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Effect of Silicon Amendment on Growth and Nitrogen Status of Common Landscaping Plants

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Abstract

Agriculture and natural vegetations in South Florida face with significant environmental threats such as heat and saltwater intrusion. This study aimed to investigate how silicon application could improve growth parameters and plant health of landscaping plants under extreme temperatures, influenced by global climate changes. Cocoplum (*Chrysobalanus icaco*), cabbage palm (*Sabal palmetto*), satinleaf (*Chrysophyllum oliviforme*), and wild coffee (*Psychotria nervosa*) plants received an initial slow-release fertilizer of 15 g/pot with an 8N-3P-9K composition. Silicon was applied as a 1% silicic acid solution, with concentrations ranging from 0 g/pot to 6 g/pot of 7.5 L. Evaluations were carried out every 30 days, continuing until 180 days after the treatment was completed. Phenotypic traits, including leaf count and plant height, were assessed alongside measurements from handheld optical non-destructive sensors. These measurements included the normalized difference vegetation index (NDVI), SPAD-502, and atLEAF chlorophyll meters. Application of 4 g/pot and 6 g/pot of silicon significantly improved NDVI values (0.78). Conversely, cocoplum plants exhibited greater plant height (79.6) at 0 g/pot silicon compared to other treatments. In wild coffee samplings, the control group showed the highest plant height and SPAD readings (93.49) compared to other treatments. Interestingly, the control treatment also demonstrated a superior atLEAF value as compared to other treatments, while the tallest samplings were observed with 6 g/pot of silicon (62.82) in cabbage palm plants. The findings indicate that silicon application positively influenced plant growth, particularly evident in cabbage palms. However, cocoplum and wild coffee exhibited a negative correlation between plant height and silicon concentrations.

Keywords

Silicon Application, Chlorophyll Content, Cocoplum, Cabbage Palm,

Satinleaf, Wild Coffee

1. Introduction

Specialty crops play a significant role in American agriculture, covering a wide range of produce, such as culinary herbs, fruits, vegetables, spices, tree nuts, medicinal plants, nursery, floriculture, and horticulture crops. According to the 2023 data from the U.S. Department of Agriculture (USDA), farms specializing in these crops accounted for 10% of all farm operations [1]. In 2022, these operations generated approximately $84 billion in cash receipts, representing 15% of the total U.S. agricultural cash receipts [1].

In August 2023, global temperatures surpassed the 20th-century average by 1.25˚C, with projections indicating a further acceleration [2]. Florida has experienced a temperature increase of approximately 1˚C over the past several decades, with forecasts suggesting temperatures could exceed 83˚C within two decades [3]. A yearly sea level rise of approximately 1/8th of an inch as of 2023 exacerbates risks to local ecosystems and inhabitants [4].

Silicon (Si), though considered "quasi-essential", is not indispensable for plant growth. Its accumulation in plants varies significantly between species, primarily due to differences in uptake mechanisms [5]. Additionally, silicon is known to enhance plant resistance to biotic and abiotic stresses and plays a crucial role in nutrient absorption. Studies have highlighted its beneficial impacts across various species and environmental conditions [6], leading to its recognition as a valuable element for plant growth and development [7]. Consequently, the exploration of silicon fertilization effects on crops has become a subject of interest for numerous researchers. Silicon exhibits significant potential in mitigating a broad spectrum of abiotic and biotic stresses [8]. Its application can stimulate plant growth and alleviate multiple stressors, including extreme temperatures, nutritional imbalances, and challenges associated with global climate change [9]. Furthermore, Si plays a pivotal role in enhancing plant resistance against insect pests, as well as fungal, bacterial, and viral diseases, which are major limiting factors impacting crop production worldwide [10].

Recent studies have underscored the advantages of Si application for various plant species across different conditions. Under normal circumstances, Si proves beneficial for plants, such as soybean (*Glycine max* L.) [11], poinsettia (*Euphorbia pulcherrima*) [12], and sugarcane (*Saccharum officinarum*) [13]. In conditions of abiotic stress, it benefits plants such as wheat (*Triticum aestivum* L.) [14], tomato (*Solanum lycopersicum* L.) [15], sugarcane (*Saccharum officinarum* L.) [16], and radish (*Raphanus sativus* L.) [17]. Moreover, in biotic stress conditions, Si aids banana (*Musa paradisiaca* L.) [18] and faba bean (*Vicia faba* L.) [19].

