GPH-International Journal of Agriculture and Research
(Online ISSN 3050-9602)
Volume 09 | Issue 02 | February 2026
Published by: Global Publication House
DOI: https://doi.org/10.5281/zenodo.19184580
Available online at: www.gphjournal.org
Journal homepage: https://gphjournal.org/index.php/ar/index

INFLUENCE OF ENRICHED CORN COB BIOCHAR ON SOIL PROPERTIES, GROWTH PERFORMANCE AND YIELD OF PEANUT (*Arachis hypogaea L.*)

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Abstract

In the search for alternative and sustainable inputs for agricultural production, biochar has been shown to improve soil quality and eventually lead to improved crop productivity. Enriching biochar with chemical fertilizers is an innovative way further to explore its benefits on the soil-plant-environment system. A pot experiment was conducted to study the influence of enriched biochar, with and without the combination of other soil amendments, on the growth and yield of peanut and changes on the chemical properties of soil. The high absorptive capacity and slow nutrient release property of enriched biochar demonstrated an increase in peanut yield and enhanced soil chemical properties. A higher bacterial count was recorded in the 2.5 tons/ha FECCBC + microbial inoculant compared to the other treatments. Several growth traits (marketable pod weight, plant fresh weight and root fresh and dry matter weight) were higher in 5 tons/ha FECCBC compared to other treatments. Such results were associated with its higher nitrogen, phosphorus and potassium concentrations in the plant and root. On the other hand, the treatment applied with 5 tons/ha corn cob biochar showed significantly higher nodule formation than other treatments. The 5 tons/ha FECCBC (Treatment 3) and 2.5 tons/ha FECCBC plus microbial inoculant application (Treatment 7) are recommended in sandy loam soil for they both improved the soil chemical, microbial properties, growth and yield of peanut.

Keywords:

Enriched Biochar; Microbial Inoculant; Macronutrient Uptake; Soil Amendments.

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INTRODUCTION

In recent years, the utilization of biochar has gained interest due to its beneficial roles in carbon (C) sequestration and as soil amendment. Jaiswal *et al*., (2017) reported the benefits of biochar utilization as the "biochar effect" in inducing plant growth and health stimulation that influences plant nutrition and improvement of the physicochemical properties of soils including induced changes in microbial community structure, diversity and activity.

Biochar and/or compost applied to soils independently or in combination has been reported to improve plant health by neutralizing acidity, improvement in water and nutrient retention, and drainage and aeration (Verheijen *et al*, 2010). Agegnehu *et al*., (2016) stated that the high degree of microbial and chemical stability in biochar and mineralization of nutrients in the organic matter of composts, can contribute to plant growth, and minimize the impact of nutrient losses. These inputs are viewed as promising resources for soil fertility management in the short and long term due to their economic and environmental benefits (Adugna, 2018). The International Biochar Initiative (IBI) promoted the soil application of co-composted biochar (COMBI) through compost and biochar mixture (IBI, 2015). Additionally, to increase the performance of biochar it may be necessary to apply inorganic fertilizer and inoculate the plants with beneficial microorganisms with the enriched biochar (de Figuereido 2021).

The study aimed to determine the effect of enriched corn cob biochar application on the chemical and microbial properties, growth and yield of peanut in acidic sandy loam soil.

MATERIALS AND METHODS

Soil Preparation

Sariaya sandy loam soil (*Cumulic Hapludolls*) was collected from an uncultivated area in Barangay Canda, Sariaya, Quezon, Philippines. The soil was air-dried, made free of organic debris, sieved in 2mm mesh and placed in 30 cm diameter x 30cm height polyethylene black plastic pots. Each pot was filled with 10 kg of air-dried soil.

