproductive and flowering processes of crops, indirectly affecting the number of leaves. Potassium plays a vital role in regulating the opening and closing of stomata, which affects the amount of water lost from the leaves and enhances plant health and resistance to harsh environmental conditions, such as drought, enabling the plant to maintain a sufficient number of leaves. It also enhances the plant's metabolism, thereby increasing the efficiency of nitrogen and phosphorus in growth [12, 13].

It did not differ significantly from the M_2 addition. The results of the statistical analysis also showed that there were no significant differences when foliar spraying with silicon in the characteristics of the number of leaves per plant. As for the results of the interaction between the study factors, the treatment (M_2Si_2) excelled by giving the highest average number of leaves per plant, reaching 12.013 (leaf plant⁻¹), with an

increase of 17.97% compared to the comparison treatment (M_0Si_0). It did not differ significantly from the treatments (M_1Si_2 , M_2Si_1 , M_1Si_1 , and M_2Si_0), which reached (11.903, 11.860, 11.807, and 11.780), respectively.

Leaf area ($\text{cm}^2 \text{ plant}^{-1}$)

The results in Table 3 show that the addition of mineral fertilizer (NPK) at a level of 100% M_2 of fertilizer significantly increased the average leaf area, which reached ($6220.60 \text{ cm}^2 \text{ plant}^{-1}$), with an increase of 14.40% compared to the treatment without mineral fertilizer addition, M_0 , which reached ($5452.70 \text{ cm}^2 \text{ plant}^{-1}$). The addition of mineral fertilizer (NPK) at a level of 50% M_1 of mineral fertilizer reached $5867.90 \text{ cm}^2 \text{ plant}^{-1}$. This superiority may be attributed to the fact that fertilization leads to increased availability of macronutrients, which stimulate the effectiveness of cellular metabolic processes, thereby promoting cell growth and elongation, increasing the leaf area of maize plants. In addition, potassium delays leaf senescence, improves leaf flexibility and water capacity, and increases carbon metabolism. It also promotes cell division, leading to an increase in leaf area. [14,15]

Table (2): Effect of mineral fertilization (NPK), Silicone spray, and their interaction on Leaves per plant (leaf plant^{-1})

Mineral Fertilization (Kg ha^{-1})	Silicon concentration (ml L^{-1})			Means
	Si_0	Si_1	Si_2	
M_0	10.183	10.383	10.597	10.388
M_1	11.667	11.807	11.903	11.792
M_2	11.780	11.860	12.013	11.884
Means	11.210	11.350	11.504	

$LSD_{0.05} \text{ Silicon (Si)} = NS$

$LSD_{0.05} \text{ mineral fertilization (M)} = 0.334$

$LSD_{0.05} \text{ Si} \times \text{M Interactions} = 0.579$

The results also showed significant differences in leaf area when foliar spraying with silicon was applied. Spraying with a concentration of (6 ml L^{-1}) significantly outperformed, giving the highest average of ($5917.30 \text{ cm}^2 \text{ plant}^{-1}$) compared to the control treatment, which reached ($5760.80 \text{ cm}^2 \text{ plant}^{-1}$). The significant superiority when spraying with a concentration of 6 ml L^{-1} may be due to the positive effect of silicon, as it increases the efficiency of enzymatic activity. Also, the silicon accumulated in the epidermal cells affects the angle of the leaf, making it upright and increasing light interception. Furthermore, silicon leads to an increase in the ratio of chlorophyll a and

chlorophyll b and total chlorophyll, thereby enhancing photosynthesis, inhibiting transpiration, and increasing water use efficiency [16]. These results are consistent with what [17] indicated, which is that spraying silicon increases the leaf area of maize plants. Regarding the interaction effects between the study factors, the treatment (M_2Si_2) excelled by yielding the highest average leaf area, reaching $6303.80 \text{ cm}^2 \text{ plant}^{-1}$. This represents an increase of 16.47% compared to the control treatment (M_0Si_0), which reached ($5412.10 \text{ cm}^2 \text{ plant}^{-1}$).

