

Effect of spraying with Nano-Silicon, Irrigation Intervals and Cultivars, and Their Interactions on Some Growth Traits of Soybean (*Glycine max L.*)

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ABSTRACT

The purpose of the field experiment was to examine the influence of spraying with Nano-Silicon, irrigation frequency, cultivars, and their interaction on some vegetative growth characteristics of soybean (*Glycine max L.*) under the conditions of agriculture season 2024 in one of the experimental fields of Al-Musaib Mashrue, Babylon Government, Iraq. There were three levels of Nano-Silicon (0, 2, and 4 ml L⁻¹), three irrigation periods (6, 8 and 10 days), and three cultivars of soybean (Shaimaa, Warka and Rami). It was a three-replication split-split plot design of a randomized complete block design (RCBD). The results showed that spraying with 4 ml L⁻¹ of Nano-Silicon significantly increased plant height (139.04 cm plant⁻¹), number of branches (10.22 branches plant⁻¹), and leaf area (119.35 cm² plant⁻¹), compared to the control treatment (spraying with distilled water). Among cultivars, Shaimaa exceeded Warka and Rami, recording the highest averages for most studied traits. Regarding irrigation intervals, irrigation every 6 days gave the highest means of plant height, number of branches, and leaf area compared to 8- and 10-day intervals. The interaction between Shaimaa cultivar, spraying with 4 ml L⁻¹ of Nano-Silicon, and irrigation every 6 days achieved the highest values for all traits under study, indicating the importance of integrating Nano-Silicon spraying with proper irrigation management and cultivar selection to improve soybean growth performance under local conditions.

Keywords: Nano-Silicon, Soybean, Irrigation Intervals, Shaimaa

1. Introduction

The soybean (*Glycine max L.*) is regarded as one of the most significant leguminous crops of immense economic importance, since the seeds provide high amount of protein (30-50%), and oil (14-24%). Moreover, it contains high amounts of unsaturated fatty acids e.g. oleic and linoleic acids, most essential amino acids and various vitamins that are vital. However,

soybean production is often constrained by environmental stresses, particularly water scarcity during the summer season due to limited water resources and elevated temperatures. Therefore, increasing attention has been directed toward selecting cultivars with a broad genetic base and early maturity to escape water deficit conditions. Among the promising strategies to mitigate these challenges is the application of silicon, which plays a pivotal role in enhancing plant tolerance to various biotic and abiotic stresses. Silicon contributes to the formation of a protective layer in the cell walls of leaves, thereby reducing water loss and protecting plants against heat stress. Moreover, it takes part in various physiological functions, that is, growth, photosynthesis, cellular metabolism, protein synthesis, stomatal control and gas exchange. Silicon also increases the plant defense mechanism against diseases, increases the activity of the antioxidant compounds and enzymes, increases nutrient uptake and translocation, and lowers the rate of transpiration (Al-Bayati, 2003). Globally, the United States of America ranks first in soybean production, contributing about 66% of total world output, followed by Brazil with 16% and China with 13%. Other contributions come from Argentina, Japan, Indonesia, Korea, Germany, France, and Romania. At the Arab world level, soybean cultivation is concentrated mainly in Egypt, which accounted for 75.95% of the total cultivated area in 1998, followed by Syria (18.77%) and Iraq (5.26%). These three countries therefore represent the primary Arab producers of soybean up to 2018 (Arab Organization for Agricultural Development, 2019).

Foliar spraying of nutrients has particular importance under the conditions of central and southern Iraq, where soils are typically alkaline and rich in carbonates and clay, factors that limit nutrient availability to plants. Foliar feeding thus provides an effective alternative, as the fundamental mechanism of nutrient absorption through leaves is comparable to that through roots. The key process involves the movement of nutrients across cellular membranes, driven by water potential differences between the spray solution and the leaf tissue (Abdul-Qadir *et al.*, 1990).

