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Evaluation of Si Fertilization and Spraying of Nano-K and Ca on Si Content, Si Uptake, and Si Use Efficiency of Rice

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Abstract. A study was carried out in Al-Tale'a town (District of 41-Al-Husseiniyah, south of Hilla City) in the Babylon Governorate of Iraq from the 15th of June to the 19th of November 2020 to evaluate the effects of Si fertilization and Nano-K and Nano-Ca spraying on the content and uptake of Si and its use efficiency in rice crops. This experiment was conducted in an effort to determine the This experiment was conducted between the 15th and 19th of June, 2020. (*Oryza sativa* L.). The research was done using a split-plot design, and the parameter distribution was carried out using a randomized full blocks approach (RCBD). The supplied amounts of Si fertilizer served as the major plot, while the concentrations of nano-fertilizer concentrations served as the secondary plot. There were a total of sixteen treatments, and each was replicated three times. The analysis and interpretation of the research's results were conducted using statistical tools. The amount of silica fertilizer was the first variable with four levels: 0 kg ha^{-1}, 100 kg ha^{-1}, 200 kg ha^{-1}, and 300 kg ha^{-1}. The second component was the application of nano-fertilizers, which contained four separate treatment options: the control, nano-potassium, nano-calcium, and nano-(K + Ca). The only treatment option that did not include nano-fertilizers was the control. According to the findings, silica fertilization at a rate of 300 kg ha-1 led to the highest silicon content in grain and straw (0.961 and 0.952)%, as well as the maximum Si-uptake in grain and straw (55.363, 122.337 and 177.700) kg Si ha^{-1}. The use of nano foliar spraying with potassium and calcium produced the highest grain silicon concentration (44.540) kg Si ha^{-1} and total silicon content among all treatments (153.339) kg Si ha^{-1}. Strong interaction between Si fertilization and foliar spraying with nano-K and Ca led in the largest mean of total Si-uptake (179.268) kg Si ha^{-1} and silicon utilization efficiency. This was accomplished by a mixture of silica fertilizer and nano-potassium and calcium foliar sprays. This outcome was achieved by using silica fertilizer in combination with nano-potassium and calcium-containing foliar sprays (66.95)%.

Keywords. Rice, Fertilization ,Silica, Nano-fertilizers, Spray.

1. Introduction

Rice is a plant that stores silicon in significant quantities and derives nutritional advantages from the element as a result. Rice plants have the ability to absorb between 230 and 470 kg Si ha-1 of the element silicon, which is essential for the development of plants and is required in agriculture to boost rice output. Silicon has a number of benefits, including improving the availability of nutrients (nitrogen, phosphorus, potassium, magnesium, and zinc), lowering the toxicity of nutrients (iron, phosphorus, and aluminum), and protecting plants from the effects of both biotic and abiotic stress. In rice soil, the addition of silicon to the soil or plant is beneficial not only for increasing output but also for lessening concerns related to iron toxicity. This is because silicon reduces the amount of iron that is harmful to the plant. Silicon has been shown to boost the mechanical strength of plant stems, which helps prevent crop lodging [1]. Because silicon is not a highly mobile element for plants in the soil, a steady supply of this element is required for the development of plants in a healthy and productive manner at all phases of plant growth.

Silicon enhances the thickness of the culm wall as well as the size of the vascular bundles, which reduces lodging. Silicon increases the thickness of the cell walls of sclerenchyma tissue in the stalk, the shortening and thickening of the interphalangeal internodes, and the increase in Si content in the inferior interphalangeal internodes, which all contribute to mechanical strength [1]. Silicon also shortens and thickens the interphalangeal internodes. The application of silicon to the rice crop dropped the transpiration rate by 30 percent, compared to 20 percent in untreated plants [2]. This was due to the development of a second layer (silicon cuticle) under the leaf cuticle and between the dermis and epidermis cells in the seed coats. Silicon seems to be effective in lowering the rate of transpiration that happens in seed coats. This is because seed coats do not have pores, which is why transpiration occurs mostly via the epidermis of leaves.

[3] discovered an increase in growth indicators and nutrient uptake with increased levels of calcium silicate added to the soil rice, which increased chlorophyll content (12.36, 17.70, and 21.08 %), grain yield (14.71, 20.11, and 22.71 %), and straw yield (11.18, 16.33, and 18.42 %) with the effect of treatment with levels of 60, 10, and 180 kg Si ha-1, respectively, compared to no application.