The application of Silicon showed the promise to enhance nutrient availability in the rhizosphere and facilitate root uptake through intricate mechanisms that warrant further elucidation [20]. Furthermore, Si application positively impacts various aspects of nitrogen (N) nutrition, encompassing uptake, assimilation, and remobilization [21]. Additionally, according to reference [22], Si augments nutrient acquisition by roots. Notably, the enhancement of nutrient uptake under suboptimal N supply facilitated by Si has been demonstrated in many plants such as cowpea (*Vigna unguiculata*) [23], maize (*Zea mays*) [24], and rice (*Oryza sativa*) [25].

Other studies indicated that Si significantly contributes to phosphorous (P) nutrition. Two primary mechanisms have been proposed for Si-mediated alleviation of P deficiency: 1) enhanced root uptake and 2) improved utilization of P within the tissues [20]. Increased P uptake following soil Si fertilization has been widely reported [26]-[28]. While the interaction between Si and K in plants has received less attention compared to its interactions with N and P, several studies have demonstrated that Si can influence tissue K concentrations, particularly under stressful conditions like salinity, drought, or excessive nitrogen [26] [29] [30].

The focus of this study revolves around several native Florida plants, namely cocoplum, cabbage palm, satin leaf, and wild coffee, which are extensively cultivated in numerous nurseries and utilized in landscaping across South Florida. However, the production of these species has encountered significant fluctuations attributable to the impacts of climate change. Consequently, it becomes imperative to explore novel approaches to enhance the growth and productivity of these plants. One potential avenue for such enhancement is the application of Si, which merits thorough investigation and consideration within the context of agricultural practices aimed at mitigating the effects of climate change on specialty crop production.

Although numerous studies are available on the benefits of Si application in various plants, limited information is available on the effects of Si on native plants of South Florida, necessitating further investigation. Studying these native plants, particularly those cultivated in nurseries for landscaping purposes, is crucial for developing more resilient plants that are better at nutrient absorption and resistant to pests, diseases, and adverse conditions—a vital consideration given the significant fluctuations in current climatic conditions. This study aimed to investigate how silicon application could improve growth parameters and plant health of landscaping plants under extreme temperatures, influenced by global climate changes.

2. Materials and Methods

The study was performed at the Organic Garden of the Florida International University (FIU), in Miami, Florida, USA. Five native plants were used: cocoplum, cabbage palm, satinleaf, and wild coffee. The plants were cultivated from May until November of 2022 in shade house condition, the plants were irrigated with city water at three times per week. The plants were fertilized with 15 g/pot initial slow-release fertilizer 8N-3P-9K (Harrell's®). The treatments were four concentrations (0 g/pot, 2 g/pot, 4 g/pot, and 6 g/pot) of silicon in the form of 1% silicic acid solution ($SiO_2 \cdot XH_2O$) (Pereira *et al.*, 2010). The treatment was applied around the plant strain (*drench*). Evaluations were conducted at 0 days (one day before treatment) and at 30, 60, 90, 120, 150, and 180 days after treatment (DAT). The analyses performed include:

2.1. Growth Analysis

Every month, five plants per treatment were assessed for leaf count using a counter and for plant height in centimeters using a tape measure. Two branches from each plant, one larger and one smaller, were selected and measured, with the average of these measurements representing the plant's height. Except for the satin leaf, the plant height of the main branch was measured.

2.2. Plant Health Assessment Using Handheld Optical Non-Destructive Sensor Technology

Chlorophyll content of individual plants was measured from five pots per treatment using a SPAD-502 chlorophyll meter (SPAD-502, Japan) and an atLEAF chlorophyll meter (Wilmington, DE). The GreenSeeker™ was used to obtain the normalized difference vegetation index (NDVI). For NDVI measurements, the sensor was positioned 45 cm above the plant canopy. SPAD and atLEAF readings were taken from four mature leaves in the middle section of each plant, and the average values were calculated.