Production and Enrichment of Corn Cob Biochar

Corn cobs were collected from the Corn Section of the Institute of Plant Breeding, College of Agriculture and Food Science, U.P. Los Baños, Laguna. Disease-free corn cobs were selected, air-dried and chopped into 3-5cm sizes. After which corn cob biochars were produced using the slow-pyrolysis biochar-producing stove Three kgs of raw materials were charred for 3 hours at temperatures ranging from $350^{o}C$ to $600^{o}C$. The biochar was then pulverized using Spice and Herb Grinder IC-50B and stored in a dry container until ready for use. The enrichment of corn cob biochar was performed at the Agricultural Systems Institute Composting and Demonstration Area, College of Agriculture and Food Science, U.P. Los Baños. Urea (46-0-0), Solophos (0-18-0), and Muriate of Potash (0-0-60) were mixed in distilled water based on a formulated rate of 10-10-10 kg/ha. The corn cob biochar was inoculated for 15 days before soil application.

Chemical Analyses of Soil, Biochar, Soil Amendments and Plant Tissues

The sandy loam soil was analyzed for total N using Kjeldahl method (Grewling and Peech, 1960), available P by Olsen method (Jackson, 1958), exchangeable K by flame photometry (Peech, 1945), organic carbon (OC) by Walkley-Black method (Jackson, 1958), pH by potentiometric method (Black, 1965), bacterial count by aerobic plate count (Maturin and Peeler, 2001), and fungal count by dilution plating count (Tournas *et al*., 2001).

The organic fertilizer, vermicompost and biochars were analyzed for total N using Kjeldahl method (Grewling and Peech, 1960), available P by Olsen method (Jackson, 1958), exchangeable K by flame photometry (Peech, 1945), organic carbon (OC) by Walkley-Black method (Jackson, 1958), pH by 10:1 biochar-water ratio (w/v) for the biochar using a glass electrode pH meter.

The plant tissue analyses on total N were measured by Kjeldahl method (Grewling and Peech, 1960), total phosphorus by Olsen method (Jackson, 1958), and total potassium by flame photometry (Peech, 1945).

The soil, biochar, soil amendments and plant tissues were analyzed at the Regional Soils Laboratory, Department of Agriculture, Regional Field Office- 3, San Fernando, Pampanga, Philippines while the bacterial and fungal count analysis was conducted at the Philippine National Collection of Microorganisms (PNCM)- BIOTECH, UP Los Baños, Laguna, Philippines.

Surface Morphological Characterization of Enriched Corn Cob Biochar

The surface morphology of enriched biochar was revealed using Field Emission- Scanning Electron Microscope (FESEM) Imaging with Energy Dispersive X-Ray Spectroscopy (EDS) Point Analysis at 2,000x-20,000x magnifications. EDS data were obtained using the Inca software. The FESEM and the Elemental Analysis by EDS were analyzed by the Materials Science Division, Industrial Technology Development Institute- Department of Science and Technology, General Santos Avenue, Taguig City, Philippines.

Peanut Cultural Management

The test crop is peanut (var NSIC Pn 9) with 90 days maturity duration. Three seeds were sown in each pot and thinned to only two plants per pot 15 days after sowing. The soil moisture was supplied using distilled water and maintained at field capacity. The pots were randomly arranged at equal distances for uniform spacing and re-arranged every month to avoid bias that may arise because of location.

Plant Parameters

The Minolta SPAD 502 chlorophyll meter was used and sampling was done on the third topmost leaves. The weight of marketable and non-marketable pods, fresh root and plant biomass were taken at harvest. The fresh root and plant biomass were oven-dried for 72 hours at 70^oC. The number of marketable, non-marketable pods and nodules were counted at harvest.

Experimental Design, Data and Statistical Analysis

The study was laid out in a completely randomized design (CRD). The treatments are shown in Table 1. Data were analyzed using the Analysis of Variance STAR 2.0.1 (Statistical Tool for Agricultural Research). The differences between treatment means were compared using Tukey's HSD test at 5% level of significance.

