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Evaluating the Impact of Biochar, Composted Organic Waste, and Inorganic Fertilizer on Soil Carbon Dynamics and Their Role as Climate-Resilient Farming Tools: A Case Study in Northern Guam

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Abstract

The purpose of this study was to evaluate how different soil amendments, such as biochar, compost, a combination of biochar and compost mix, and inorganic fertilizer, affect crop productivity, soil health, and carbon dioxide (CO_2) emission in the cobbly clay soils of northern Guam. The soil under the study had an average total carbon (TC) range of 8% to 12% and a total nitrogen (TN) range of 0.3% to 0.7% throughout each cropping season. The compost-only and compost/biochar mix plots had the highest carbon (C) levels, with biochar-treated plots surpassing both the fertilizer and control treatments. Despite the lower nitrogen levels in compost and compost/biochar mix during soil testing, both produced similar crops during most of the cropping season, comparable to the plots treated with fertilizers. The fertilizer-treated plots however had lower yields during the wet season, likely due to the lack of soil organic matter (SOM) or the leaching caused by intense rainfall. During the dry season, the compost/biochar mix had significantly lower CO_2 emissions compared to compost-only plots. However, during the wet season, the emissions of CO_2 were similar in compost/biochar mix as well as the compost only. Furthermore, compost and compost/biochar mix treatments had the highest response in basal (biological) soil response (BSR) as tested.

Keywords: *Biochar, Carbon sequestration, Soil fertility, Climate resilience, Carbon dioxide.*

Introduction

Soil organic carbon (SOC) is the largest carbon pool in soils and plays a crucial role in carbon (C) storage and exchange of CO_2 in the atmosphere (Follett, Ronald., 2001; Kutsch, W., *et al*., 2010) [1,2]. According to Lorenz and Lal (2018) [3] and Lal (2011) [4], crop intensification through methods such as tillage, fertilization, irrigation, and liming has affected SOC dynamics, leading to a significant loss of terrestrial C estimated at 98.4 Pg from 1850 to 2015. Intense tilling increases aerobic microorganisms, which consume soil C and release greenhouse gases like CO_2 and methane (CH_4) gas. In addition, changes in weather conditions (e.g., increase in soil temperature and moisture) also affect microbial activities contributing to soil C emissions and nutrient cycles in the soil (He, L., *et al*., 2021) [5].

Soil respiration, as reported by NOAA (2023) [6] and Bond-Lamberty and Thomson (2010) [7], is a significant contributor to CO_2 emissions, ranking second to fossil fuel burning, and cement manufacturing. It has been on the rise over the past few decades and is predicted to continue increasing as the weather warms. Warmer tropical soils are also highly vulnerable to intensive soil disturbance that can accelerate CO_2 emissions and loss of SOC. A two-year study in the tropical forest soil of Panama revealed that the increase in temperature caused a 55% rise in CO_2 emissions, indicating that SOC in tropical forests is impacted by warming temperatures (Nottingham *et al*., 2017) [8].

Challenges with soil and crop management are prevalent in Guam and other Pacific islands, particularly in the northern regions of Guam, where calcareous soils have low SOM content (Golabi *et al*., 2004) [9]. Furthermore, over 300 plant pathogens have been reported on Guam since 1905, mainly affecting vegetable and fruit crops. Consequently, farmers struggle to produce quality and high-yield crops in Guam. To address these problems, farmers employ large quantities of agricultural chemicals, such as commercial fertilizers, pesticides, and herbicides. However, these practices can lead to increased farm production expenses and negative environmental impacts, such as contamination of drinking water as well as harming the marine life surrounding the island. Therefore, innovative approaches to increase crop production with minimal environmental impact are critical for improving agricultural production for food security in Guam and the other island in Micronesia.

An environmentally friendly alternative to commercial inorganic fertilizer is the land application of composted organic waste, or compost. Soil is a mixture of inorganic (e.g., sand, silt, and clay) and organic materials (e.g., living and dead organisms), water, and air (SSSA, 2023). When compost is added to the soil, it increases the SOM, which provides vital nutrients for plants, nourishes soil organisms, enhances soil structure, and boosts the capacity to retain nutrients and water (University of Minnesota Extension, 2021) [10]. Compost also stores more global carbon than plants and the atmosphere combined [11].

A compost-to-soil application study was conducted for southern and northern Guam, resulting in improved soil health and crop yield (Golabi *et al*., 2007 and 2017) [9]. However, in large-scale and short-term farming, composting alone may not be cost-effective for crops that require large amounts of nutrients.