2. Material and methods

A field experimental was conducted on the year 2024 Babylon Government, the Al-Musaib district, the soybean (*Glycine max* L.), in a private field during the agriculture season to examine the impact of foliar spraying with nano-silicon, irrigation schedules, varieties, and their interactions on some growth characteristics of the soybean. The experiment was designed as a split-split plot arrangement within a Randomized Complete Block Design (R.C.B.D) with three replications. The main plots were assigned to irrigation intervals (every 6, 8, and 10 days), the sub-plots to cultivars (Shaimaa, Warka, and Rami), and the sub-sub plots to Nano-Silicon concentrations (0, 2, and 4 ml L⁻¹). The total number of experimental units was 81.

2.1. Soil Preparation and Planting

The field was plowed, leveled, and prepared according to standard agricultural practices. Sowing took place on 15/4/2024, with a row spacing of 75 cm and plant spacing of 25 cm within the row. Each cultivar was planted in four rows per plot, and thinning was performed to maintain one healthy plant per hill after full emergence. Weeds (*Cyperus rotundus* L. and *Portulaca oleracea* L.) were manually controlled throughout the season

2.2. Fertilization

Nitrogen fertilizer (urea 46% N) was applied at a rate of 160 kg N ha⁻¹ in two equal splits: the first at sowing and the second during flowering. Phosphorus fertilizer (superphosphate, 21%

P₂O₅) was applied at 80 kg P₂O₅ ha⁻¹ before sowing and incorporated into the soil. These rates were determined according to previous recommendations (Hussein, 2015, Al-Dulaimi, 2017).

2.3. Nano-Silicon Spraying

Nano-Silicon treatments were applied as foliar sprays at concentrations of 0 (control, distilled water only), 2, and 4 ml L⁻¹ until complete leaf wetness using a hand sprayer. The first spraying was at 14 days after sowing, and the second at 40 days after sowing (Singh et al., 2013).

Studied Traits:

1. Plant height (cm): Measured from the soil surface to the tip of the plant at harvesting stage, using the average of six randomly selected plants per plot.
2. Number of branches per plant : Determined by counting the branches of six randomly selected plants per plot before flowering.
3. Leaf Area per Plant (dm² plant⁻¹) : The disc method was used to measure the leaf area at the onset of flowering stage. A total of 40 leaf discs (1.6 cm diameter) were gathered on the leaves of 40 leaves of 5 plants (in the middle 2 rows that were in each experimental unit). The dry weights of the leaves and discs were then compared and their weights noted individually. The computation of the leaf area was done based on the following equation (Johnson and Harris, 1967) =

$$\text{Leaf area per plant} = \frac{\text{Dry weight of plant leaves}}{\text{Dry weight of discs}} \times \text{Total disc area}$$

Results

Table 1 : The effect of Nano-Silicon spraying, irrigation periods, cultivars, and interactions with cultivars on the spring 2024 soybean plant height (cm plant⁻¹).

2024					
Nano-Silicon MI L ⁻¹	cultivars	day/ irrigation intervals			silicon X cultivars
		6	8	10	
0	shaimaa	130.51	130.46	129.99	132.57
	warka	130.40	130.17	129.74	131.85
	Rami	130.39	129.28	128.40	129.36
2	shaimaa	137.21	135.93	135.58	133.43
	warka	133.15	131.67	131.14	131.65
	Rami	132.76	131.31	130.51	130.08
4	shaimaa	139.04	136.10	135.75	136.96
	warka	134.69	133.81	132.24	134.24
	Rami	134.65	133.46	132.15	130.31
L.S.D 5%		1.12			0.65
					Cultivars means
irrigation intervals X cultivars	shaimaa	135.58	132.76	132.64	133.66
	warka	134.17	131.59	131.55	132.44
	Rami	133.77	130.80	130.59	131.72
L.S.D 5 %		0.69			0.37
					Silicon means
Silicon X	0	130.50	129.87	129.37	129.91
	2	134.37	132.97	132.41	133.25

2024					
irrigation intervals	4	136.12	134.46	133.38	134.65
L.S.D 5%		0.65			0.41
irrigation intervals means		133.66	132.43	131.72	
L.S.D 5%		0.51			

Table 2 : The effect of Nano-Silicon spraying, irrigation periods, cultivars, and their interactions in the yield of soybean in terms of number of branches per plant in the spring of 2024.

