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EFFECTS OF SILICON AMENDMENT ON THE PRODUCTIVITY AND CARBON SEQUESTRATION POTENTIALS OF THREE VARIETIES OF COWPEA (*Vigna unguiculata* L. Walp)

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Abstract
This study determined the effects of silica treatments at different concentrations on the productivity and carbon sequestration potentials of three varieties of cowpea (Honey bean, FUAMPEA 1 and FUAMPEA 2) planted in a replicated multifactorial trial. Data was collected on vegetative growth and yield parameters from week 2 to 10. Dry weight was determined while Total sequestrated carbon (TSC) and sequestered carbon dioxide equivalent (SCO_2E) were computed. Data analysis was done using the Genstat application (17.0 version) for multifactorial analysis. Analysis of variance was conducted while mean separation (post-hoc) was done using Tukey HSD at $P\leq0.05$. From the results, vegetative characters increased progressively from week 2 to 10. Significant varietal differences were recorded in cowpea. Honey bean had the widest diameter and it produced many leaves like FUAMPEA 2 while FUAMPEA 1 was the tallest in height. Significant varietal differences ($P<005$) exist in number of pods and 100 seed weight among the yield characters. FUAMPEA 1 produced the highest number of pods while Honey bean had the largest seed weight. All levels of silica treatments (250g, 500g and 750g) had positive influence on flowering in cowpea. Honey bean variety gave the highest dry weight (8.2g), TSC value (4.7Mg) and SCO_2E (15.0Mg) in 250g silica treatment. Cowpea has demonstrated carbon sequestration potentials although performances depend on the varieties. Duration of planting and type of varieties are important factors that influenced the performances of this legume. The honey bean variety is highly recommended for carbon sequestration when planted in soil amended with 250g silica based on dry weight, TSC value and SCO_2E values. This may help mitigate the effects of climate change.

Key words: Cowpea, Silicon, Productivity, Carbon sequestration, Climate change

Introduction

Cowpea (*Vigna unguiculata* L. Walp) is an important food grain legume for over 200 million people in the dry savanna of tropical Africa. It is particularly important in West Africa with over 9.3 million metric tons of annual production (FAO, 2020). The grain is a good source of human protein, while the haulms are valuable source of livestock protein (Fatokun, 2002). It is also a source of income for many smallholder farmers in sub-Saharan Africa. It contributes to the sustainability of cropping systems and soil fertility improvement in marginal lands through provision of ground cover and plant residue, nitrogen fixation and suppressing weed. However, despite its great importance, grain yield of cowpea crop is low, around 300 kg ha-1 compared with many other crops (Nwokwu, 2020). Low soil fertility has been implicated to cause low yields, as most tropical soils are deficient in essential nutrients particularly N and P (Nwokwu, 2020).

Climate change and environmental stresses can affect the productivity and overall performances of legumes, thereby restricting carbon fixation and vigour (Kovacs *et al.,* 2022). A vigorous growth will undoubtedly result in higher biomass accumulation and ultimately carbon storage. It has been suggested that silicon accumulation in plants may increase the adaptive capacity and performances of plants under abiotic and biotic stresses (Kim *et al*. 2012; Radkowski *et al.,* 2017; Mitani-Ueno and Ma, 2020). Meanwhile, Okoh *et al.* (2023) demonstrated that different levels of silica enhanced the productivity and carbon accumulation of soybean. Cowpea is an important legume crop intensively cultivated by farmers in the study area. The aim of the present study was to determine the effects of silica treatments at different concentrations on the productivity and carbon sequestration potentials of three varieties of cowpea (Honey bean, FUAMPEA 1 and FUAMPEA 2).

