Response of Rice (Oryza sativa L.) to Silica Fertilization and Spraying with Nano-Potassium and Calcium

A. M. K. Al-Shahmani and H. W. A. Al-Juthery

1Department of Soil Science and Water Resources, College of Agriculture, University of Al-Qadisiyah, Iraq.

Email: agri.post21@qu.edu.iq

Abstract

In order to assess the response of rice (cv. Anber 33) to silica fertilization and spraying with nano-potassium and calcium in some indicators of growth and yield of the plant, a field study was conducted in Al-Tale'a Township (district of 41-Al-Husseinib, south of Hilla City)/ Babylon Governorate/ Iraq for the period from 15/6/2020 until 19/11/2020. The experiment was carried out according to the split-plot design, and the parameters were distributed according to the arrangement of Randomized Complete Blocks Design (RCBD), where the levels of silica fertilizer were the main plot and the concentrations of the nano fertilizers were the subplot. The number of treatments became 16 treatment, with three replications arrangement of Randomized Complete Blocks Design (RCBD), where the levels of silica fertilizer were the main plot and the second factor represented by spraying nano fertilizers consisted of four treatments: control, nano-K, nano-Ca, nano-(K + Ca). Results showed that fertilizing by silica at a level of 300 kg ha$^{-1}$ recorded the highest means of chlorophyll content (39.59 SPAD), plant height (143.67 cm), weight of 1000 grains (21.04 g), grains yield (5.76 Mg ha$^{-1}$), and harvest index (30.96%). Also, the spraying by nano (K + Ca) achieved the highest means of chlorophyll content (39.71 SPAD), plant height (142.84 cm), weight of 1000 grains (20.92 g), grains yield (5.52 Mg ha$^{-1}$), biological yield (99.18 Mg ha$^{-1}$), and harvest index (29.04%). The interaction between fertilization with silica and spraying by nano (K + Ca) achieved the highest means of growth and yield indicators for rice plants when treated with silica (300 kg ha$^{-1}$) and spraying by nano (K + Ca), it’s reached the chlorophyll content (41.17 SPAD) and plant height (146.60 cm), weight of 1000 grains (21.40 g), grain yield (6.14 Mg ha$^{-1}$), biological yield (19.20 Mg ha$^{-1}$), and harvest index (32.00%) against the lowest means of growth and yield indicators recorded in control plants, it’s reached the chlorophyll content (36.87 SPAD), plant height (133.19 cm), weight of 1000 grains (19.70 g), grains yield (4.25 Mg ha$^{-1}$), biological yield (16.87 Mg ha$^{-1}$) and harvest index (25.19%).

Keywords: Rice, Silica, Nano, Potassium, Calcium.

1. Introduction

1.1. Background

Rice (Oryza sativa L.) is cultivated in 114 countries around the world [1]. It is one of the crops that consumes large quantities of mineral fertilizers in different growth stages [2]. Silicon plays a major role in improving plant growth and increasing its grains yield, and its deficiency can lead to a serious problem in crop production, especially with regard to rice yield [3]. Silicon has a double effect on the plant and soil systems, as it increases the ability of plants to tolerate biotic and abiotic stresses, and increases soil fertility by improving its physical properties in the root zone as well as preserving the nutrients available to plants [4]. Plants uptake silicon from the soil solution in the form of Mono-silicic acid [Si (OH)₄] [5], and its concentration increases in the cell, the solution becomes supersaturated and changes to form a highly polymerized gel, the acid precipitates in the form of amorphous silica (SiO₂-nH₂O), then turns into polymers (Phytoliths) that enter into the cell wall synthesis, which in turn bind with many other biological compounds, they interact with pectin and polyphenol thus enhance the toughness and strength of the cell wall without having a direct role in the plants metabolism process [6].