Additionally, to reduce greenhouse gases, researchers are studying biochar. This carbonated organic material is rich in carbon and produced in a controlled environment of high temperatures with limited or no oxygen, called pyrolysis. Compared to regular charcoal, it contains about 65% or more C. The C content in biochar, however, depends on the feedstock type and pyrolysis conditions.

Objectives

The objectives of this study were to:

1. Investigate the biochar's C sequestration potentials and compare them to composted organic waste (compost) and commercial fertilizer (inorganic).
2. Evaluate corn (maize) yield and quality affected by the above treatments.
3. Verify if biochar can sequester carbon in calcareous and poor soil conditions of northern Guam.

Materials and Methods

Experimentation Site

This project was conducted at the University of Guam's Yigo Research & Education Center in northern Guam, at latitude13°25' 51.302" N and longitude 144° 48' 5.218" E and 145 m to 155 m elevation above sea level (Figure 1). Northern Guam is relatively flat with no surface drainage as all rainfall percolates directly into the permeable limestone (Soil Survey of Territory of Guam, 1984) [12]. Guam has a mean annual rainfall of approximately 2540 mm, with a distinct dry season from January to June, with an average rainfall of approximately 800 mm. The mean annual temperature is 26°C, and the monthly temperature ranges vary approximately ±2°C from the mean.

The soil underlying the site is the Guam soil series (clayey, gibbsitic, nonacid, isohypothermic lithic ustorthents) formed in sediment over porous coralline limestone. Soils in northern Guam are typically nutrient deficient and high in calcium carbonate.

Figure 1: Location of the experimental site at the Yigo Research & Education Center. Photo (left): Kaya Taitano, University of Guam Drone Corps. Photo (right): Google Maps.

Experimental Field Design

A randomized complete block design (RCBD) with four replications per treatment was used. The experimental field (Figure 2) was divided into 20 plots (10-by-20 feet, or 3-by-6 meters). Conventional tillage and drip irrigation were implemented in all plots. Drip irrigation was used to minimize water evaporation and leaching of nutrients. A t-test statistical analysis was performed to compare treatments and determine significant differences in paired measurements.

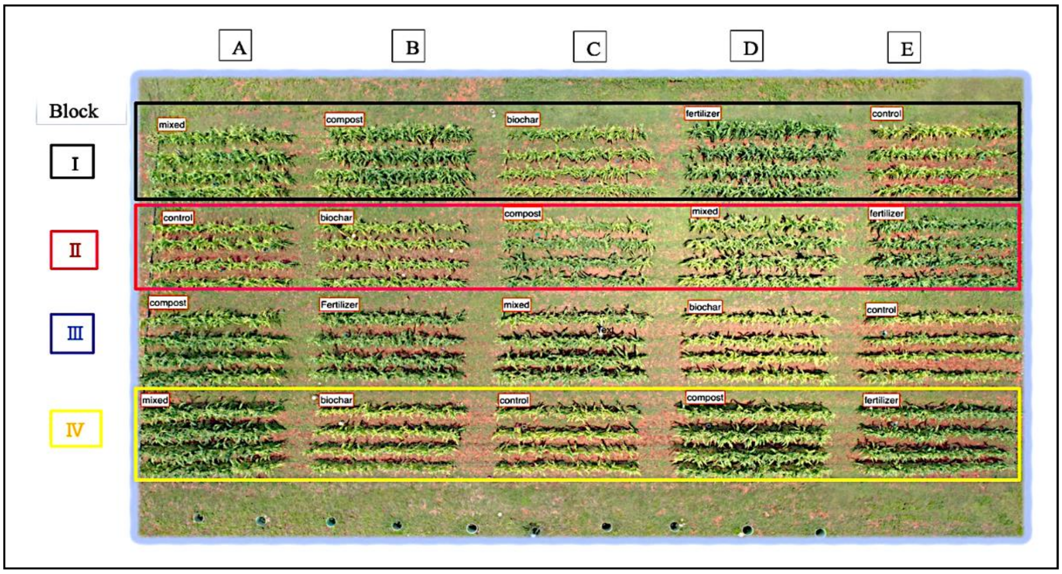

Figure 2. Similar experimental plots are grouped into blocks or replicates.

Photo: Chieriel Sano Desamito

Treatments:

We used compost and non-composted organic material (biochar) as well as synthetic fertilizers at comparative rates as soil amendments. Biochar, compost, and compost/biochar mix treatments were integrated into the topsoil at 0-8 inches (0-20 cm) depth. Commercial inorganic fertilizer (triple 16) was applied using the side dressing method in the fertilizer treatment plots only. Triple 16 fertilizer contains 16% nitrogen (N), 16% phosphorus (P), and 16% potassium (K).