Index of chlorophyll in leaves (SPAD unit).

The results in Table 4 show that the addition of mineral fertilizers (NPK) at a level of 100% M_2 significantly increased the average chlorophyll index, which reached 53.82 SPAD, with an increase of 14.40% compared to the treatment without the addition of mineral fertilizers M_0 , which reached 45.49 SPAD. The significant superiority in the chlorophyll index may be attributed to the role of these nutrients in enhancing vital processes that stimulate chlorophyll production. Nitrogen is the primary nutrient in chlorophyll formation and directly enters the structure of the chlorophyll molecule. Phosphorus also plays a fundamental role in photosynthesis, as it is an essential component of nucleic acids, DNA and RNA, and a significant factor in energy production. Adequate levels of phosphorus help in the formation of ATP, which is necessary for storing and transporting energy within cells. In addition, potassium plays a role in increasing the efficiency of the photosynthesis process and thus increasing the chlorophyll content in the leaves [18].

Table (3): Effect of mineral fertilization (NPK), Silicone spray, and their interaction on Leaf area ($\text{cm}^2 \text{ plant}^{-1}$)

Mineral Fertilization (Kg ha^{-1})	Silicon concentration (ml L^{-1})			Means
	Si_0	Si_1	Si_2	
M_0	5412.10	5446.90	5499.20	5452.70
M_1	5719.30	5935.20	5949.00	5867.90
M_2	6151.10	6207.00	6303.80	6220.60
Means	5760.80	5863.00	5917.30	

LSD_{0.05} Silicon (Si) = 9.95

LSD_{0.05} mineral fertilization (M) = 9.95

LSD_{0.05} Si × M Interactions = 17.24

The results in the table also showed significant differences in the average chlorophyll index when foliar spraying with silicon was applied. Spraying with a concentration of

(6 ml L⁻¹) significantly outperformed, giving the highest average of (52.55 SPAD) compared to the control treatment, which reached (47.77 SPAD), with an increase of 10.00%. The significant superiority of the 6 ml L⁻¹ concentration in increasing the total chlorophyll content may be due to the role of silicon spraying in enhancing chlorophyll formation by improving the plant's efficiency in absorbing nutrients and enhancing the plant's resistance to environmental stresses such as drought and salinity. Studies have shown that silicon contributes to strengthening cell walls and improving photosynthetic efficiency, which increases plant productivity and growth [19]. As for the results of the interaction between the study factors, the treatment (M₂Si₂) outperformed, giving the highest average chlorophyll index of (55.78 SPAD), with an increase of 27.90% compared to the control treatment (M₀Si₀), which reached (43.61 SPAD).

Table (4): Effect of mineral fertilization (NPK), Silicone spray, and their interaction on Index of chlorophyll in leaves (SPAD unit)

Mineral Fertilization (Kg ha ⁻¹)	Silicon concentration (ml L ⁻¹)			Means
	Si ₀	Si ₁	Si ₂	
M ₀	43.61	45.80	47.06	45.49
M ₁	48.42	53.08	54.81	52.10
M ₂	51.28	54.41	55.78	53.82
Means	47.77	51.10	52.55	

LSD_{0.05} Silicon (Si) = 0.783

LSD_{0.05} mineral fertilization (M) = 0.783

LSD_{0.05} Si × M Interactions = 1.357

Biological yield (ton ha⁻¹)

The results in Table 5. show that the addition of mineral fertilizers (NPK) at a level of 100% M₂ significantly increased the average biological yield, which reached (16.418-ton ha⁻¹), with an increase of 36.38% compared to the treatment without the addition of mineral fertilizers M₀, which reached (12.038-ton ha⁻¹). The reason for this superiority is attributed to the fact that fertilization contributes to increasing plant growth, increasing the vegetative mass and leaf area (Table 3), and thus increasing the plant mass and the accumulation of carbon assimilation products, which increases the weight of the biological yield [20]. These results are consistent with [21], which showed a significant effect of mineral fertilization on increasing the biological yield of maize.