Table 1. Experimental treatments

Treatments	Rate (tons/hectare)	Rate in pots (grams/10kg soil)
T1- Control (No amendment)	---	---
T2- Corn cob biochar (CCBC)	5	25
T3- Fertilizer-enriched corn con biochar (FECCBC)	5	25
T4- Inorganic fertilizer recommended rate (IFRR)	0.21	1.07
T5- Organic fertilizer + CCBC	5 + 5	25 + 25
T6- 50% T3 + 50% vermicompost (VC)	2.5 + 2.5	12.5 + 12.5
T7- 50% T3 + microbial inoculant	2.5 + 0.002	12.5 + 0.01
T8- 50% T3 + 50% T4	2.5 + 0.11	12.5 + 12.5

RESULTS AND DISCUSSION

Biochar and Soil Amendments Characterization

The chemical characteristics of the corn cob biochar, biochar after enrichment, organic fertilizers, and vermicompost are presented in Table 2. The pH level of the corn cob biochar and enriched biochar is 7.87 and 7.24, respectively. The decrease in pH in the FECCBC can be attributed to the reaction between the biochar and the acidic nature of chemical fertilizers (Dragan *et al*., 2010), however, the pH is still within the neutral level. The organic fertilizer (OF) has an alkaline pH (8.08) while the pH of vermicompost (VC) is near neutral (pH 6.44). The higher pH of the OF can be attributed with the alkaline nature of biochar that is used as raw material (Ippolito et al., 2015). The enrichment process of FECCBC evidently showed higher concentrations of, N, P, K, OM and OC compared with the corn cob biochar).

Table 2. Chemical characteristics of biochar, enriched biochar and other soil amendments.

Parameters	Corn cob biochar	Fertilizer-enriched corn cob biochar	Vermicompost	Organic Fertilizer
pH	7.87	7.24	6.44	8.08
Total nitrogen (%)	0.46	3.00	0.68	2.72
Total phosphorus (%)	0.37	3.65	0.90	3.68
Total potassium (%)	0.95	2.68	0.21	2.79

Parameters	Corn cob biochar	Fertilizer-enriched corn cob biochar	Vermicompost	Organic Fertilizer
Organic matter (%)	11.15	18.29	15.63	54.28
Organic carbon (%)	6.48	10.63	9.09	31.56

Soil Chemical and Microbiological Properties

The Sariaya sandy loam soil is categorized as moderately acidic with pH of 5.95 as set by Daly and Wainiqolo (1993). The soil had a high OC content (19%), very low N (0.08%), high in available P (34.98 mg/kg) and very high exchangeable K with 1.38 cmol/kg as set by Blakemore et al. (1987) (https://research.csiro.au/pacsoils/wp-content/uploads/sites/404/2021/12/1-Soil-Sampling-Analysis-Report-USP-19-Nov.pdf). Microbial analysis also indicated $4.7x10^6$ CFU/g bacterial count and 23/ 10g soil endomycorrhizal count (Table 4).

FECCBC Surface Morphology Analysis

The SEM images at different magnifications revealed the elevated mineral elements in the biochars. (Figure 1). The elements from the fertilizers through the enrichment process led to the formation of complexes as indicated by the pore size distribution with deposition of the minerals attached to the surface of the biochar. Visible mineral phases can be observed to occupy the surfaces of pores in the biochar in the 3- and 5-microns scale at 10,000x and 20,000x magnifications, respectively. Similar to the findings of Suman *et al*. (2016), the surface in the area of interest showed complex particle surface, shrinking and splitting. The material at 2,000x and 5,000x magnifications shows a bright image of the mineral and biochar interface and its complexity was more visible at higher magnifications as shown in the 10,000x (c) and 20,000x (d) showing close- up interface between a mineral particle and its surrounding biochar aggregate (Chia *et al*., 2015). Thies and Rillig (2009) further elaborated on the relevance of studying the microscopic physical structure of biochar as it relates to its effect on soil physical properties including its very high surface area that greatly increases reactions with the soil.