2.3. Statistical Analysis

The experiment was designed as a completely randomized trial with four treatments, each replicated five times using single-pot replications (one plant per pot), resulting in a total of 20 plants per species. Data were analyzed using analysis of variance (ANOVA), and the means were compared using Tukey's test ($p \leq 0.05$) with the SISVAR statistical program [31].

3. Results and Discussion

In this study, silicon fertilization rates were applied to enhance plant growth and mitigate multiple stresses, including extreme temperatures, nutritional imbalances, and climate-related challenges. This was assessed by monitoring growth parameters and using optical sensors to measure chlorophyll content.

Chlorophyll content, indicative of leaf greenness, serves as a proxy for plant photosynthetic activity and overall health [32]-[37]. Optical sensors were thus employed to gauge chlorophyll levels and assess plant vigor. The beneficial impact of silicon on photosynthesis may arise from its protective effects on chloroplasts, increased concentrations of photosynthetic pigments responsible for light absorption, or both [38].

The growth characteristics and sensor parameters did not show significant differences ($p \leq 0.05$) for the interaction between silicon fertilization rate and evaluation period, represented by days after treatment (DAT), for all samplings. Consequently, these factors were evaluated separately.

3.1. Growth Characteristics, Relative Chlorophyll Content (SPAD and atLEAF), and Normalized Difference Vegetation Index (NDVI) of Satinleaf

Silicon fertilization rates were not significantly different in number of leaves, plant height, atLEAF, and SPAD. However, NDVI values were significantly different ($p \leq 0.05$). Using 4 g/pot and 6 g/pot of silicon provided an increase in NDVI (0.78) compared to the control (0.72) in satinleaf plants (Table 1).

Table 1. Number of leaves (NL), plant height, relative chlorophyll content (SPAD and atLEAF), and normalized difference vegetation index (NDVI) of satinleaf grown in different silicon fertilization rates.

Silicon fertilization rate (g/pot)	NL (unit)	Plant height (cm)	atLEAF	SPAD	NDVI
0	122 a	110.4 a	73.65 a	76.69 a	0.72 b
2	108 a	115.6 a	73.16 a	73.47 a	0.77 ab
4	118 a	112.3 a	73.37 a	74.18 a	0.78 a
6	126 a	113.1 a	73.31 a	75.69 a	0.78 a

Note: Means followed by the same letter within columns are not significantly different by Tukey's test ($p \leq 0.05$).

An increase in the number of leaves (146.85 and 131.40) was observed at 60 and 180 DAT, respectively. The highest plant height was recorded at 60 (119.65), and 180 DAT (120.65). 30 DAF provided the higher atLEAF values (77.54). An increase in SPAD values was observed at 150 DAT (80.82). The highest NDVI values were recorded at 0 (0.82), and 60 DAT (0.81) (Table 2).

Table 2. Number of leaves (NL), plant height, relative chlorophyll content (SPAD and atLEAF), and normalized difference vegetation index (NDVI) of satinleaf at 0, 30, 60, 90, 120, 150, and 180 days after treatment.

Days after treatment (DAT)	NL (unit)	Plant height (cm)	atLEAF	SPAD	NDVI
0	93 b	108.9 bc	68.84 c	73.62 bc	0.82 a
30	113 ab	113.5 ab	77.54 a	75.41 b	0.68 c
60	147 a	119.7 a	74.18 ab	73.92 bc	0.81 a
90	110 ab	103.9 c	74.35 ab	74.08 bc	0.70 bc
120	114 ab	109.1 bc	73.87 abc	70.44 d	0.77 ab
150	120 ab	114.3 ab	73.85 abc	80.82 a	0.77 ab
180	131 a	120.7 a	70.98 bc	76.94 ab	0.79 ab

Note: Means followed by the same letter within columns are not significantly different by Tukey's test ($p \leq 0.05$).

This study demonstrated no difference between silicon fertilization rate on the growth parameters, relative chlorophyll content, and normalized difference vegetation index (NDVI) for satinleaf plants. This may have occurred because the mechanism of silicon absorption in dicotyledonous plants is still questioned, since little is known about the absorption and transport of this nutrient in this type of plant, it is known that the absorption potential of this nutrient in monocotyledons is greater.