Nano fertilizers improve crop yields in both quantitative and qualitative terms for their high efficiency in delivering the nutrients needed and necessary for plant growth while reducing the cost of production and thus contributing towards agricultural sustainability. Nano fertilizers enhance the vital processes of plants, growth indicators such as plant height, leaf area, Dry matter production, chlorophyll production, and photosynthesis rate that results in more production and transport of nutrients to different plant parts [7]. Potassium increases the plant’s ability to tolerate drought and reduces the harmful effects on plant growth, it’s regulates the process of opening and closing stomata, as well as regulating osmosis, which improves plant growth, photosynthetic pigments and nutrients, so the activity of the photosynthesis process increases as well as improving the growth of apical tissues that have positive effect in prolonging plant growth, delaying the aging of its organs, and then increasing the yield [8]. Calcium, it has many effects on the biological reactions in plants, as it contributes to the
continuation of cell division because it is included in the components of the cell wall, helps in nitrogen metabolism, and reduce the speed of transpiration as well as its role in the transfer of nutrients from the sites of their production to the areas of their use and activating the action of some enzymes [9]. Therefore, nano fertilizers improve plant metabolism and nutrient uptake through nano pores, which are facilitated by molecular transporters or nanostructured epidermis pores, so the effectiveness of using nano fertilizers increases by an average of 18-29 % compared to traditional mineral fertilizers [10, 11].

1.2. Objectives
The present study aims to assess the response of rice plant towards ground fertilization by silica and foliar spray by nano-potassium and calcium and the interaction between them, and to determine the best fertilizer treatment in achieving the highest indicators of plant growth and yield.

2. Materials and Methods
2.1. The site of the experiment
A field study was conducted in Al-Talea'a Township (district of 41-Al-Husseiniyah, south of Hilla City)/ Babylon Governorate/ Iraq within a latitude (N - 3560050) and a longitude (E - 481907) at an average height of 35 m above the sea level, for the period from 15 / 6/2020 to 11/19/2020.

2.2. The experiment design
The experiment was carried out according to the split-plot design, and the parameters were distributed according to the Randomized Complete Blocks Design (RCBD) arrangement, where the levels of silica fertilizer were the main plot and the concentrations of the nano fertilizers were the subplot. The number of treatments became 16 treatment, with three replications per treatment [12]. The first factor represented by silica fertilizer consisted of four levels: 0, 100, 200 and 300 kg ha⁻¹, while the second factor represented by spraying nano fertilizers consisted of four treatments: control, nano-K, nano-Ca, nano-(K + Ca).

2.3. Preparation of the experiment field
The experiment field was assigned, and the process of orthogonal plowing, smoothing and leveling was performed, and a sample of field soil was taken at a depth of 30 cm from five sites represented by the four sides of the field and the center to be a representative sample of field soil that is characterized as a sedimentary soil with a texture of Silty Clay Loam and its classification as Entisols Torrifluvents according to the modern American classification [13].

The laboratory analyzes of the soil sample were carried out according to the methods presented by [14], it included electrical conductivity (EC) = 3.02 mS cm⁻¹, pH = 7.56, Soluble-N = 24.00 mg N kg⁻¹, Soluble-P = 2.90 Mg P kg⁻¹, Soluble-K = 126.00 mg K kg⁻¹, organic matter = 0.72%. The experiment field, with an area of 328 m², was divided into three equal blocks, and each block was divided into 16 experimental units, the area of one plot (experimental unit) was (3 × 2 = 6 m²) in addition to opening the necessary watering channels for irrigation of the plots (experimental units) and the drainage of the excess water.

2.4. Plantation and Crop Management
Dry rice seeds (cv. Anber 33) certified by the Rice Research Station in Al-Mishkhab district/ Najaf governorate were planted on 15/6/2020, with an amount of 120 kg ha⁻¹ seeds directly on previously prepared soil and then cover it with soil to prevent its erosion with irrigation water and picking it up by birds.

The soil was watered and the irrigation process continued (every 3 days) starting from the irrigation of germination until the patching phase (1-3/8/2020), after that the irrigation water depth was maintained at about 10 cm to ensure the availability of the appropriate amount of water necessary for the growth of the plant to reach the stage of full maturity of plants, the irrigation water was cut off from the field 15 days before harvest, in addition the weeds were removed continuously.