2024					
Nano-Silicon ml L ⁻¹	cultivars	day/ irrigation intervals			silicon X cultivars
		6	8	10	
0	shaimaa	9.22	9.20	9.10	9.51
	warka	9.20	9.20	9.10	9.25
	Rami	9.10	9.10	8.88	9.10
2	shaimaa	9.80	9.77	9.33	9.70
	warka	9.55	9.47	9.22	9.41
	Rami	9.44	9.22	9.10	9.18
4	shaimaa	10.22	10.00	9.88	10.29
	warka	9.90	9.78	9.66	9.62
	Rami	9.40	9.47	9.22	9.22
L.S.D 5%		0.67			0.40
					Cultivars means
irrigation intervals X cultivars	shaimaa	10.07	9.59	9.48	9.71
	warka	9.56	9.52	9.22	9.43
	Rami	9.35	9.30	9.21	9.29
L.S.D 5 %		0.40			0.22
					Silicon means
Silicon X irrigation intervals	0	9.22	9.17	9.10	9.17
	2	9.85	9.49	9.22	9.43
	4	10.17	9.75	9.58	9.83
L.S.D 5%		0.35			0.27
irrigation intervals means		9.64	9.48	9.30	
L.S.D 5%		0.20			

Table 3. Effect of Nano-Silicon spraying, irrigation intervals, cultivars, and their interactions on leaf area (cm² plant⁻¹) of soybean during the spring season of 2024

2024					
Nano-silicon Ml L-1	cultivars	day/ irrigation intervals			silicon X cultivars
		6	8	10	
0	shaimaa	112.59	111.66	110.73	111.66
	warka	110.52	110.20	109.63	110.11
	Rami	110.21	109.81	109.57	109.86
2	shaimaa	116.59	115.99	115.64	114.09
	warka	111.56	111.50	111.44	111.50
	Rami	111.29	110.84	111.42	111.18
4	shaimaa	119.35	116.33	114.63	116.77
	warka	112.94	112.64	112.17	112.53

2024					
	Rami	112.28	111.99	112.01	112.15
L.S.D 5%		1.03			0.62
					Cultivars means
irrigation intervals	shaimaa	116.17	114.66	113.68	114.84
X	warka	112.66	111.77	111.34	111.91
cultivars	Rami	111.31	111.19	111.08	111.25
L.S.D 5 %		0.66			0.33
					Silicon means
Silicon	0	111.11	110.55	109.98	110.55
X	2	113.15	112.78	112.85	112.92
irrigation intervals	4	114.86	113.65	112.94	113.81
L.S.D 5%		0.54			0.43
irrigation intervals means		114.04	112.33	111.92	
L.S.D 5%		0.35			

Discussion

1. Plant Height (cm)

The results (Table 1) showed significant differences ($p \leq 0.05$) among cultivars in plant height during the cultivar season of 2024. The Shaimaa cultivar recorded the highest mean (132.44 cm), followed by Warka (131.72 cm), while Rami recorded the lowest mean (128.40 cm). The differences in plant height among cultivars may be attributed to their genetic variability and their ability to absorb nutrients and utilize solar radiation, leading to differences in photosynthetic efficiency (Zigan *et al.*, 2018).

In terms of Nano-Silicon concentrations, the maximum plant height (134.65 cm) was achieved by spraying the plants with 4 ml L⁻¹ whereas the lowest height (129.91 cm) was achieved in the treatment that used only distilled water (control). The increase in plant height with Nano-Silicon spraying is attributed to its role in enhancing cell wall strength, improving light interception, and increasing photosynthetic activity (Kamindiou *et al.*, 2010).