Si fertilizer is the fourth most critical element for the rice crop in Southeast Asia, behind nitrogen, phosphorus, and potassium [4]. Si fertilizer increases crop growth and productivity because it promotes plant growth, strengthens stalks, promotes early panicle formation, increases the number of spikelets per panicle and the proportion of ripe rice grains, and aids in the maintenance of erect leaves, which are essential for enhancing the rate of photosynthesis. Silicon is essential to the development of the rice hull, which affects the quality of the grain [5].

[6] reported that the use of silicon fertilizers improved growth indicators, yield and yield characteristics as well as rice yield quality. [7] indicated that silicon increased rice grain yield by increasing the number of spikelets per panicle, as well as significantly increasing biological yield and Si concentration in the plant. [8] demonstrated the role of silicon in the tolerance of rice to relatively high temperatures, due to the thermal stability provided by silicon to lipids in cell membranes. In contrast, silicon had a role in relieving freezing stress and promoting plant growth through increased antioxidant activity and decreased lipid peroxidation and membrane permeability through silicon-enhanced water retention in leaf tissues [9].

Because nutrients are salt-based (cations/ anions), they may resist entry into inner plant tissue cells owing to the pore size of the cell wall, which ranges between 5 and 20 nm [10,11]. Thus, nanoparticles aggregate with a diameter smaller than the pore size of the plant cell wall, allowing them to permeate the plasma membrane with relative ease [12,13].

[14] showed that the feasibility of using Nano-fertilizers as an effective strategy for improving fertilizer use in crop systems and achieving sustainable agriculture, through the use of Nano-fertilizers by foliar spray method, particularly Nano-potassium fertilizer (Nano-K; chelated potassium 27 %), which significantly increased the yield and yield components of both rice and soybean.

Calcium is a vital mineral for plants; it plays a crucial role by aiding in the absorption of other nutrients, stimulating plant cell elongation, reinforcing the cell wall, and engaging in enzymatic and hormonal activities. In addition, elevated Ca2+ concentrations may change the development and exclusion of Na+ from the roots of plants under NaCl stress [15]. In addition, roots with high Ca2+ concentrations are often able to maintain steady K+ concentrations, while roots with low calcium concentrations are typically unable to [16,17]. Ca2+ must be present in sufficient amounts in the extracellular media to preserve the selectivity and structural integrity of the cell membrane. Because calcium competes with positively charged ions such as Na+, K+, and Mg2+, an excessive supply of these ions may limit the uptake of calcium by plants.

The current study aims to assessment the role of silica fertilization and spraying of Nano-K and Ca on the content and uptake of Si and use efficiency of Si element in rice crop (*Oryza sativa* L.).

2. Materials and Methods

2.1. Location and Execution of the Experiment

In the Babylon Governorate of Iraq, field study was conducted in Al-Talea'a Township (located in district 41-Al-Husseiniyah, to the south of Hilla City) between the dates of June 15, 2020 and November 19, 2020. According to a randomized complete blocks design (RCBD) and a split-plot design, the concentrations of silica fertilizer were the main plot, and the concentrations of Nano-fertilizer were the sub-plot. This was done in order to compare the two types of fertilizer. Because there were three separate replications of each of the 16 different treatments, a total of 32 trials were conducted. While there were four different degrees of spraying nano-fertilizers, there were only four different levels of silica fertilizer: 0 kg ha^{-1}, 100 kg ha^{-1}, 200 kg ha^{-1}, and 300 kg ha^{-1}.

The experimental field with an area of 328 m^2 was divided into three equal blocks, and each block was divided into 16 experimental units, so that the area of one plot was ($3 \times 2 = 6$ m^2). A soil sample was taken from the field and chemical and physical analyzes were conducted on it [18] in the central laboratory of the College of Agriculture/ University of Baghdad (Table 1).

Table 1. Some chemical and physical characteristics of field soil before planting.

Chemical traits		Value	Unit
pH		7.4	-
EC		2.1	ds m^{-1}
Organic matter		16.0	g kg^{-1}
Calcium carbonate		215	g kg^{-1}
CEC		25.1	$Centimole^{+}$ kg^{-1}
Bulk density		1.4	Mg m^{-3}
Available	N	16.50	mg N kg^{-1}soil
	P	13.00	mg P kg^{-1}soil
	K	290.00	mg K kg^{-1}soil
	Ca	212.12	mg Ca kg^{-1}soil
	Na	752.00	mg Na kg^{-1}soil
	Si	12.35	mg Si kg^{-1}soil
Soil texture		Silty clay loam	

2.2. Plantation and Crop Management

The Rice Research Station in the Al-Mishkhab region of the Najaf governorate approved dry rice seeds of the variety Anber 33, which were planted directly on previously prepared soil on June 15, 2020 at a rate of 120 kg ha^{-1}. Following planting, the soil was covered to avoid its erosion by irrigation water and consumption by birds. After the patching phase (1-3/8/2020), the irrigation water depth was maintained at around 10 cm to guarantee the availability of the adequate quantity of water required for the plant to attain full maturity. The field was deprived of irrigation 15 days previous to harvest, and weeds were eliminated. Following this, the patching process concluded.