2.5. Fertilization
2.5.1. Full-fertilization [15]
Application of urea fertilizer by 300 kg ha⁻¹ in three batches: the first addition (75 kg ha⁻¹ was a month after the planting process), the second addition (150 kg ha⁻¹ was a month after the first addition), and the third addition (75 kg ha⁻¹ was a month after the second addition). Application of di ammonium phosphate (DAP) fertilizer (N = 18% and P = 46%) by 120 kg ha⁻¹ in two batches: the first addition (60 kg ha⁻¹ after 35 days of planting date), and the second addition (60 kg ha⁻¹ after one month of the first addition).

2.5.2. Silica fertilization
Fertilization with silica Ultramax Silicate (Granule) at levels (0, 100, 200, 300 kg ha⁻¹) was a month after the date of planting. The application quantities were calculated according to the area of the experimental unit.
2.5.3. **Foliar fertilization (spraying) by nano fertilizers**

Nano Chelated Potassium 27% and Nano Chelated Calcium 7% were added in concentration (2 g L\(^{-1}\) for the first spray of each fertilizer before the flowering stage and 3 g L\(^{-1}\) for the second spray of each fertilizer after 14 days of the first spraying, according to the instructions of the fertilizer manufacturer (KHAZRA, Iran) by using the method of foliar spraying on the shoots of the plant (400 L ha\(^{-1}\)), which is equivalent to 1600 g ha\(^{-1}\) of fertilizers in the first spray and 2400 g ha\(^{-1}\) of fertilizers in the second spray.

2.6. **The 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% [16].

2.7. **Studied Indicators**

2.7.1. **Chlorophyll content (SPAD)**

Leaf chlorophyll content (SPAD) was measured using a Portable SPAD-502 chlorophyll meter (MIMOLTA CO. LTD. JAPAN) to obtain a rapid estimate of leaf chlorophyll content simultaneously in the field [17].

2.7.2. **Plant height (cm)**

Plant height was measured using a tape measure, from the level of the soil surface to the highest peak of the plant after flowering.

2.7.3. **Biological yield (Mg ha\(^{-1}\))**

Biological yield estimated by the weight of the harvested plants (after their weight is constant) within the specified square meter of each experimental unit, and then mathematically converted to the Mega gram per hectare [18].

2.7.4. **Grains yield (Mg ha\(^{-1}\))**

Grains yield estimated by the weight of the harvested plant grains (after their weight is constant) within the specified square meter of each experimental unit, and then mathematically converted to the Mega gram per hectare at a moisture content of 14% [18]:

\[
\text{Harvest index (\%)} = \frac{\text{Grains yield}}{\text{Biological yield}} \times 100
\]

2.7.5. **Statistical Analysis**

Results data were analyzed statistically according to RCBD by using the analysis of variance test. The means treatments were compared when the differences between them were significant by using the Least Significant Difference (LSD) test at 0.05 probability level [12].

3. **Results**

3.1. **Chlorophyll content (SPAD)**

Results of Table (1) showed the significant effect of fertilizing with silica and spraying with nano-potassium and calcium on the chlorophyll content in leaves. The fertilization with the highest level of silica used (300 kg ha\(^{-1}\)) achieved the highest mean of chlorophyll content in the leaves reached 39.53 SPAD compared with the mean recorded 38.07 SPAD by untreated plants with silica. The spraying by nano (K + Ca) achieved the highest mean of chlorophyll content in leaves reached 39.71 SPAD compared with 37.89 SPAD for control plants. The interaction between silica with nano-potassium and calcium achieved the highest mean of chlorophyll content in leaves reached 41.17 SPAD, compared with the lowest mean for the trait recorded by untreated plants (control) reached 36.87 SPAD.

| Table 1. Response of rice to silica fertilization and spraying with nano-potassium and calcium in chlorophyll content (SPAD). |
|---------------------------------------------------------------|
| Silica fertilizer (kg ha\(^{-1}\)) | Nano fertilizers spray (g L\(^{-1}\)) | Mean of nano fertilizers |
| A | B | Control | K | Ca | K + Ca |
|---|---|---------|---|---|------|
| 0  | 36.87 | 38.47 | 38.17 | 38.77 | 38.07 |
| 100 | 38.43 | 39.63 | 38.67 | 39.00 | 38.93 |
| 200 | 38.13 | 38.47 | 37.47 | 39.90 | 38.49 |
| 300 | 38.13 | 38.67 | 40.13 | 41.17 | 39.53 |
| Mean of nano fertilizer spray | 37.89 | 38.81 | 38.61 | 39.71 | |
| L.S.D\((0.05)\) | A = 0.017 | B = 0.017 | AB = 0.035 |
3.2. Plant height (cm)