The irrigation intervals also had significant effects ($p \leq 0.05$). Irrigation every 6 days resulted in the tallest plants (133.66 cm), while irrigation every 10 days gave the lowest value (131.72 cm). The reduction at longer intervals is likely due to lower soil moisture, which decreases cell expansion and photosynthetic efficiency (Morsy *et al.*, 2018).

The three-way interaction among cultivar, nano-silicon, and irrigation intervals showed that Shaimaa cultivar with 4 ml L⁻¹ Nano-Silicon and irrigation every 6 days produced the tallest plants (139.04 cm), whereas Rami under control treatment and 10 day irrigation interval gave the lowest plant height (128.40 cm).

2. Number of Branches per Plant

Table 2 revealed that the cultivars had significant differences ($p=0.05$) in the number of branches. Shaimaa had the highest average of (9.71 branches plant⁻¹), then Warka (9.43), and lastly Rami (9.29). The variation is due to differences in genetic background and environmental adaptability, as previously reported by (Afif *et al.*, 2010) and (Al-Hasnawi, 2012).

The number of branches was influenced considerably by Nano-Silicon. The maximum mean (9.83 branches plant⁻¹) was achieved with Spraying with 4 ml L⁻¹ and control treatment had the lowest result (9.17). This has been enhanced by the fact that silicon is

known to enhance cell walls, increase water uptake, and efficiency of photosynthesis (Guerriero *et al.*, 2016).

The results further indicated a significant effect of irrigation intervals on the number of branches per plant. The highest mean of 9.64 branches plant⁻¹ was recorded in the first irrigation interval (after every 6 days) in comparison to other intervals with the lowest mean value of 9.30 branches plant⁻¹ being in the third irrigation interval (after every 10 days). This may be attributed to the provision of favorable growth conditions and the maintenance of suitable soil moisture content in the early stages, in addition to accompanying environmental temperature, which collectively enhance plant growth and development. This in turn improves growth traits through increased photosynthetic efficiency, the regulation of enzymatic and metabolic pathways, and enhancement of morphological appearance of the plant. These findings are in line with the findings of (Mahmoud *et al.*, 2013), who had reported the effect of the irrigation intervals on the growth of soybean.

The table of results revealed that significant difference ($p \leq 0.05$) was observed between silicon and irrigation intervals in the fact that when the concentration of 4 ml L⁻¹ was used with an irrigation period of 6 days, the average was the highest of 10.17 branches plant⁻¹, whereas the highest average of 9.10 branches plant⁻¹ was observed in the case of the control and an irrigation period of 10 days.

The table of results also revealed that there were very strong differences in cultivar and irrigation periods whereby the cultivar Shaimaa having an irrigation period of 6 days produced the highest average of 10.07 branches plant⁻¹, whereas the cultivar Rami having irrigation period of 10 days produced the lowest average of 9.21 branches plant⁻¹.

In terms of the three-way interaction between the cultivar and silicon and the period of irrigation, the cultivar Shaimaa at a concentration of 4 ml L⁻¹ silicon and 6 days as the basic irrigation interval recorded the highest average of 10.22 branches plant⁻¹ and the cultivar Rami under the same control condition and 10 days as the basic irrigation interval recorded the lowest average of 8.88 branches plant⁻¹.

3. Leaf Area (cm² plant⁻¹)

The results of Table (3) showed the presence of significant differences ($p \leq 0.05$) among the cultivars, where the cultivar Shaimaa recorded the highest average leaf area per plant during the 2024 growing season, amounting to 114.84 cm² plant⁻¹. This cultivar significantly outperformed the two other cultivars, Warkaa and Rami, which recorded averages of 111.91 and 111.25 cm² plant⁻¹, respectively. The excellent cultivar Shaimaa can be explained by the fact that the number of leaves per plant is more, which also causes the increase of the area of leaves. Such outcome is in line with the reports of (Abd El-Azeiz *et al.*, 2021) and (Salim *et al.*, 2022) who found a difference between soybean cultivars in terms of leaf area.