Materials and Methods

3.1. Study area

The experiment was carried at the Botanical Garden of the Department of Botany, Joseph Sarwuan Tarka University Makurdi (JOSTUM). Makurdi, the State Capital of Benue State, lies within Longitude $8^0$30'E, $8^0$30'E and Latitude $7^0$30'N, $7^0$43'N. It is a 16km radius circle, covering 804km2 land mass (Onah and Omudu, 2016). Makurdi has an estimated population of 500,797 (The World Gazetteer, 2003). Benue farmers engage in intensive cowpea production. They source their seeds from the JOSTUM where breeding work takes place. This has led to the release of some improved varieties of cowpea and they are freely available to the farmers and researchers.

Seed collection

Seeds of three varieties each of cowpea were obtained from the Seed Store of the Department of Plant Breeding and Science, JOSTUM. The seeds were products of crop improvement programme of the Molecular Biology Laboratory of the University. The seeds were coded V1-V3 for each variety of each plant type as given bellow:

V1= Variety 1= FUAMPEA 1

V2= Variety 2= Honey bean

V2= Variety 3= FUAMPEA 2

Preliminary physicochemical analysis of experimental soil

Soil was collected at Botanical garden of the Department of Botany, Federal University of Agriculture Makurdi, filtered and put into 240 polythene bags each weighing 20kg (Klotzbucher *et al.,* 2017). Soil particles was distributed into clay, silt and silt using Bouyoucous (1951) hydrometer method as given by Udo *et al.* (2009). Soil pH was determined in the laboratory with a calibrated Suntex TS-2 pH meter. Soil organic matter was determined using the gravimetric procedure by Miyazawa *et al.* (2000). Soil nitrogen was determined using the Kjeldahl digestion method Electrical conductivity and Cation exchange capacity (CEC) were determined with a HACH conductivity meter CO-150 and filtration method respectively (Udo *et al.,* 2009).

Experimental design, seed sowing and treatment application

The experiment was conducted in a 3x4 factorial experiment consisting of 3 varieties and powdered silicon at 4 levels of treatments (0, 250, 500 and 750 mg) of 4 replicates per treatment level in a Completely Randomized Design (CRD) structure consisting of 48 experimental units (Olson *et al.,* 2014). Three seeds of each of the variety were sown in pots after the soils were treated with silicon. The plants were treated with powdered silicon by broadcasting around the plant and on the soil Two weeks after germination (Gong *et al.,* 2003).

Collection of growth and yield data

Data on growth, yield and carbon sequestration parameters were collected bi-weekly from week 2 to 10 weeks after planting (WAP) following the method of Gong *et al* .(2003). Growth parameters were evaluated following the methods outlined in Gong *et al.* (2003). They were: plant height, stem diameter and number of leaves. Plant height was measured using a metre rule to the nearest centimeter (cm) from the stand to the top. Stem diameter was measured using a Vernier caliper to the nearest cm. Number of leaves present on plant stands was counted Yield parameters were evaluated following the methods by Abejide *et al.* (2018). They were: Number of flower, Number of pods, Pod sizes, 100 seed weight and Total dry weight (g). Number of flower was counted at flowering stage. Total number of pods produced from each pot was counted at maturity. Pod length was measured using the meter rule in cm. Sizes of ten randomly picked pods were measured and average pod length recorded. The weight of 100 seeds from pods of each variety was taken using the digital weighing balance measured in gram (g). Fresh plant was put in an oven at 68^0 C for one week, and plants were dried until constant weight (Parveen *et al*., 2022). Plant biomass was determined as total dry weight (Oven dry weight) following the methods given by Parveen *et al*. (2022).

Total sequestered carbon in soil and plant

Total sequestered soil carbon was measured using Walkley-Black Chromic acid wet oxidation method (Schaller *et al.,* 2019). Total sequestered carbon in plant biomass was determined as 50% 0f Dry weight of Plant (Zichuan *et al.,* 2019). Harvested plant was dried at constant temperature in the oven for 24 hours and used to determine total organic carbon stock in plant.

Data analysis

Data analysis was done using the Genstat application (17.0 version). Result presentation was done using bar graphs where each bar with error bar represents means ± standard error. Analysis of variance was conducted while mean separation (post-hoc) was done using Turkey HSD. Bars with the same alphabets are not statistically different (p>0.05) from each other while bars with different alphabets are statistically significant (p<0.05).