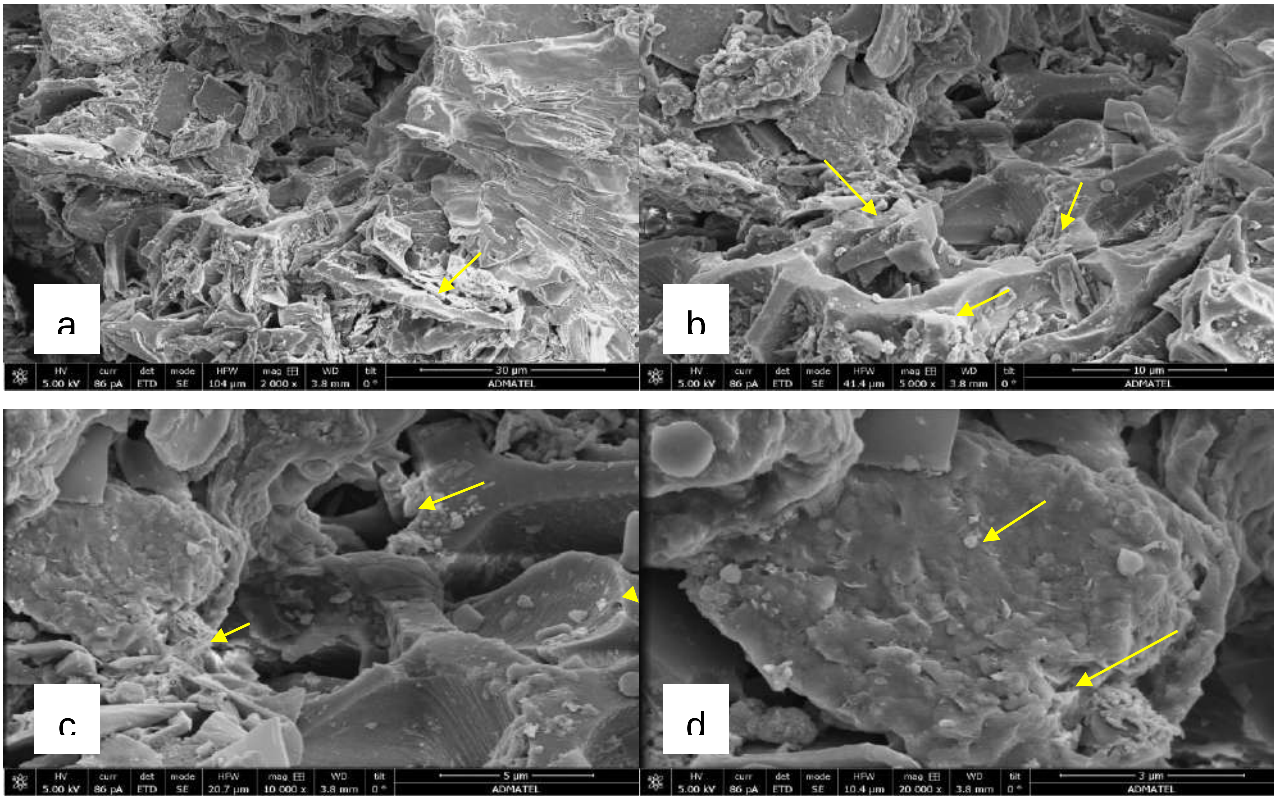
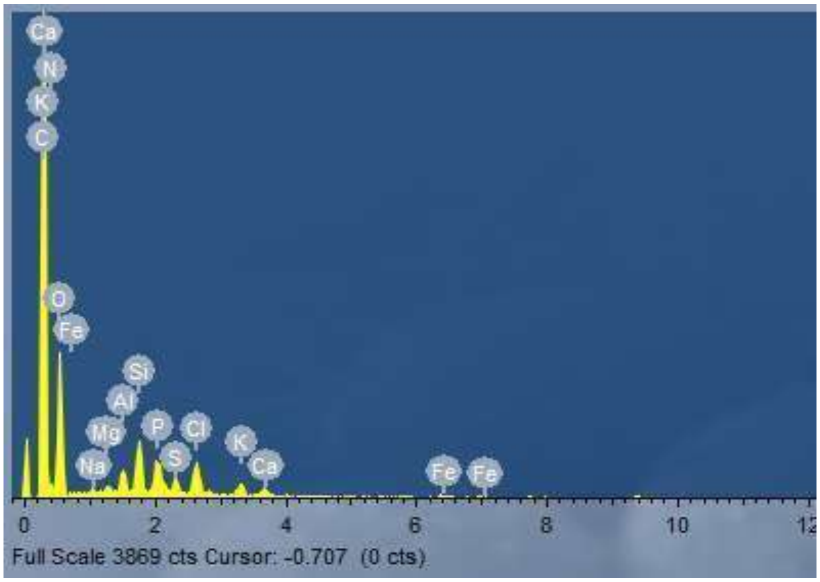