2.3. Fertilization

- It is recommended that urea fertilizer be used in three stages: in the first month after planting, 75 kg ha-1 of urea fertilizer should be applied, followed by 150 kg ha-1 of urea fertilizer one month later, and finally 300 kg ha^{-1} of urea fertilizer should be applied (75 kg ha^{-1} was a month after the second addition). 120 kg ha^{-1} of DAP fertilizer (N = 18% and P = 46%) will be applied in two stages: the first (30 kg ha^{-1}) will be applied after 35 days of planting, and the second (30 kg ha^{-1}) will be applied after 65 days of planting (60 kg ha^{-1} after one month of the first addition).
- 0 kg ha^{-1}, 100 kg ha^{-1}, 200 kg ha^{-1}, and 300 kg ha^{-1} of Ultramax Silicate (Granule) (25 percent SiO_2) were treated before planting. Based on the experimental unit's surface area, the application quantities were calculated.

- In the case of Nano-fertilizers, foliar spraying was used to apply Nano Chelated Potassium 27 % and Nano Chelated Calcium 7% in concentrations of 2 g L^{-1} for the first spray before flowering and 3 g L^{-1} for the second spray after 14 days, according to the instructions of the fertilizer manufacturer (KHAZRA, Iran).

2.4. Harvest
The rice crop was harvested on 19/11/2020 when all the plants reached the stage of full maturity and the moisture content of the grains ranged between 18-25 % [20].

2.5. Studied Indicators

- Determination of silicon content in plants according to [18] based on the standard solution of silicon by Atomic Absorption Spectrometry (AAS) (Perkin Elmer type, 5000, USA, USA) by applying the equation:

$$\text{Element (ppm)} = \text{ppm element (from calibration curve)} \times \frac{\text{V}}{\text{Wt}}$$

Where: V = total volume of sample digestion (ml), Wt = dry weight of the sample (g).

- Determination of Si-uptake (kg ha^{-1}) in grains, straws and total according to the equation:

$$\text{Uptake of nutrient (Kg ha}^{-1}) = \frac{\text{Nutrient Conc.} \times \text{Dray matter(Kg ha}^{-1})}{100}$$

Plant of Si-uptake was estimated from the sum of Si-uptake in the grain and straw.

- Silicon use efficiency (%) was calculated according to the equation proposed by [21]:

$$\text{Si use efficiency (\%)} = \frac{\text{Si uptake in treatment} - \text{Si uptake in control}}{\text{Si applied}}$$

2.6. Statistical Analysis
Statistical analysis was performed on the results data using the analysis of variance test. With a 0.05 probability, the Least Significant Difference (LSD) test was used to compare the means of the treatments when there was a significant difference between them [22].

3. Results

3.1. Silicon Content in Grain and Straw
Results of table (2) indicated that significant differences were recorded for the mean of grain content of silicon by the effect of silica fertilizer. Silicon content increased with the increase in the level of fertilization and in a direct manner, so the highest mean was 0.961 % at the highest level of silica fertilizer (300 kg ha^{-1}) compared with the lowest silicon content recorded by the control plants was 0.686 %. This is due to the fact that rice is a plant that collects silicon and requires it in a high proportion, and its content increases exponentially with the increase in the level of the element applied to the soil [23].
The treatment with Nano-K recorded the lowest silicon content 0.800 % compared with the significantly higher content of the untreated plants, which scored 0.812 %, for a reason due to the nutritious and supportive role provided by Nano-fertilizers in increasing the plant's ability, especially the root group, to uptake nutrients from the soil.
The interaction of the two components in the research resulted in the greatest mean silicon concentration in the grains (0.979%) and a substantial superiority over all other combinations of the mean grain content of silicon, including the control combination (0.690%).
It was noticed from results presented in table (2) that the straw content of silicon increased significantly with the increase of the silica fertilization level from 0.741 % for the control plants to 0.952 % for the plants treated with 300 kg ha^{-1} of silica. This result is normal in itself and is consistent

with was mentioned above. Moreover, rice is a Si-accumulator plant and a crop with a high requirement for it [24].