Observed from results of Table (2) the significant effect of silica fertilization (300 kg ha⁻¹) in registering the highest mean of plant height reached 143.67 cm, compared to the lowest mean recorded by the control plants reached 136.33 cm. The spraying by nano (K + Ca) gave the highest mean reached 142.84 cm, compared with the lowest mean for the control plants reached 138.45 cm. The interaction between the study factors also recorded the highest mean of plant height reached 146.60 cm in plants treated with silica (300 kg ha⁻¹) and sprayed with nano (K + Ca), compared with the lowest mean was 133.19 cm in control plants.

Table 2. Response of rice to silica fertilization and spraying with nano-potassium and calcium in plant height (cm)

| Silica fertilizer (kg ha⁻¹) | Nano fertilizers spray (g L⁻¹) | Mean of nano fertilizers |
|----------------------------|-------------------------------|-------------------------|
| A                          | Control | K | Ca | K + Ca |                     |
| 0                          | 133.19  | 136.33 | 137.14 | 138.67 | 136.33              |
| 100                        | 138.63  | 141.14 | 141.16 | 142.01 | 140.74              |
| 200                        | 140.49  | 141.95 | 142.33 | 144.08 | 142.21              |
| 300                        | 141.50  | 142.48 | 144.08 | 146.60 | 143.67              |
| Mean of nano fertilizer spray | 138.45  | 140.48 | 141.18 | 142.84 |                     |
| L.S.D(0.05)                | A = 0.55 | B = 0.055 | AB = 0.110 |         |

3.3. Weight of 1000 grains (g)

Results of Table (3) indicated that fertilization by silica (300 kg ha⁻¹) gave the highest weight of 1000 grains mean was 21.04 g, compared with 20.39 g for the untreated plants by silica. Also, the spraying by nano (K + Ca) recorded the highest weight of 1000 grains mean reached 20.92 g compared to 20.20 g in the control plants. In the same context, the interaction between silica (300 kg ha⁻¹) and spraying with nano (K + Ca) recorded the highest mean for the trait of 21.40 g, compared with the lowest mean for untreated plants (control) reached 19.70 g.

Table 3. Response of rice to silica fertilization and spraying with nano-potassium and calcium in weight of 1000 grains (g)

| Silica fertilizer (kg ha⁻¹) | Nano fertilizers spray (g L⁻¹) | Mean of nano fertilizers |
|----------------------------|-------------------------------|-------------------------|
| A                          | Control | K | Ca | K + Ca |                     |
| 0                          | 19.70   | 20.62 | 20.58 | 20.66  | 20.39               |
| 100                        | 19.86   | 20.71 | 20.69 | 20.74  | 20.50               |
| 200                        | 20.48   | 20.72 | 20.71 | 20.86  | 20.69               |
| 300                        | 20.76   | 21.11 | 20.88 | 21.40  | 21.04               |
| Mean of nano fertilizer spray | 20.20  | 20.79 | 20.72 | 20.92  |                     |
| L.S.D(0.05)                | A = 0.007 | B = 0.007 | AB = 0.013 |         |

3.4. Grains yield (Mg ha⁻¹)

Results of Table (4) showed the significant effect of fertilizing with silica and spraying with nano-potassium and calcium on the mean of grains yield of the rice plant, the fertilization with the highest level of silica (300 kg ha⁻¹) achieved the highest mean reached 5.76 Mg ha⁻¹ compared with the recorded by control plants reached 4.71 Mg ha⁻¹. Also, the spraying by nano (K + Ca) achieved the highest mean of grains yield was 5.52 Mg ha⁻¹, compared with 4.87 Mg ha⁻¹ for the control plants. The interaction between silica with nano-potassium and calcium achieved the highest mean of grains yield was 6.14 Mg ha⁻¹, compared with the lowest mean for untreated plants (control) reached 4.25 Mg ha⁻¹.