Results

Soil properties

Physicochemical property of soil samples (table 1) at the pre-planting stage showed that it was sandy (68.6%-69.8%) with little quantity of clay (18.2%-20.3%) and silt (11.0%-12.0%). It was acidic where pH values were between 5.65 and 5.68. Organic carbon content varied from 0.92% to 1.72% while organic matter was between 1.59% and 2.97%. Other parameters and their values were: Nitrogen (0.1%), Mg (2.75-2.90 mol/kg), Ca (2.9-3.1 mol/kg), EA (1.11-1.14 mol/kg), CEC (7.27-7.57 mol/kg) and BS (84.5% -84.9%).

Vegetative growth parameter of cowpea grown in silica treated soils

Periodicity showed significant variation in vegetative characters (figure 1). Values of these characters increased progressively with the weeks. Plant height varied from 14.5±1.43cm (week 2) to 39.55±2.44cm (week 10). Number of leaves varied from 12.5 leaves (week 2) to 56.8 leaves (week 10) while stem diameter varied from 1.0cm to 2.4cm (week 2-10 respectively). Varieties showed significant differences in their vegetative characters (figure 2). Plant height varied significantly across variety. The highest height was found in variety 3 (26.7±2.50) and the least occurred in variety 2. There was no variation in number of leaves in variety 2 and 3. Also, stem diameter was also not significant in variety 1 and 3.There was no significant different (P>0.06) between control and the various silica concentration as growth parameter remained same after treatment (figure 3).

Effect of soil silica treatments on yield parameters of three varieties of cowpea

Number of flowers was significant (P<0.05) in variety1 but not in variety 2 and variety 3 across all treatment (figure 4). Three-seeded pod was significant across all varieties in all treatments but four-seeded pod showed no significant variation across varieties. However, 100 seeds weight was significant across all the varieties. Number of flowers showed significant difference between control and the different silica concentration. However, there was no significant difference among the treatments. There was also no significant difference in number of pods, length of 2,3 and 4 seeds in both control and all treatments There was significant difference between control and different silica concentration in 100 seeds weight (figure 5).

Carbon Sequestration of plants grown in different soil silica concentrations

Table 2 gives the results of carbon Sequestration parameters in cowpea treated with different concentrations of silica. The highest dry weight was found in variety 2 in the control (9.3g) and 250g silica treatments (8.2g) while the least value (2.1g) was found in variety 1 under 750g of silica treatment. Variety 2 had the highest TSC value of 4.7mg and 4.1mg in the control and 250g silica treatment respectively. The same trend was observed in SCO_2E where variety 2 had the highest value in the control (17.1mg) and 250g silica treatment (15.0mg). Variety 3 under the control treatment was the second best in the parameters of carbon Sequestration while variety 1 performed best in 250g silica. The lowest TSC and SCO_2E was recorded in 750g silica concentration in variety 1

Table 1: Pre-planting physico-chemical analysis of soil samples

Soil sample	pH	% sand	% clay	% silt	% organic carbon	% organic matter	% Nitrogen	Mg (mol/kg)	Ca (mol/kg)	EA (mol/kg)	CEC (mol/kg)	% BS
1	5.68	68.8	20.1	11.1	1.72	2.97	0.10	2.80	3.10	1.14	7.57	84.94
2	5.65	69.8	18.2	12.0	0.92	1.59	0.10	2.75	2.90	1.11	7.24	84.67
3	5.67	68.64	20.26	11.0	1.64	2.83	0.10	2.90	3.0	1.13	7.27	84.46

