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Productivity and carbon accumulation in three varieties of *Glycine max* (L.) Merill grown on soil amended with different levels of silica

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Abstract
Increased plant vigor is advantageous to crops in the face of climate change. Crops with high vigor have higher biomass and carbon accumulation, hence mitigating climate change. Silicon exerts beneficial effects in stimulating plant growth, boosts plant biomass accumulation and crop yield. Soybean is one of the major crops cultivated for both industrial and food purposes on every continent. This study investigated the effect of soil amendment with powdered silica on the growth, biomass accumulation and carbon assimilation of soybean. Seeds of three varieties of soybean, TGX1904, TMX1441 and MAX1951 were sown in polythene pots filled with garden soil after which the plants were treated with three levels of powdered silica (250, 500 and 750g) two weeks after planting in a 3 x 4 x 3 completely randomized design. Parameters evaluated include growth characters, reproductive characters, protein and chlorophyll content, soil organic carbon sequestered and sequestered CO_2 equivalent. Results showed amendment with silica significantly increased plant growth with the 750g silica treatment producing the longest plants and highest numbers of leaf of 13.66±0.17cm and 33.00±1.41 respectively compared to the control setup with mean height of 12.06±0.15cm and 22.39±0.85 leaves ($p < 0.05$). Similarly, the amended soils produced significantly higher numbers of flowers, pods and 100 seed weight with the 750g amendment having 22.33±3.27 flowers compared to 7.22±2.99 flowers in the control, and 38.00±2.91 pods in the 500g amendment compared with 19.67±2.28 pods in the control. In addition, the dry weight of the MAX1951 variety increased with increasing concentration of silica however, the 750g treatment of TMX1441 consistently recorded the highest dry weight (11.20g), total sequestered carbon (5.60g) and sequestered CO_2 equivalent (20.60g). Although treatment with silica did not significantly affect protein and chlorophyll content, it had significant positive impact on biomass and yield traits as well as sequestered carbon.
Keywords: Silica, Carbon, sequester, biomass.

Introduction

Climate change and global warming are both caused by greenhouse gas emissions that cover the earth and trap the sun's heat. Food security and the livelihoods of people involved in production systems and their value chains are impacted by climate change. Despite the fact that food production has doubled over the past three decades, the number of people suffering from hunger worldwide is on the increase, with 25.9% of the world's population either going hungry or without access to nutritious and sufficient amounts of food (5). While tropical regions are predicted to experience a decrease in agricultural productivity as a result of climate change, temperate regions will see an increase (9). However, warming above crop thresholds will result in decreases even in temperate locations (18). Carbon (iv) oxide (CO_2) is a major greenhouse gas and its concentration in the atmosphere is steadily rising, necessitating the need to lower its concentration in the atmosphere. Soils are natural sinks for storing CO_2. Through carbon sequestration, CO_2 is stored and kept from warming the earth's atmosphere and averting climate change. The process entails storing CO_2 in various forms or transferring it from the atmosphere into the soil. According to (10), soil carbon sequestration is also important for improving soil nutrient and increasing resource use efficiency of crop plants to ensure better growth and productivity in a sustainable manner.

Soybean (*Glycine max*) is one of the major crops cultivated for both industrial and food purposes on every continent. Because of its variety of domestic uses, nutritional value, and cheap agricultural input requirements, it is grown in many States in Nigeria. Additionally, it is a significant supplier of vegetable oil on the global market. (16) posited that soybean seeds have an average protein content of 40%, making them one of the most protein-rich food sources available in Nigeria. In addition, the seeds also have an oil content of 20% on a dry matter basis, 85% of which is unsaturated and cholesterol-free. Soybean has the potential to significantly alleviate poverty in rural areas by improving household food and nutrition security, boosting rural earnings, and mitigating the loss of soil fertility (3). Projections suggest that its growth can reach an additional 50% worldwide by 2050 excluding potential growth in the use of soybeans as biofuel which can further increase demand (1). These projections however do not take into account the impact of climate change on the agro-ecological areas of soybean even though climate change is already affecting food security through increasing temperatures, changing precipitation patterns, and increased frequency of extreme weather events. Food security will be increasingly affected by projected future climate change.