Figure 1. FE-SEM images of the area of study were taken at 2,000x (a), 5,000x (b), 10,000x (c), and 20,000x (d) magnifications. The yellow arrows show the fertilizer minerals attached to the area of interest in the biochar. The white bar at the bottom indicates the scale.

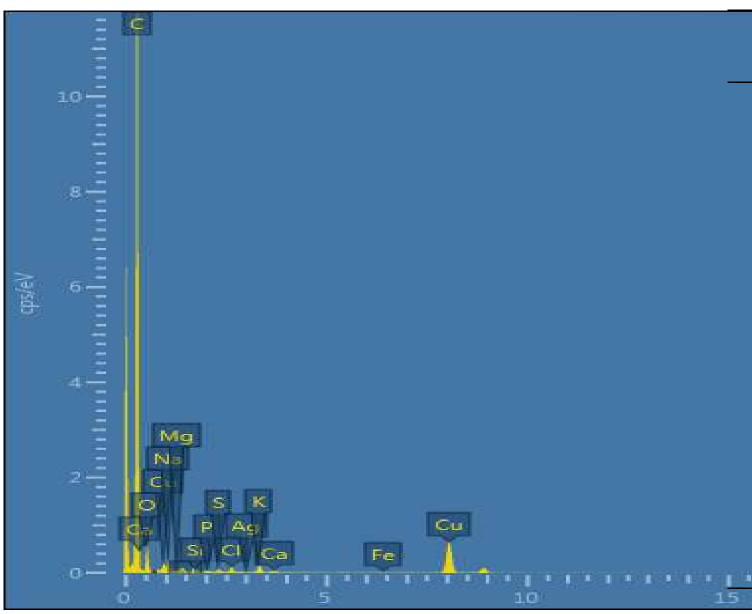
The EDS spectra of the FECCBC are shown in Figure 2. Carbon was the most abundant element in the areas of interest with 64.75% C. It was followed by 25.94% oxygen and 4.82% nitrogen. The enriched biochar contained 4.82% nitrogen which is an indication of positive attachment of N in the biochar. Comparable lower concentrations of Si, Cl, P, K, S, Ca and Na were recorded in the FECCBC sample. In this study, the CCBC elemental properties were a function of the feedstock used as well as the pyrolysis duration and heat treatment employed (Bulfa et al., 2023).



Elements	% Composition
Carbon (C)	64.75
Nitrogen (N)	4.82
Oxygen (O)	25.94
Sodium (Na)	0.07
Magnesium (Mg)	0.16
Aluminum (Al)	0.43
Silicon (Si)	1.02
Phosphorus (P)	0.73
Sulfur (S)	0.36
Chlorine (Cl)	0.88
Potassium (K)	0.38
Calcium (Ca)	0.19
Iron (Fe)	0.26

Figure 2. EDS spectra in the enriched corn cob biochar (Left); and the elements detected with their corresponding concentrations in terms of weight percentage in the summarized table (Right).

Figure 3 shows the EDS spectra of the CCBC. Like FECCBC, carbon was the most abundant element in the area of interest with 88.40% in the CCBC. It was followed by oxygen with 3.00%, however, N including Mg, Fe and Al were not detected in the raw corn cob biochar. Comparable lower concentrations of Si, Cl, P, K, S, Ca and Na were also recorded in the CCBC sample. The raw CCBC elemental concentrations were consistent with the findings of Lehmann et al. (2011) stating biochar contains high amount of carbon, high surface area and CEC but low nutrient content.