The same table of results also depicted considerable differences between the concentrations of the nano-silicon concentrations where the highest average (113.81 cm² plant⁻¹) was recorded at the concentration of 4 ml L⁻¹ as compared to the lowest average (110.55 cm² plant⁻¹) at the control treatment (distilled water only). This improvement might be due to the role of silicon in enhancing total chlorophyll content through stimulating enzymatic activity inside chloroplasts, which increases the rate of photosynthesis and subsequently boosts dry matter accumulation in leaves. This, in turn, contributes to increasing leaf area per plant, making them more efficient in capturing light energy, and enhancing chlorophyll synthesis, thereby stimulating the photosynthetic process. These results are consistent with the findings of (Liang *et al.*, 2015, Abdul Qados .2015) and (Moftah

.2015). The results in the table also showed a significant effect ($p \leq 0.05$) from the interaction between cultivars and nano-silicon on the leaf area trait. The combination of the Shiamaa cultivar and a nano-silicon spray at the concentration of 4 mL L^{-1} recorded the highest average of $116.77 \text{ dm}^2 \text{ plant}^{-1}$ and the lowest average of $109.86 \text{ dm}^2 \text{ plant}^{-1}$ was realized in the combination of the Rami cultivar and the control treatment. The results also show that there is a strong impact of the irrigation periods on the leaf area trait. The initial 6 day period of irrigation had an average of $114.04 \text{ dm}^2 \text{ plant}^{-1}$ as compared to the other irrigation periods, the 10 day period had the lowest average of $111.92 \text{ dm}^2 \text{ plant}^{-1}$. This may be due to drought, which leads to a decrease in cell size as a result of the reduced water potential of the leaf tissues. This, in turn, causes the cells to lose their ability to elongate and leads to leaf restriction due to the loss of pressure on the cell walls. These findings are consistent with the results reached by (Morsy *et al.*, 2018) in greenhouses and (Okasha *et al.*, 2020) on common bean plants in their study on the superiority of the first irrigation period regarding the leaf area trait.

These findings indicated that the effect of interaction of nano-silicon and irrigation periods on the trait was also significant. Choosing a 4 mL L^{-1} concentration of nano-silicon and a 6-day irrigation cycle produced the highest average of $114.86 \text{ dm}^2 \text{ plant}^{-1}$ but weight of control treatment and 10 days irrigation produced the lowest average of $109.98 \text{ dm}^2 \text{ plant}^{-1}$. Irrigation periods and cultivars were also found to significantly differ in the results of the table. Shiamaa cultivar which had a 6 days irrigation period was the best cultivar compared with the others as it yielded the highest average of $116.17 \text{ dm}^2 \text{ plant}^{-1}$. Conversely, the Rami cultivar where the irrigation period was 10 days produced the lowest average of $111.08 \text{ dm}^2 \text{ plant}^{-1}$.

Regarding the triple interaction, the combination of the Shiamaa cultivar, the 6 day irrigation period, and the nano-silicon spray at a 4 mL L^{-1} concentration achieved an average of $119.35 \text{ dm}^2 \text{ plant}^{-1}$. Meanwhile, the treatment with the control and the interaction between the 10 day irrigation period and the cultivar Rami gave the lowest average of 110.73 dm^2 of the plant^{-1} .

Conclusion

In summary, our research showed the superiority of the Shaimaa variety, with a concentration of 4 mL L^{-1} and a 6 day irrigation intervals, in terms of plant height, number of plant branches, and leaf area over the two varieties, Warkaa and Rami, and at concentrations of 0 and 2. It also showed superiority over irrigation periods of 8 and 10 days.

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