Smallholder production is estimated to account for 50-70% of global food production (6) hence play a crucial role in food systems. The long-term sustainability of agricultural systems strongly depends on soil use with better soil management holding the potential to enhance food security. Plants exposed to biotic and abiotic stresses frequently experience a decrease in crop yield as well as plant biomass. Reduction in biomass results in a corresponding reduction in carbon incorporated into biomass formation. (19) reported beneficial effects of Silicon (Si) in stimulating plant growth, particularly those affected by stressful conditions. Through a variety of resistance mechanisms, Si in the rhizosphere and within plants boost plant biomass accumulation and crop yield. Silicon-mediated recovery generally increases plant biomass carbon by 35% and crop yield by 24% (13). In the soil, Si is divided into liquid/adsorbed and solid phases which are normally released through chemical or biological processes. The solid phase Si can be produced from biogenic or non-biogenic forms. Non-biogenic forms results from complexes with metals and/or soil organic matter while biogenic forms are derived from microorganisms and/or plant residues while the liquid phase is composed of polysilicic acids, silicic acid, and organic or inorganic dissolved complexes. (2) explained that the bioavailable form of silicon to plants is silicic acid. Si exerts its protective activity by forming a physical barrier that increases the cell wall's resistance to external stress by precipitating as SiO_2 and integrating with biological structures such as the cell wall (7) there by improving plant Vigor. Increased plant vigor is advantageous to crops in the face of climate change. Crops with high vigor will also have higher biomass and carbon accumulation, hence mitigating climate change. This study therefore sought to investigate the effect of silicon on the growth, biomass accumulation and carbon assimilation of soybean.

Materials and methods

Seeds of three varieties of soybean (TGX1904, TMX1441 and MAX1951) were obtained from the gene bank of the Seed Science Centre of the Federal University of Agriculture Makurdi. Electrical conductivity was used to test the viability of the seeds by weighing three replicates of 20 seeds of each variety and placing in 30ml deionized water. The seeds were soaked for 24 hours at 25°C. The leachate of the water was measured by an electrical conductivity meter.

Soil sample was collected from the Botanical Garden in the Department of Botany, Federal University of Agriculture Makurdi and taken to the Soil Science Laboratory in the Department of Soil Science of the University of Agriculture Makurdi for analysis before planting. The same was done after harvest. Soil samples were further collected from the garden and used to fill up polythene pots for the experiment. Three levels of powdered silica (250, 500 and 750g) along with a control setup were used for the experiment. The experiment consisted of three varieties and four treatment levels replicated three times giving a 3x4x3 completely randomized design. The polythene pots were irrigated after which two seeds of each variety was sown in appropriately labeled pots. Two weeks after germination, the seedlings were treated with powdered silicon by broadcasting the respective concentrations around the plant and on the soil with the exception of the control setup.

Biometric characters for which data was collected included plant height, stem girth and number of leaves. The plant height was measured using a metre rule from the base of the stand to the top while stem girth was measured using a vernier caliper. Both measurements were taken to the nearest centimeters (cm). Number of leaves was taken by physical counting. Reproductive characters measured included number of flowers, number of pods, pod length and 100 seed weight while productivity parameters evaluated included leaf protein content, chlorophyll content, plant biomass, soil organic carbon sequestered and sequestered CO_2 equivalent.

Results and Discussion

Amendment with powdered silica significantly increased plant height, number of leaves and stem diameter with the 750g silica treatment producing the longest plants and highest numbers of leaf of 13.66cm and 33.00 leaves respectively compared to the control setup with mean height of 12.06cm and 22.39 leaves ($p < 0.05$). The largest stem girth resulted from the plants treated with 250g silica powder (Table. 1).

Table 1: Effect of different concentrations of powdered silica on vegetative growth of Soybean varieties

Powdered Silica (g)	Plant Height (cm)	Number of leaves (No.)	Stem Diameter (cm)
Control	12.06 ± 0.15^{c}	22.39 ± 0.85^{c}	1.39 ± 0.04^{b}
250	13.32 ± 0.17^{ab}	30.62 ± 1.24^{b}	1.52 ± 0.06^{a}
500	13.09 ± 0.15^{b}	30.30 ± 1.35^{b}	1.44 ± 0.04^{ab}
750	13.66 ± 0.17^{a}	33.00 ± 1.41^{a}	1.50 ± 0.04^{a}

Values with different superscripts in a column are significantly different; $p < 0.05$

Table 2 shows TMX1441 consistently produced the longest plants (13.48±0.16cm) and highest number of leaves (30.46±1.16) while TGX1904 had the largest stem girth of 1.51±0.05cm (Table 2).

Table 2: Vegetative growth in three Soybean varieties

Variety	Plant Height (cm)	Number of leaves (No.)	Stem diameter (cm)
TGX1904	12.97 ± 0.15[c]	22.39 ± 0.85[c]	1.39 ± 0.04[b]
TMX1441	13.48 ± 0.16[a]	30.46 ± 1.16[a]	1.50 ± 0.04[a]
MAX1951	12.79 ± 0.12[b]	28.02 ± 1.09[c]	1.39 ± 0.04[b]

Values with different superscripts in a column are significantly different; p < 0.05

While the length of pods with both three and two seeds showed no significant difference ($p < 0.05$) between the control and treatment setups (Table 3), the treatments differed in their number of flowers, pods and 100 seed weight with the control having the least number of flowers (7.22 ± 2.99) and pods (19.67 ± 2.28). The 750g silica treatment produced the most flowers (22.33 ± 3.27) while 500g silica produced the highest number of pods (14.25 ± 0.48).