Table 4. Response of rice to silica fertilization and spraying with nano-potassium and calcium in grains yield (Mg ha⁻¹)

| Silica fertilizer (kg ha⁻¹) | Nano fertilizers spray (g L⁻¹) | Mean of nano fertilizers |
|----------------------------|-------------------------------|-------------------------|
| A                          | Control | K | Ca | K + Ca |                     |
| 0                          | 4.25    | 4.89 | 4.76 | 4.95   | 4.71                |
| 100                        | 4.89    | 5.09 | 5.00 | 5.26   | 5.06                |
| 200                        | 5.03    | 5.26 | 5.18 | 5.72   | 5.30                |
| 300                        | 5.33    | 5.80 | 5.78 | 6.14   | 5.76                |
| Mean of nano fertilizer spray | 4.87  | 5.26 | 5.18 | 5.52   |                     |
| L.S.D(0.05)                | A = 0.008 | B = 0.008 | AB = 0.016 |         |
3.5. Biological yield (Mg ha$^{-1}$)

Oberved from results of Table (5) the significant effect of silica fertilization (200 kg ha$^{-1}$) in recording the highest mean of biological yield was 18.77 Mg ha$^{-1}$ compared to the lowest mean recorded by control plants reached 18.08 Mg ha$^{-1}$. The spraying by nano (K + Ca) gave the highest mean reached 18.99 Mg ha$^{-1}$ compared to the lowest mean recorded by the control plants was 18.13 Mg ha$^{-1}$. The interaction between the study factors recorded the highest mean of biological yield, which reached 19.20 Mg ha$^{-1}$ when treated with silica (300 kg ha$^{-1}$) and sprayed with nano (K + Ca), compared with the lowest mean was 16.87 Mg ha$^{-1}$ in the control plants.

Also, spraying by nano (K + Ca) recorded the highest mean for harvest index was 29.04%, compared to the lowest mean of 26.84% for the control plants. In the same context, the interaction compared with 26.04% for plants untreated with silica. Also, spraying by nano (K + Ca) recorded the highest mean for the trait was 32.00% compared to the lowest mean of 25.19% in the untreated plants (control).

### Table 5: Response of rice to silica fertilization and spraying with nano-potassium and calcium in biological yield (Mg ha$^{-1}$)

| Silica fertilizer (kg ha$^{-1}$) | Nano fertilizers spray (g L$^{-1}$) | Mean of nano fertilizers |
|-------------------------------|-----------------------------------|-------------------------|
| A                             | Control K Ca K + Ca               |                         |
| 0                             | 16.87 18.24 18.31 18.88          | 18.08                   |
| 100                           | 18.53 18.86 18.45 18.83          | 18.67                   |
| 200                           | 18.62 18.91 18.50 19.06          | 18.77                   |
| 300                           | 18.51 18.31 18.42 19.20          | 18.61                   |
| Mean of nano fertilizer spray  | 18.13 18.58 18.42 18.99          |                         |
| L.S.D(0.05)                   | A = 0.009 B = 0.009 AB = 0.018   |                         |

3.6. Harvest index (Mg ha$^{-1}$)

Results of Table (6) indicated that fertilization by silica (300 kg ha$^{-1}$) gave the highest mean of harvest index reached 30.96%, compared with 26.04% for plants untreated with silica. Also, spraying by nano (K + Ca) recorded the highest mean for harvest index was 29.04%, compared to the lowest mean of 26.84% for the control plants. In the same context, the interaction between silica (300 kg ha$^{-1}$) and spraying with nano (K + Ca) recorded the highest mean for the trait was 32.00% compared to the lowest mean of 25.19% in the untreated plants (control).

### Table 6: Response of rice to silica fertilization and spraying with nano-potassium and calcium in harvest index (%) 

| Silica fertilizer (kg ha$^{-1}$) | Nano fertilizers spray (g L$^{-1}$) | Mean of nano fertilizers |
|-------------------------------|-----------------------------------|-------------------------|
| A                             | Control K Ca K + Ca               |                         |
| 0                             | 25.19 26.80 25.99 26.20           | 26.04                   |
| 100                           | 26.40 26.99 27.08 27.94           | 27.10                   |
| 200                           | 27.00 27.80 28.00 30.01           | 28.20                   |
| 300                           | 28.79 31.69 31.36 32.00           | 30.96                   |
| Mean of nano fertilizer spray  | 26.84 28.32 28.11 29.04           |                         |
| L.S.D(0.05)                   | A = 0.035 B = 0.035 AB = 0.071   |                         |