3.2. Growth Characteristics, Relative Chlorophyll Content (SPAD and atLEAF), and Normalized Difference Vegetation Index (NDVI) of Cocoplum

An increase in the plant height (79.60) was observed using 0 g/pot of silicon (control) compared to the other treatments. However, silicon fertilization rates were not significantly different ($p \leq 0.05$) in number of leaves, atLEAF, SPAD, and NDVI in cocoplum plants (Table 3).

Table 3. Number of leaves (NL), plant height, relative chlorophyll content (SPAD and atLEAF), and normalized difference vegetation index (NDVI) of cocoplum grown in different silicon fertilization rates.

Silicon fertilization rate (g/pot)	NL (unit)	Plant height (cm)	atLEAF	SPAD	NDVI
0	224 a	79.6 a	58.97 a	53.53 a	0.79 a
2	223 a	71.8 b	58.83 a	53.60 a	0.81 a
4	258 a	71.4 b	59.15 a	52.90 a	0.80 a
6	242 a	69.3 b	59.97 a	55.02 a	0.80 a

Note: Means followed by the same letter within columns are not significantly different by Tukey's test ($p \leq 0.05$).

Table 4. Number of leaves (NL), plant height, relative chlorophyll content (SPAD and atLEAF), and normalized difference vegetation index (NDVI) of cocoplum at 0, 30, 60, 90, 120, 150, and 180 days after treatment.

Days after treatment (DAT)	NL (unit)	Plant height (cm)	atLEAF	SPAD	NDVI
0	199 cd	63.8 d	62.17 b	59.15 a	0.81 ab
30	222 abc	66.1 d	66.77 a	58.41 a	0.81 ab
60	310 a	66.5 d	57.97 cd	55.76 ab	0.84 a
90	186 d	73.9 c	59.13 bc	52.53 bc	0.74 c
120	228 abc	76.9 bc	55.26 d	50.41 c	0.80 b
150	244 bc	80.1 ab	57.01 cd	50.11 c	0.79 b
180	268 ab	83.8 a	56.29 cd	49.96 c	0.82 ab

Note: Means followed by the same letter within columns are not significantly different by Tukey's test ($p \leq 0.05$).

The highest number of leaves and NDVI was recorded at 60 DAT (310.10 and

0.84), respectively. The plant height increased at 180 DAT (83.74). An increase in the atLEAF values was observed at 30 DAT (66.77), and an increase in the SPAD values was observed at day 0 (59.15), and 30 DAT (58.41) (Table 4).

3.3. Growth Characteristics, Relative Chlorophyll Content (SPAD and atLEAF), and Normalized Difference Vegetation Index (NDVI) of Wild Coffee

Silicon fertilization rates showed no significant differences in leaf count and atLEAF. However, plant height, SPAD values, and NDVI exhibited significant variations ($p \le 0.05$). The highest plant height was observed in the control (93.49) compared to the other treatments, using 4 g/pot and 6 g/pot of silicon (84.34, and 82.57) respectively, and provided an increase in the plant height compared to 2 g/pot of silicon (70.43). The control provided an increase in SPAD (51.49) than 2 g/pot of silicon (47.95). The highest NDVI was observed using 0 g/pot (Control), 4 g/pot and 6 g/pot of silicon (0.80, 0.81, and 0.82), respectively compared to 2 g/pot of silicon (0.74) in wild coffee (Table 5).

Table 5. Number of leaves (NL), plant height, relative chlorophyll content (SPAD and atLEAF), and normalized difference vegetation index (NDVI) of wild coffee grown in different silicon fertilization rates.

Silicon fertilization rate (g/pot)	NL (unit)	Plant height (cm)	atLEAF	SPAD	NDVI
0	379 a	93.5 a	54.82 a	51.49 a	0.80 a
2	401 a	70.4 c	52.88 a	47.95 b	0.74 b
4	357 a	84.3 b	52.50 a	48.85 ab	0.81 a
6	407 a	82.6 b	52.43 a	49.43 ab	0.82 a

Note: Means followed by the same letter within columns are not significantly different by Tukey's test ($p \le 0.05$).