The results in the table also showed significant differences in the average biological yield when foliar spraying with silicon was applied. Spraying with a concentration of

(6 ml L⁻¹) significantly outperformed, giving the highest average of (15.173-ton ha⁻¹) compared to the control treatment, which reached (13.542-ton ha⁻¹), with an increase of 12.04%. This significant superiority may be due to the role of silicon in increasing

Table (5): Effect of mineral fertilization (NPK), Silicone spray, and their interaction on Biological yield (ton ha⁻¹).

Mineral Fertilization (Kg ha ⁻¹)	Silicon concentration (ml L ⁻¹)			Means
	Si ₀	Si ₁	Si ₂	
M ₀	10.810	12.257	13.048	12.038
M ₁	14.107	14.987	15.426	14.840
M ₂	15.709	16.500	17.045	16.418
Means	13.542	14.582	15.173	

LSD_{0.05} Silicon (Si) = 0.340

LSD_{0.05} mineral fertilization (M) = 0.340

LSD_{0.05} Si × M Interactions = 0.590

the number of leaves and leaf area (Tables 2 and 3). These results are consistent with what [22] found, who showed that spraying with silicon led to an increase in the biological yield of maize. As for the results of the interaction between the study factors, the treatment (M₂Si₂) outperformed, giving the highest average for the biological yield, reaching (17.045 tons ha⁻¹), with an increase of 80.52% compared to the control treatment (M₀Si₀), which reached (10.810 tons ha⁻¹).

Grain yield (ton ha⁻¹)

The results in Table 6 show that the addition of mineral fertilizers (NPK) at 100% of the fertilizer recommendation (M₂) significantly increased the average grain yield, which reached 7.827 tons ha⁻¹, with an increase of 50.28% compared to the treatment without mineral fertilizer addition (M₀), which was 5.208 tons ha⁻¹. This superiority may be attributed to the fact that mineral fertilization provides the plant with nutrients, thereby increasing the ability of carbon assimilation, which supports the processes of protein and carbohydrate synthesis, and consequently increases the total grain yield [23, 24].

The results in the table also showed significant differences in the average grain yield with foliar spraying of silicon. Spraying with a concentration of (6 ml L⁻¹) significantly outperformed, giving the highest average of (7.112-ton ha⁻¹) compared to the control treatment, which was (6.120-ton ha⁻¹), with an increase of 16.20%. This may be due to the role of silicon in increasing the yield components that determine the increase or

decrease in the grain yield of maize. These results are consistent with [25], who indicated that increasing the concentration of silicon spraying led to an increase in grain yield in maize.

As for the results of the interaction between the two study factors, the treatment (M_2Si_2) outperformed, giving the highest average grain yield of 8.250-ton ha^{-1} , with an increase of 80.52% compared to the control treatment (M_0Si_0), which was 4.570 ton ha^{-1} .

Table (6): Effect of mineral fertilization (NPK), Silicone spray, and their interaction on grain yield (ton ha^{-1})

Mineral Fertilization (Kg ha^{-1})	Silicon concentration (ml L^{-1})			Means
	Si_0	Si_1	Si_2	
M_0	4.570	5.317	5.737	5.208
M_1	6.477	7.057	7.350	6.961
M_2	7.313	7.917	8.250	7.827
Means	6.120	6.763	7.112	

LSD_{0.05} Silicon (Si) = 0.077

LSD_{0.05} mineral fertilization (M) = 0.077

LSD_{0.05} Si × M Interactions = 0.134

These results allow us to conclude that mineral fertilization (NPK) and foliar spraying with silicon promote vegetative growth, which enhances photosynthesis, thereby improving the composition of crop components, ultimately improving grain yield and corn quality. The interaction between mineral fertilization (NPK) and foliar spraying with silicon was found to be the most responsive in improving corn growth, yield, and quality.

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