4. Discussion

The reason behind the significant superiority of the treatment with silica at the highest level (300 kg ha$^{-1}$) with foliar spraying by nano-(K + Ca) were explained on the basis of the synergistic action of the fertilizer treatments in recording the highest means of the studied indicators, the addition of silica fertilizer to the soil led to an increase in the nutrients available of the represented by nitrogen, phosphorus and potassium, which increased their uptake by the plant, which reflected positively on the growth and yield indicators of the plant, and this is consistent with the findings [19] that the increase in the levels of the added Si increased the absorption of Si and other nutrients such as nitrogen, phosphorous and potassium in the biological yield of rice, as well as the role of silicon in reducing the soil’s ability to absorb retaining phosphorus, which increases its available in the soil solution of the plant. Results of the current study regarding the stimulating effect of silica fertilization were consistent with the findings of [20] of the significant role of calcium silicate fertilization at levels (150, 300 and 450 kg Si ha$^{-1}$) to increasing the chlorophyll content, plant height, grains yield, biological yield and harvest index with increasing levels of fertilizer application in a positive manner, respectively, and the reason for this may be due to the specific role of silicon for the production of the rice crop that is one of the plants known to accumulate large amounts of silicon inside (up to about 10% of its dry weight), because the rice of having different silicon transporter genes (such as: LSi1, LSi2 and LSi6) to aid in its transport [21]. On the other hand, the application of silicates to the soil increases the lignification of xylem cell walls, making it more erect [22, 23].

Results of the study also show the synergistic action of nano fertilizers with the aforementioned silica that the use of nano-potassium and nano-calcium fertilizer significantly affected most of the growth and yield indicators of the rice plant (cv. Anber 33). The reason for the increase in plant height due to the action of nano fertilizers is due to the area of the nano fertilizer particles have the large surface areas lead to increased biochemical reactions, peroxidase and catalase leading to...
increased cell divisions, as well as the nanoparticles to reduce or inhibit the formation of reactive oxygen species (ROS), which reduces oxidative damage, delays aging, and encourages plant vegetative growth of the positively reflected increase on its yield characteristics [24], represented by the weight of 1000 grains, grains yield and biological yield, are attributed to the increase in the plant vegetative growth indicators of the rice plant represented by the number of leaves and total leaf area of the plant, which is directly related to the increase in the chlorophyll content as a result of the increase in the surface area exposed to sunlight, all of which is attributed to the role of fertilizer nanoparticles increase the area of enzymatic reactions, activities and their rates, and thus production of raw materials sufficient to continue cell division and encourage nutrient uptake from leaves compared to soil [25], increase the surface area of leaves and their numbers, which is positively reflected in the increase on the yield characteristics [26, 27, 28]. These results are consistent with results of [29] in which the role of nano-potassium was superior in obtaining the highest grains yield of rice cultivars (Tarom Hashemi and Tarom Mahalli), respectively, as well as consistent with results of [30] on the rice plant in which Ca$_3$(PO$_4$)$_2$ NP changes growth and antioxidant responses in a dose-dependent fertilizer, it naturally improves growth and reduces the percentage of free radicals at a concentration of 10 and 20 mg L$^{-1}$, and therefore the nanoparticles interfere with the plant and change its physiological indicators depending on the dose or fertilizer level.

Conclusion

The most important finding of the current study is the recording of the highest means of the target indicators in the rice plant due to the effect of treatment with silica at the highest level and spraying with nano-potassium and nano-calcium, which indicates the synergistic role of fertilizers in providing integrated nutrition for the plant, which in turn achieved the highest indicators for the growth and yield of rice (cv. Ander 33). So this can help reduce the amount of fertilizer applied to crops and reduce the waste of fertilizers and thus pollute the environment due to wrong agricultural practices. However, a detailed physiological and molecular understanding of the effect of these fertilizers, especially nanoparticles, on rice or other crop plants in the future is needed to validate their potential application in agriculture.

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