Elements	% Composition
Carbon (C)	88.40
Nitrogen (N)	---
Oxygen (O)	3.00
Sodium (Na)	0.70
Magnesium (Mg)	---
Aluminum (Al)	---
Silicon (Si)	0.20
Phosphorus (P)	0.20
Sulfur (S)	0.20
Chlorine (Cl)	0.50
Potassium (K)	0.70
Calcium (Ca)	0.10
Iron (Fe)	---

Figure 3. EDS spectra in the raw corn cob biochar (Left); and the elements detected with their corresponding concentrations in terms of weight percentage in the summarized table (Right).

Effects of Treatments on Soil Properties

The soil pH in all treatments after cropping ranged from 6.05 to 6.90, with T7 (50% FECCBC + MI) the lowest and T3 the highest. Soil pH is a very important indicator of nutrient mineralization and availability (Fu *et al*., 2012). The OM levels increased from 2.47% to 20.60% which can be attributed to the high carbon content of biochar and its ability to store carbon (El Naggar *et al*., 2018). The 5 tons/ha CCBC plus 5 tons/ha OF recorded the highest OM level (1.99%). However, the treatment effects to demonstrate deliberate changes on the chemical properties of soil (N, P and K) were not observed.

Table 3. Chemical composition of soil as influenced by the different treatments for peanut production.

Treatments	Parameters				
	pH	Organic Matter (%)	Total N (%)	Available Phosphorus (ppm)	Exchangeable Potassium (cmol/kg)
Initial soil	5.95	1.52	0.08	34.98	1.38
T1- Control	6.81	1.58	0.09	34.07	0.95
T2- CCBC	6.90	1.73	0.08	35.05	0.98
T3- FECCBC	6.17	1.62	0.09	30.79	1.03
T4- IFRR	6.35	1.62	0.09	39.97	0.95
T5- OF + CCBC	6.79	1.99	0.10	28.66	0.96
T6- 50% VC + 50% FECCBC	6.07	1.98	0.09	41.60	0.96
T7- 50% FECCBC + MI	6.05	1.65	0.09	41.93	0.96
T8- 50% FECCBC + 50% IFRR	6.39	1.80	0.10	45.86	0.92

In this study, the varying effects of treatments on microbial abundance is presented in Table _4_. The T7 (50% FECCBC+ microbial inoculant) and T8 (50% FECCBC +50%IFRR) resulted in $8.2x10^6$and $7.7x10^6$ bacterial count, respectively, compared with the control. The addition of microbial inoculant could have initiated the colonization of bacteria in the soil system, resulting in an increased population. Similarly, Rousk et al. (2010) reported that pH influences microbial abundance due to biochar applications as supported by the findings of Angelini et al. (2003) that resulted in lower rhizobia infection in legumes.

Moreover, the endomycorrhizal count was not affected by the treatment applications. This finding corroborated with the study by Warnock *et al*. (2010) who reported that the decrease in abundance can be attributed to reduced requirement for mycorrhizal symbiosis due to increased nutrient and water availability after biochar application.

Table 4. Microbial analysis of soils planted with peanut as influenced by the treatments

Treatments	Bacterial count (CFU/g)	Endomycorrhizal count (Spore count/10g soil)
Initial soil	$4.7x10^6$	23
T1- Control	$1.9x10^5$	129
T2- CCBC	$1.2x10^5$	93
T3- FECCBC	$1.7x10^5$	81
T4- IFRR	$1.7x10^5$	100
T5- OF + CCBC	$1.7x10^5$	76
T6- 50% VC + 50% FECCBC	$2.1x10^5$	109
T7- 50% FECCBC + Microbial Inoculant	$8.2x10^6$	107
T8- 50% FECCBC + 50% IFRR	$7.7x10^6$	104

Effects of Treatments on Growth and Yield of Peanut

The enriched biochar treatment applications resulted in comparable physiological and morphological responses in peanut. The chlorophyll concentration, total number of pods, number and weight of marketable and non-marketable pods, root fresh and dry matter weight, and plant fresh and dry matter weight showed no significant differences as affected by the treatments. Notably heavier marketable pods, plant dry matter weight and root fresh and dry matter weight were observed in the 5 tons/ha FECCBC treatment (Table 5). These results can be attributed to the treatment having the highest values in terms of NPK uptake in both the plant and root systems of the peanut plant. Figure 4 shows that the 5 tons/ha CCBC recorded the highest number of nodules with 180.33, 20.52% and 31.24% higher compared to IFRR (143.33) and the control treatment (124.00).