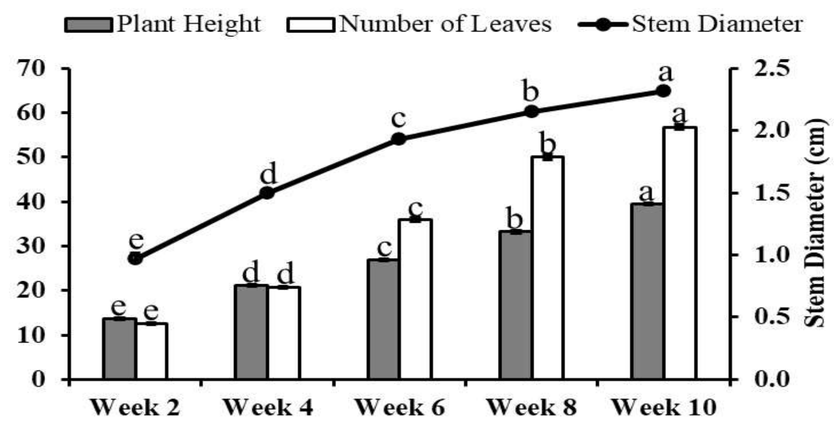

Figure 1: Weekly vegetative growth analysis of cowpea plants grown in silica treated soils

Vertical bars represent means; error bars represent ± standard error. Mean separation (post-hoc) was done using Tukey HSD. Bars with the same alphabets are not statistically different ($p>0.05$) from each other while bars with different alphabets are statistically significant ($p<0.05$).

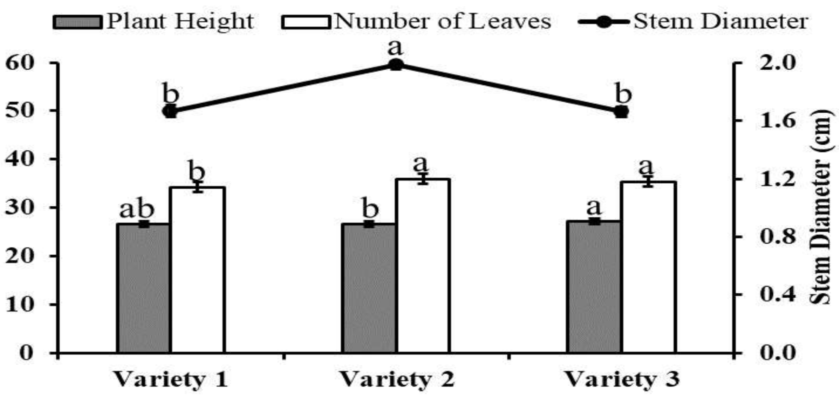

Figure 2: Effect of silica treatments on vegetative growth of three varieties of cowpea
Vertical bars represent means; error bars represent ± standard error. Mean separation (post-hoc) was done using Tukey HSD. Bars with the same alphabets are not statistically different ($p>0.05$) from each other while bars with different alphabets are statistically significant ($p<0.05$).
Variety 1= FUAMPEA 1; Variety 2= Honey bean; Variety 3= FUAMPEA 2