Table 3: Effect of different concentrations of powdered silica on vegetative growth of Soybean varieties

Powdered Silica (g)	Number of flowers (No)	Number of pods (No)	Length of pods with 3 seeds	Length of pods with 2 seeds	100 seed weight
Control	7.22 ± 2.99[b]	19.67 ± 2.28[b]	4.94 ± 0.04[a]	3.17 ± 0.04[a]	14.05 ± 0.34[b]
250	19.78 ± 2.90[a]	31.44 ± 1.98[a]	4.97 ± 0.03[a]	3.21 ± 0.03[a]	13.88 ± 0.62[c]
500	17.22 ± 2.47[ab]	38.00 ± 2.91[a]	4.98 ± 0.03[a]	3.19 ± 0.03[a]	14.25 ± 0.48[a]
750	22.33 ± 3.27[a]	34.44 ± 2.20[a]	5.04 ± 0.04[a]	3.23 ± 0.04[a]	14.02 ± 0.49[bc]

Values with different superscripts in a column are significantly different; p < 0.05

The three varieties showed no significant difference ($p < 0.05$) in their number of flowers, number of pods and length of pods with three seeds. However, the length of pods with two seeds and the 100 seed weight differed significantly with MAX1951 having the longest pods and highest weights of 3.28 ± 0.01 and 15.86 ± 0.12 respectively. TMX1441 had the least pod length (3.13 ± 0.02) and weight of 12.59 ± 0.14 (Table 4)

Table 4: Reproductive growth in three Soybean varieties

Variety	Number of flowers (No)	Number of pods (No)	Length of pods with 3 seeds	Length of pods with 2 seeds	100 seed weight
TGX1904	18.75 ± 2.83[a]	33.33 ± 3.58[a]	5.03 ± 0.03[a]	3.20 ± 0.02[b]	13.71 ± 0.07[b]
TMX1441	17.08 ± 3.10[a]	30.33 ± 2.03[a]	4.98 ± 0.03[a]	3.13 ± 0.02[c]	12.59 ± 0.14[c]
MAX1951	14.08 ± 2.99[a]	29.00 ± 2.70[a]	4.94 ± 0.03[a]	3.28 ± 0.01[a]	15.86 ± 0.12[a]

Values with different superscripts in a column are significantly different; p < 0.05

The protein content was generally higher than both chlorophyll A and B in all three varieties studied with TGX1904 having the highest protein content while MAX1951 had the least (Fig. 1). Similarly, the content of chlorophyll B was generally higher than chlorophyll A in all three varieties with the chlorophyll b content highest in TGX1904 and lowest in MAX1951. Of the three varieties, MAX1951 had the highest chlorophyll A content followed by TGX1904

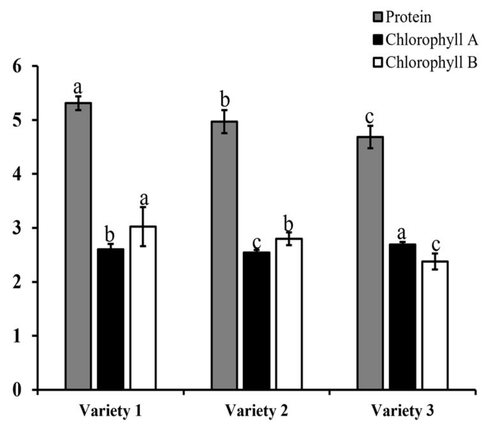

Fig. 1: Mean Protein, chlorophyll A and Chlorophyll B content of three cowpea varieties

The protein content was similar for all the treatment levels and generally higher than chlorophyll A and B. Also, chlorophyll A content showed no significant difference between treatment levels while the 750g silica setup had significantly lower chlorophyll B content compared to all other treatments (Fig. 2).