The highest number of leaves was recorded at 120 DAT (460.75), and the highest plant height at 150 (86.05) and 180 DAT (87.50). An increase in the atLEAF values was observed at 30 (55.58) and 120 DAT (53.76), and an increase in the NDVI values was observed at day 0 (0.84), 60 (0.85) and 90 DAT (0.84). The SPAD values increased at 180 DAT (56.39) (Table 6).

However, for cocoplum and wild coffee, there was a difference between silicon fertilization rate in relation to plant height, where the control treatment provided a higher value for this characteristic compared to Si concentrations (2 g/pot, 4 g/pot, and 6 g/pot). Unlike what was found in this study, prior studies support the positive impact of silicon on growth for some plants in passion fruit [39]; in maize [40]; in wheat [41]. Although Reference [11] found similar trends in which increased Si concentrations reduced the heights in the variety of soybean "Nandou 12" at shade conditions. Reduced plant height can be associated with a significant increase in physiologically active endogenous gibberellin [42].

Table 6. Number of leaves (NL), plant height, relative chlorophyll content (SPAD and atLEAF), and normalized difference vegetation index (NDVI) of wild coffee at 0, 30, 60, 90, 120, 150, and 180 days after treatment.

Days after treatment (DAT)	NL (unit)	Plant height (cm)	atLEAF	SPAD	NDVI
0	374 bc	78.3 b	52.62 ab	45.15 c	0.84 a
30	304 c	81.9 ab	55.58 a	49.30 bc	0.75 b
60	425 ab	81 ab	50.28 b	48.76 bc	0.85 a
90	330 c	91.9 ab	53.15 ab	46.52 c	0.84 a
120	461 a	82.4 ab	53.76 a	47.26 c	0.75 b
150	358 abc	86.1 a	53.19 ab	52.64 ab	0.74 b
180	424 ab	87.5 a	53.52 ab	56.39 a	0.77 b

Note: Means followed by the same letter within columns are not significantly different by Tukey's test ($p \leq 0.05$).

Wild coffee had higher relative chlorophyll content (indicated by SPAD) at a Si fertilization rate of 0 g/pot (control) than at (2 g/pot). For normalized difference vegetation index (NDVI) the control, and fertilization rate of 4 g/pot and 6 g/pot provided higher values for this characteristic. Recent studies show that Si increased the chlorophyll content in some plants, such as onion [43], sorghum [44] and wheat [45].

3.4. Growth Characteristics, Relative Chlorophyll Content (SPAD and atLEAF), and Normalized Difference Vegetation Index (NDVI) of Cabbage Palm

Silicon fertilization rates were not significantly different in relative chlorophyll content (SPAD). However, the number of leaves, plant height, atLEAF, and NDVI were significantly different ($p \leq 0.05$). The control provided an increase in number of leaves (9.23) compared to the 2 g/pot of silicon (7.83), and 6 g of silicon (7.87). The highest plant height was observed using 4 g/pot of silicon (59.94), and 6 g of silicon (62.82) than 2 g/pot of silicon (50.42). The control provided an increase in atLEAF (54.28) compared to the other treatments. An increase in NDVI was observed using 6 g/pot of silicon (0.63), and in the control (0.64) compared to 2 g/pot g of silicon (0.54), and 4 g/pot g of silicon (0.55) in cabbage palm plants (Table 7).

Table 7. Number of leaves (NL), plant height, relative chlorophyll content (SPAD and atLEAF), and normalized difference vegetation index (NDVI) of cabbage palm grown in different silicon fertilization rates.

Silicon fertilization rate (g/pot)	NL (unit)	Plant height (cm)	atLEAF	SPAD	NDVI
0	9.2 a	56.9 ab	54.28 a	49.11 a	0.64 a
2	7.8 b	50.42 b	50.65 b	46.94 a	0.54 b

Continued

4	8.3 ab	59.94 a	49.02 b	47.51 a	0.55 b
6	7.9 b	62.82 a	48.12 b	48.97 a	0.63 a

Note: Means followed by the same letter within columns are not significantly different by Tukey's test ($p \leq 0.05$).