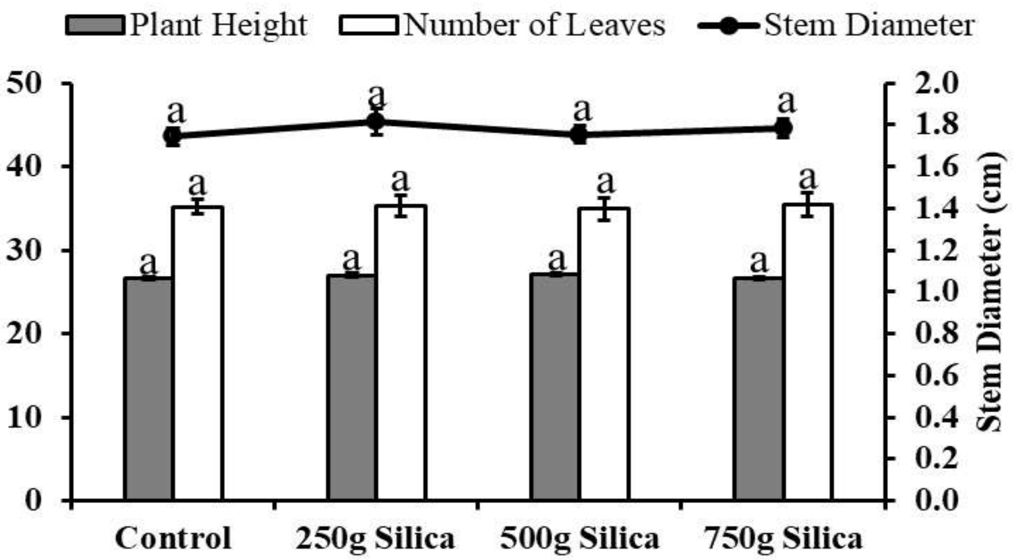

Figure 3: Effect of different concentrations of silica on growth of cowpea
Vertical bars represent means; error bars represent ± standard error. Mean separation (post-hoc) was done using Tukey HSD. Bars with the same alphabets are not statistically different ($p>0.05$) from each other while bars with different alphabets are statistically significant ($p<0.05$).

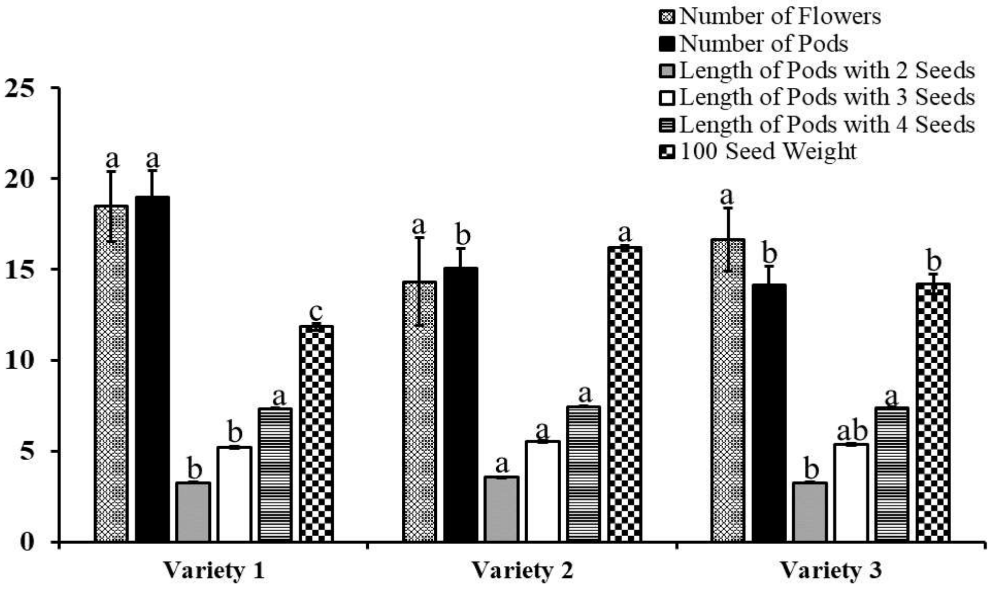

Figure 4: Effect of soil silica treatments on reproductive parameter of three varieties of cowpea
Vertical bars represent means; error bars represent ± standard error. Mean separation (post-hoc) was done using Tukey HSD. Bars with the same alphabets are not statistically different (p>0.05) from each other while bars with different alphabets are statistically significant (p<0.05).
Variety 1= FUAMPEA 1; Variety 2= Honey bean; Variety 3= FUAMPEA 2