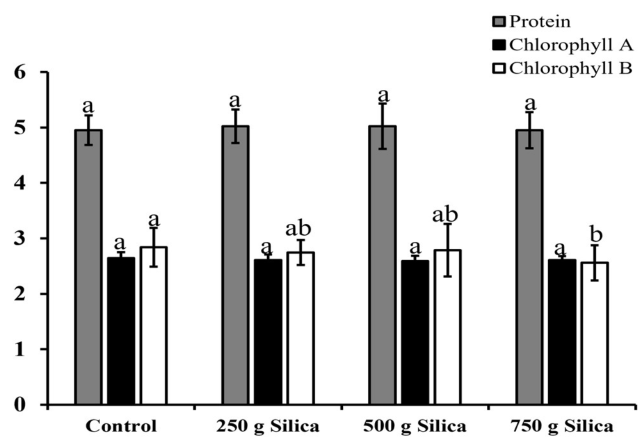

Fig. 2: Protein, chlorophyll A and Chlorophyll B content of three cowpea varieties subjected to different powdered silica treatments

Generally, the percentage soil organic carbon reduced post-sowing across all varieties from 1.43% with the 500g silica of TGX1904 and TMX1441 producing the highest percentage soil organic carbon of 0.78% and 0.70% among all the treatments for the respective varieties. In the MAX1951 variety, the 500g silica treatment resulted in the highest soil carbon of 0.78% compared to the other treatments.

Table 5: Percentage Soil Organic Carbon (%)

TGX1904	TGX1904	TGX1904	TGX1904	TGX1904
TGX1904	0.68	0.40	0.78	0.70
TMX1441	0.68	0.54	0.70	0.54
MAX1951	0.62	0.74	0.54	0.58

Soil carbon pre-sowing= 1.43g

Dry weight of MAX1951 increased with increasing concentration of silica. Total sequestered carbon ranged from 0.90g in the 500g silica treatment for TGX1904 to 2.70g for the 250g treatment while the 750g treatment of MAX1951 produced the highest sequestered carbon of 3.60g. Of the three varieties, MAX1951 produced the highest sequestered carbon across each treatment with the 750g treatment having a total sequestered carbon of 5.60g. Similarly, TMX1441 also produced the highest sequestered CO_2 equivalent across all treatment levels with the 750g producing the highest sequestered CO_2 equivalent (Table 6).

Table 6: Dry weight and sequestered carbon in three soybean varieties

Parameter	Variety	Control	250g Silica	500g Silica	750g Silica
Dry weight of Soybean varieties (g)	TGX1904	2.60	5.40	1.70	4.40
	TMX1441	10.60	7.60	7.30	11.20
	MAX1951	3.00	3.90	4.40	7.10
Total sequestered carbon (g)	TGX1904	1.30	2.70	0.90	2.20
	TMX1441	5.30	3.80	3.70	5.60
	MAX1951	1.50	2.00	2.20	3.60
Sequestered CO_2 Equivalent (g)	TGX1904	4.80	9.90	3.10	8.10
	TMX1441	19.50	13.90	13.40	20.60
	MAX1951	5.50	7.20	8.10	13.00

Treatment with silica was seen to have significantly increased vegetative growth as well as number of flowers and 100 seed weight of the different soybean varieties studied implying that silica enhances plant growth and development. This is in consonance with Hamayun *et al*., (2010) who posited that Silicon has beneficial effects on plant growth and development and promotes growth by altering the levels of endogenous growth hormones. In the same vein, (11,17) also reported the role of Silicon in increasing yield related characters like number such as spikelets, filled spikelet percentage, and total grain yield in rice. Silicon-mediated recovery increases crop yield by 24% (13). Furthermore, Treatment with silica was not seen to significantly affect the protein and chlorophyll A content of the plants, although they exhibited great varietal differences in their protein, chlorophyll A and B content. The dry weight however increased significantly with increasing silica concentration indicative of the growth stimulating capacity of silicon corroborating (13) that silicon-mediated recovery generally increases plant biomass carbon by 35%.

Clearly, amendment with silica increased sequestered carbon in plants treated with silica-treated setups having generally higher carbon content. However, varietal differences were shown to play roles and affect the sequestration ability of plants. The amount of silicon that plants absorb and accumulate varies depending on the composition, uptake processes, forms, and deposition places of the silicon. When soil silicon availability is low, some species increase their active uptake of the element, suggesting an active response to meet plants' internal silicon needs when passive uptake is insufficient (4). Under low Si availability conditions, this is accomplished by increasing the expression of Si transporter genes and the density of these transporters, indicating a truly active uptake that depends not only on active uptake mechanisms but also on physiological responses of these mechanisms (14). Additionally, Si uptake is influenced by rates of transpiration, with some species exhibiting both passive (transpiration-driven) and active (transporter-governed) Si intake (15). According to (12), silicon uptake and accumulation are expected to contribute in some way to the removal of atmospheric CO_2, which in turn regulates the composition of the atmosphere and the global climate.

Conclusion

Although varietal differences play roles in the carbon sequestration ability of soybean, amendment with powdered silica further enhances carbon accumulation in plants thereby ensuring its removal from the atmosphere and its incorporation into biomass formation as well as increased yield.

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