The highest number of leaves, plant height, and SPAD was recorded at 180 DAT (9.85, 67.23, and 52.26), respectively. The atLEAF values increased at 150 DAT (52.93), and the highest NDVI values were observed at day 0 (0.64) (Table 8).

Table 8. Number of leaves (NL), plant height, relative chlorophyll content (SPAD and atLEAF), and normalized difference vegetation index (NDVI) of cabbage palm at 0, 30, 60, 90, 120, 150, and 180 days after treatment.

Days after treatment (DAT)	NL (unit)	Plant height (cm)	atLEAF	SPAD	NDVI
0	6.90 d	51.54 c	48.17 b	45.19 c	0.64 a
30	7.05 d	52.68 c	48.88 ab	47.17 bc	0.52 c
60	7.60 cd	52.03 c	49.98 ab	46.39 bc	0.60 ab
90	8.30 b	53.28 c	51.76 ab	48.56 bc	0.57 bc
120	8.80 b	61.20 b	49.77 ab	47.85 bc	0.59 ab
150	9.10 ab	64.65 ab	52.93 a	49.51 ab	0.58 ab
180	9.85 a	67.23 a	52.13 ab	52.26 a	0.62 ab

Note: Means followed by the same letter within columns are not significantly different by Tukey's test ($p \leq 0.05$).

Cabbage palm had higher relative chlorophyll content (indicated by atLEAF) at Si fertilization rate of 0 g/pot (control) than at other concentrations (2 g/pot, 4 g/pot, and 6 g/pot). For normalized difference vegetation index (NDVI) the control, and fertilization rate of 6 g/pot provided higher values for this characteristic. The normalized difference vegetation index (NDVI) values, which represent green vegetation of a sample, range from 0 to 1. An NDVI value of 0 indicates no green vegetation, while a value of 1 represents maximum greenness. These values correlate with the nitrogen content of plants, photosynthetic efficiency, leaf area index, and plant biomass [32]. Despite the NDVI values being lower for cabbage palm compared to other plants, they were perfectly healthy. This lower index is due to their less dense canopy compared to the other plants in the study.

Plants belonging to the Poaceae, Cyperaceae, and Equisetaceae families exhibit high silicon accumulation (>4% Si), while species from *Brassicaceae*, *Urticaceae*, and *Commelinaceae* show intermediate accumulation (2% - 4% Si). Most other species typically accumulate silicon below 2% [43] [44]. According to reference [45], non-accumulating plants like tomatoes have lower densities of silicon transporters from the apoplast to the symplast and show defects in silicon transporters from cortex cells to the xylem, traits observed in accumulating plants.

Based on the results of this study, it is inferred that the species studied, particularly satinleaf, can be classified as non-silicon accumulating due to the absence of significant treatment effects on the parameters studied. However, it is crucial to note that these outcomes might be attributed to the single application of silicon, which can easily leach as silicic acid. To achieve more precise results, split applications and multiple treatments are recommended.

This study investigated the impact of days after treatment (DAT) on growth parameters (number of leaves and plant height), relative chlorophyll content (measured by atLEAF and SPAD), and normalized difference vegetation index (NDVI) across all plant species studied. Generally, growth parameters showed an increase over the DAT period. In contrast, relative chlorophyll content (atLEAF and SPAD) and NDVI exhibited initial increases followed by stabilization or decline, with exceptions noted in cabbage palm and wild coffee for atLEAF and SPAD, and satinleaf for SPAD, showing higher values towards the end of the DAT period. Further research on silicon application in these plants is crucial to better understand their nutrient absorption dynamics.

4. Conclusion

The study suggests that silicon (Si) can enhance the growth of plants, such as cabbage palms. Nevertheless, some plants can have a negative relationship between plant height and silicon (Si) concentrations, as seen in cocoplum and wild coffee cases. Satinleaf can be considered a non-silicon accumulating plant, as no effect between the treatments for parameters studied was found for this species. However, further studies are needed to better understand the behavior of the studied plants with respect to Si absorption.

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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