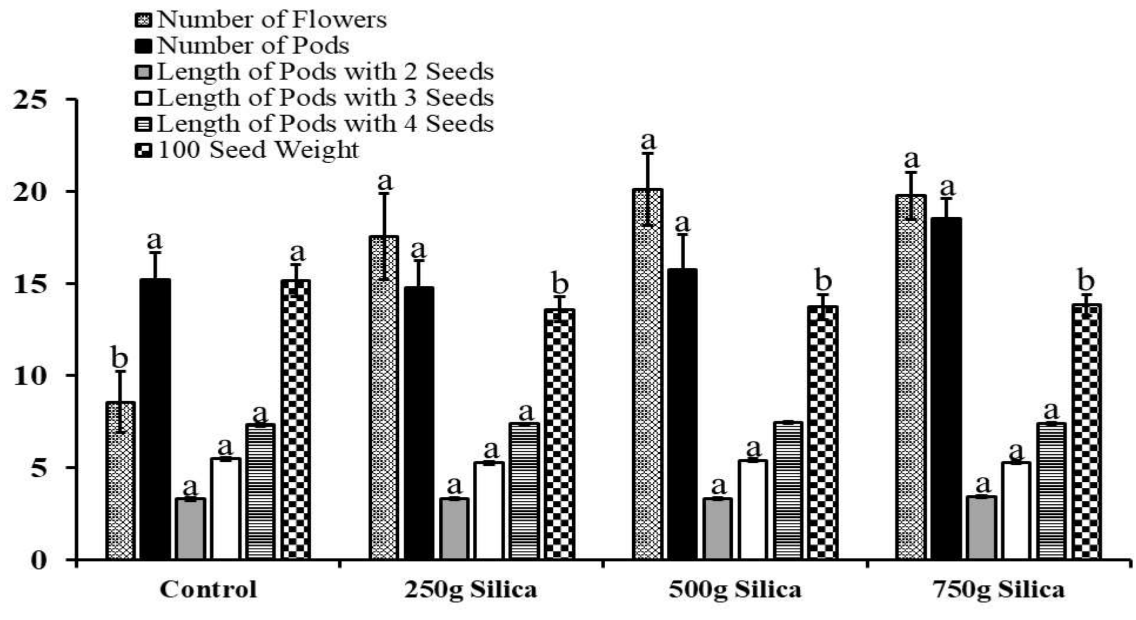

Figure 5: Effect of different concentrations of silica on reproductive parameter of three varieties of cowpea
Vertical bars represent means; error bars represent ± standard error. Mean separation (post-hoc) was done using Tukey HSD. Bars with the same alphabets are not statistically different (p>0.05) from each other while bars with different alphabets are statistically significant (p<0.05).

Table 2: Carbon Sequestration of cowpea grown in different soil silica concentrations

Species	Treatment	Dry Weight (g)			TSC (Mg) (50% Dry Weight)			SCO_2E (Mg)		
		V1	V2	V3	V1	V2	V3	V1	V2	V3
Cowpea	Control	3.4	9.3	5.9	1.7	4.7	3.0	6.2	17.1	10.8
	250g Silica	5.3	8.2	3.2	2.7	4.1	1.6	9.7	15.0	5.9
	500g Silica	5.2	3.3	5.3	2.6	1.7	2.7	9.5	6.1	9.7
	750g Silica	2.1	4.9	5.2	1.1	2.5	2.6	3.9	9.0	9.5

V1= Variety 1= FUAMPEA 1; V2= Variety 2= Honey bean; V2= Variety 3= FUAMPEA 2

Discussion

Cowpea has shown good performances in vegetative features in silica application. This might result from cellular and tissue differentiation during plant development most especially at week 10 that recorded the best plant growth. The progressive increase in vegetative parameter with number of weeks might probably due to an enhanced nutrient uptake potential by the plants as the week progresses. Also, silicon acts as a transporter for photosynthetic pigment (Chen *et al.,* 2011; Saud *et al.,* 2014). In other food crops such as maize, wheat and soybean, silicon amendments was found to improve leaf chlorophyll index, nitrogen uptake and biomas due to improved shoot and root development (Galindo *et al.,* 2021; Okoh *et al.,* 2023). Varietal differences had positive influence on vegetative structures possibly due to genetic factors or interplay of genes and environment (Kovacs *et al.,* 2022). Honey bean was noticeable for its wider diameter and more leaves than other varieties while FUAMPEA 1 had the tallest height. This finding corroborates the work of authors who observed the influence of silica on growth of rice (Réthoré *et al.,* 2020), finger millet (Suma and Urooj, 2012), wheat (Gong *et al* (2005) and soybean (Lee *et al.,* 2019; Okoh *et al.,* 2023). Results aligned with the position that silicon uptake depends on plant species and varieties resulting in significant differences in silicon accumulation (Kovacs, *et al.,* 2022).