The Nano-(K+Ca) treatment made straw with the lowest silicon content, which was 0.809 percent. This was a big difference from the control treatment, which made straw with the highest silicon content, which was 0.828 percent. The stimulation done by nanocomposites is meant to encourage vegetative growth and improve the absorption of extra amounts of nutrients to meet the plant's needs and keep its bio activities going because its needs are growing [25,26,27]. This is done with the help of enzymes that speed up the transfer of macro and micro nutrients.

Nanoparticles may bind to protein carriers that can pass through cell barriers, according to [28]. Making the stem larger and increasing the number of vessels in the xylem and phloem makes it easier for materials to pass through the plant. The interaction between silica fertilizer and Nano-K produced the greatest significant mean of straw silicon content of 0.968 % with its combination of silica at 300 kg ha-1 with Nano-K, compared to the content recorded by the control combination, which was 0.790 %.

Table 2. Effect of Si fertilizer and spraying of Nano-fertilizers on Si content in grain and straw (%).

	Silica fertilizer (kg ha^{-1})	**Spraying of Nano-fertilizers (g L^{-1})**				**Mean**
		Control	**K**	**Ca**	**K + Ca**	
Grain	0	0.690	0.669	0.663	0.722	0.686
	100	0.747	0.723	0.737	0.731	0.735
	200	0.840	0.829	0.850	0.829	0.837
	300	0.969	0.979	0.977	0.920	0.961
	Mean	0.812	0.800	0.807	0.801	
	L.S.D $_{(0.05)}$	A = 0.0018		B = 0.0018		AB = 0.0037
	Silica fertilizer (kg ha^{-1})	Spraying of Nano-fertilizers (g L^{-1})				Mean
		Control	K	Ca	K + Ca	
Straw	0	0.790	0.723	0.718	0.731	0.741
	100	0.747	0.743	0.759	0.746	0.749
	200	0.830	0.823	0.836	0.819	0.827
	300	0.946	0.968	0.955	0.940	0.952
	Mean	0.828	0.814	0.817	0.809	
	L.S.D $_{(0.05)}$	A = 0.0015		B = 0.0015		AB = 0.0030

3.2. Si-uptake (kg Si ha^{-1})

Results of table (3) showed that there were significant differences for the mean silicon uptake in the grains by the effect of fertilizing with silica, the mean increased with the increase in the level of fertilization and in a direct manner, the highest mean of 55.363 kg Si ha^{-1} was recorded at the highest level of silica fertilizer 300 kg ha^{-1} versus the lowest mean for silicon uptake in the grains recorded by the control plants was 32.329 kg Si ha^{-1}. This is consistent with the fact that rice is a plant that collects and requires high silicon, and its content increases exponentially with the increase in the level of the element applied to the soil [23]. The treatment with Nano-K and Ca recorded the highest mean of silicon uptake in grains of 44.540 kg Si ha^{-1} compared with the least significant mean of untreated plants, which recorded 39.942 kg Si ha^{-1}, for a reason due to the nutritious and supportive role provided by Nano-fertilizers in activating the vegetative system supporting its root group in uptake of nutrients from the soil.

The interaction between the two factors of the study gave the combination consisting of silica at the highest level with Nano-(K + Ca) the highest mean of silicon uptake in the grains amounted to 56.521 kg Si ha^{-1} and a significant superiority over all other combinations of the mean Si-uptake in the grains, including the control combination with the lowest mean was 29.326 kg Si ha^{-1}. It was also observed from results presented in table (3) that the mean silicon uptake in the straw increased significantly with the increase in the level of fertilization with silica from 98.876 kg Si ha^{-1} for control plants to 122.337

kg Si ha^{-1} for plants treated with 300 kg ha^{-1} of silica. This is explained according to mentioned above in results interpretation of grains. The control treatment achieved the highest mean of silicon uptake in the straw, which was 109.802 kg Si ha^{-1} compared with that achieved by the foliar spray treatments of the Nano-fertilizers, where the Nano-(Ca + K) treatment recorded a mean of 108.799 kg Si ha^{-1}. This is explained by the fact that the accumulation of Si in leaf blades and plant stems reduces the mutual shading and susceptibility of plants to diseases caused by nitrogen deficiency as well as increases its transport from soil to plant by a Bio-transmission mechanism that depends on the positive charge of silicon accumulated in the vegetative parts of the plant [30]. Which explains why the higher Si-uptake with foliar spraying of Nano-K compared with Nano-Ca.