Table 5. Nutrient uptake on plant tissues of peanut as affected by the treatments

Treatments	Nutrient Uptake (kg ha^{-1})					
	Plant			Root		
	N	P	K	N	P	K
T1- Control	19.76	2.47	5.64	3.16	0.86	3.22
T2- CCBC	26.93	2.62	25.68	3.62	0.77	4.09
T3- FECCBC	32.59	4.18	54.56	3.96	0.67	6.04
T4- IFRR	10.14	2.84	34.48	3.57	0.45	4.16
T5- OF + CCBC	18.42	2.23	37.04	2.26	0.34	2.28
T6- 50% VC + 50% FECCBC	22.96	3.16	36.45	2.56	0.26	1.22
T7- 50% FECCBC + MI	24.23	2.71	36.22	3.76	0.61	3.29
T8- 50% FECCBC + 50% IFRR	24.45	2.95	37.12	3.48	0.38	1.94

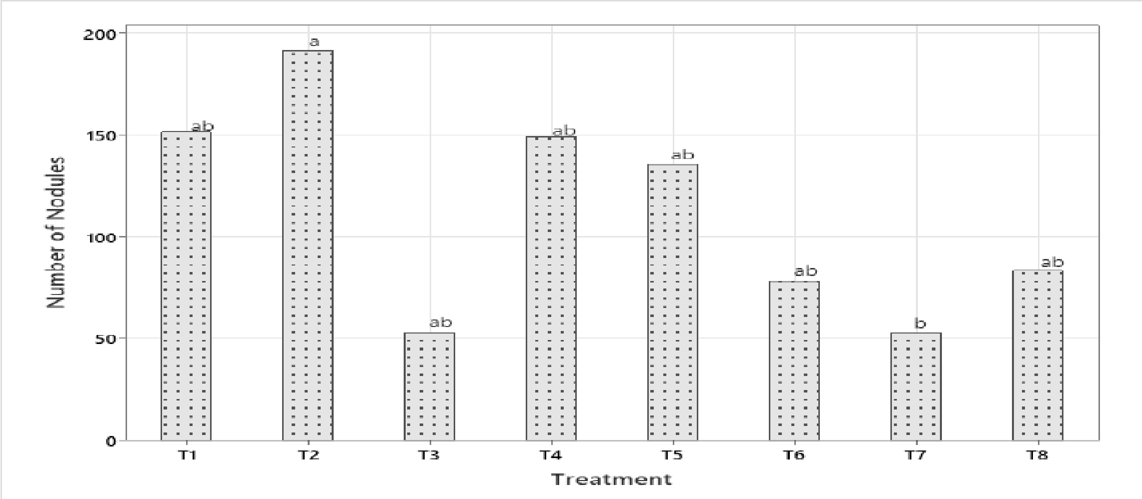


Figure 4. Number of nodules of peanut as influenced by the application of the different treatments. Bars with the same letter(s) are not significantly different at 5% level by Tukey's HSD test).

CONCLUSION

The results showed that the enriched CCBC improved the pH and OM content while the 5 tons/ha raw CCBC enhanced the formation of nodules in sandy loam soil. The 5 tons/ha FECCBC performed well in macronutrient uptake as indicated by the heavier marketable pods, plant dry matter and root fresh and dry matter weight than the other treatments. In future work, it is suggested that the 5 tons/ha FECCBC be tested under field conditions in acidic sandy loam soil to verify its efficacy and crop performance.

ACKNOWLEDGEMENT

The authors would like to thank the Department of Agriculture- Bureau of Agricultural Research (DA-BAR) for the research funds.

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