Significant varietal differences exist in number of pods and 100 seed weight among the yield characters but not flowering and pod sizes. FUAMPEA 1 produced the highest number of pods while Honey bean had the largest seed weight. Results also showed that all levels of silica treatments (250g, 500g and 750g) performed better than the control in flowering. There was no effect on number of pods, pod sizes and 100 seed weight. The effect of the treatments on reproductive characters of three cowpea varieties was significant as these parameters all varied in the varieties. This infers that silicon treatment resulted in increased number of pods and weight of seeds thus overall yield of cowpea. The increase of yield observed in this study and other studies, after applying silicon, was caused by the improvement of all or some of the yield components. Similar reports were obtained in maize where spike density, number of kernels per spike, and a mass of 1000 grains were significantly improved under different soil amendments (Amin *et al*., 2016). This effect might be attributed to the ability of silicon to prevent transpiration rate and improve many physiological and biochemical processes in plants (Thorne *et al.,* 2021; Kovacs *et al.,* 2022).

Preliminary investigation of the soil samples at the experimental site showed that it was acidic and sandy as aggravated by poor nitrogen, organic carbon content. According to Zhang *et al.,* (2020), soil C sequestration is also necessary for improving soil nutrition status and increasing resource use efficiency of crop plants to ensure better growth and productivity in a sustainable manner. In terrestrial ecosystem, different studies have determined that the main factors influencing the spatial variability of SOC were soil types, climate, topography, land use patterns, tillage practices, and fertilizer application (Zhang *et al.,* 2020). The use of cowpea in this study might have played a good role in improving the soil nitrogen content. This is because the root nodules of legumes harbor nitrogen fixing bacteria in a symbiotic relationship (Robertson and Grace, 2004). Nitrogen taken up by the plants from the soil may impact on the overall plant biomass, a process that may improves the soil organic matter and other physico-chemical parameters of the soil.

Results have elucidated the carbon sequestration potentials of the three varieties of cowpea studied. The observed differences in the parameters are well noted. Honey bean variety gave the highest dry weight (8.2g), TSC value (4.7Mg) and SCO_2E (15.0Mg) in 250g silica treatment. This may be due to the current plant breeding work and varietal development at the Joseph Sarwuan Tarka University Makurdi where cowpea improved varieties have been released. They possess useful agronomic qualities including yield performances, adaptability, and tolerance to biotic and abiotic stresses (Omoigui *et al.,* 2018; Olasan *et al.,* 2023). It is possible that breeding work might have enhanced the carbon sink value of these varieties alongside purposeful breeding. It is therefore essential to continually evaluate breeding lines for their carbon sequestration which combines environmental value with food security value. According to Oladosu *et al*. (2017), plant breeders must conduct a G × E (genotype by environment) interaction analysis to validate the stable and superior plant before releasing a commercially improved variety. The effect of silicon on soil organic carbon was also observed. SOC was significant in both control and different treatment but not significantly different was recorded in pre-sowing. From this result, we can infer that silicon concentration did not aid accumulation of soil organic carbon content as the highest organic carbon was pre-sowing.

Conclusion

Silica application has proven to be a good soil amendment to increase carbon storage in cowpea. Duration of planting and type of varieties influenced the growth and flowering performances of the crop. Although the three varieties of cowpea investigated in this study demonstrated good performances, honey bean variety was exceptional for its carbon sequestration potential when sown in soil amended with 250g silica. This cheaply available local variety is therefore recommended for planting alongside other improved varieties in order to mitigate the effect of climate change and achieve food security.

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