The interaction between silica fertilizer and Nano-K and Ca, it was achieved with the control combination of silica at the level of 300 kg ha^{-1} had the highest significant mean of silicon uptake in the straw was 124.703 kg Si ha^{-1} compared with the lowest significant mean recorded by the control combination which was 99.732 kg Si ha^{-1}. With regard to the total uptake of silicon in the plant, results of table (3) showed that there were significant differences in the mean total Si-uptake by the effect of fertilizing with silica. The mean increased with the increase in the level of fertilization, so it reached the highest mean of 177.700 kg Si ha^{-1} at the highest level of silica fertilizer 300 kg ha^{-1} compared with the lowest mean of total Si-uptake recorded by the control treatment amounted to 131.204 kg Si ha^{-1}, and this is due to the same reasons that were mentioned in interpretation of results in table (3) as it represents an aggregative characteristic of them.

The treatment by Nano-K and Ca recorded the highest mean of total Si-uptake 153.339 kg Si ha^{-1} compared with the least significant mean of untreated plants which recorded 149.744 kg Si ha^{-1}, and the same is due to the same reasons mentioned in the interpretation of results in tables (3).

The interaction between of two factors under study gave by the combination consisting of silica at the highest level with Nano-(K + Ca) the highest mean of total silicon uptake amounted to 179.268 kg Si ha^{-1} with a significant superiority over all other combinations of mean total Si-uptake, including the control combination that gave the lowest mean significantly 129.058 kg Si ha^{-1}.

Table 3. Effect of Si fertilizer and spraying of Nano-fertilizers on Si uptake in grain, straw and plant (kg Si ha^{-1}).

	Silica fertilizer (kg ha^{-1})	**Spraying of Nano-fertilizers (g L^{-1})**				**Mean**
		Control	**K**	**Ca**	**K + Ca**	
Grain	0	29.326	32.701	31.554	35.734	32.329
	100	36.553	36.811	36.840	38.475	37.170
	200	42.246	43.606	44.028	47.429	44.327
	300	51.642	56.836	56.453	56.521	55.363
	Mean	39.942	42.488	42.219	44.540	
	L.S.D $_{(0.05)}$	A = 0.3054		B = 0.3054		AB = 0.6108
	Silica fertilizer (kg ha^{-1})	Spraying of Nano-fertilizers (g L^{-1})				Mean
		Control	K	Ca	K + Ca	
Straw	0	99.732	96.546	97.329	101.894	98.876
	100	101.928	102.314	102.158	101.269	101.917
	200	112.844	112.408	111.371	109.286	111.477
	300	124.703	121.123	120.776	122.747	122.337
	Mean	109.802	108.098	107.909	108.799	
	L.S.D $_{(0.05)}$	A = 0.3198		B = 0.3198		AB = 0.6396
	Silica fertilizer (kg ha^{-1})	Spraying of Nano-fertilizers (g L^{-1})				Mean
		Control	K	Ca	K + Ca	
Plant	0	129.058	129.247	128.883	137.629	131.204
	100	138.481	139.124	138.998	139.745	139.087
	200	155.090	156.014	155.399	156.715	155.804
	300	176.346	177.959	177.229	179.268	177.700
	Mean	149.744	150.586	150.127	153.339	
	L.S.D $_{(0.05)}$	A = 0.6172		B = 0.6172		AB = 1.2344

3.3. Silicon Use Efficiency (%)

The results of calculating the Si use efficiency (Table 4) showed that the combinations of silica fertilizer (100, 200, and 300 kg ha-1) with Nano-(K + Ca) had the highest means for Si use efficiency at 42.75, 55.31, and 66.95 percent, while the control combination of silica fertilizer at the level of 100 kg ha-1 had the lowest efficiency at 37.69 %.

Table 4. Effect of silica fertilizer and spraying of Nano-fertilizers on silicon use efficiency (%) from rice plant.

Silica fertilizer (kg ha^{-1})	Spraying of Nano-fertilizers (g L^{-1})			
	Control	K	Ca	K + Ca
100	37.69	40.26	39.76	42.75
200	52.06	53.91	52.68	55.31
300	63.05	65.20	64.23	66.95

Conclusion

The most important finding of the current study is to increase the content of silicon and its uptake in grains, straws, and plant, and the Si use efficiency with an increase in the level of fertilization with silica, in addition to the significant role of foliar spraying by Nano-K and Ca in increasing Si-uptake in grains and plants, as well as Si use efficiency.

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