Treatment 1: Compost

Composting is an alternative method for developing an effectual plant nutrient as well as for a waste management strategy. In Guam and other islands in the Pacific, most agricultural lands are small-scale farming systems; therefore, composting may benefit local farmers because of the soil's poor fertility and low organic matter [9].

Composting organic waste promotes soil health by increasing organic matter, biological activity, soil water content, and nutrient exchange capacity. Biologically active soil promotes natural food webs for microorganisms by increasing organic material and maintaining ideal soil structure [13].

Because compost releases nutrients slowly in the soil compared to commercial fertilizer, compost amendment may prevent excess nutrients (e.g., N and P) from leaching and avoid contaminating the groundwater of northern Guam. A study by Galsim *et. al.* (2021) [15], indicated that land application of composted organic waste may reduce nitrate leaching into the groundwater that supplies 80% of Guam's drinking water. In addition, Guam is working on a Zero Waste Plan policy from the U.S. Department of Defense Office of Economic Adjustment as part of the alternative waste management strategies in Guam [15].

Although applying compost improves soil health and crop production, it may not be a complete substitute for fertilizer on high nutrient-demand crops (i.e., maize, wheat, and most leafy green vegetables). Compost's average macronutrient content is approximately 1.5%, almost seven times less than an all-purpose inorganic fertilizer [16]. Compared to 16 pounds of triple 16 commercial inorganic fertilizer, 112 pounds per plot of dry compost was needed per application.

Composting also produces and releases significant amounts of CO_2 and other greenhouse gases in the atmosphere that may have negative environmental and health impacts. Each time microbes consume C as their energy source, two-thirds is given off as CO_2. At the same time, the remaining third is stored in the microbe cells or part of the mature compost [17]. The long-term application of compost, however, provides lasting nutrients source to tropical soil, but an alternative treatment is recommended to sequester C and reduce greenhouse gas emissions. Woodchips and vetiver grass cuttings were the primary sources of C, while chicken manure and green material provided N source during the compost production for this study.

Treatment 2: Biochar

An alternative to improving C storage in the soil is the application of biochar. Biochar is a thermally decomposed biomass from organic material, such as woodchips, crop residues, and other organic wastes produced under pyrolysis [18]. This carbon-rich material is combusted in elevated temperatures up to 700ºC with very low to no oxygen [19]. Depending on the type of biomass, this porous and lightweight charcoal-like material contains around 70% or more carbon and other elements such as N, H, O, and minerals in the ash [20,21].

Biochar production technologies are being studied to evaluate the effect of this carbonized material for mitigating greenhouse gas emissions from the soil into the atmosphere. It is reported that some C-containing greenhouse gases may contribute to warmer climates [22] causing climate change. However, the biochar can potentially absorb and store carbon in the soil (carbon sequestration) hence preventing its emission to the atmosphere as CO_2. This process of sequestering carbon in the soil by the land application of biochar can potentially reduce the amount of GHG emission into the atmosphere as it is referred to resilient farming practices. Also, Due to its hydrophilic nature, biochar helps to improve soil water and enhance nutrient retention and increase CEC of the soil. This may lead to better crop health and crop yield production in the long run.

Benefits of Biochar in Soil

- High porosity and surface area
  - It is a potential microbial carrier for agricultural and environmental applications.
    - Enriched with organic carbon, N, P, and nutrients for microorganisms [23].
    - Increases water and nutrient holding capacity due to the adsorption of hydrated ions [24].
- Cation exchange capacity (CEC)
  - It retains soil nutrients, reduces fertilizer runoff, and improves soil water retention.
- Buffering capacity
  - It maintains soil organic matter content and base cations [25].
- Disease suppression
  - The changes in soil microbiota can affect pathogen motility and colonization [26].

Treatment 3: Biochar and Compost Mix

Plots with 'compost and biochar mix' were compared with 'compost' only and with the fertilizer application for crop yields and CO_2 emissions. Corn plants were also monitored for the presence of diseases (data not shown).

Treatment 4: Inorganic Commercial Fertilizer

An all-purpose slow-dissolving granular fertilizer with equal percentages of nitrogen (N), phosphorus (P), and potassium (K) was applied to the plots using the side-dressing method to reduce nitrate release in groundwater.

Application Rates for Applied Amendments

Five treatments were applied with three replications for each treatment using a randomized complete block design as follows:

Treatment 1: Compost only - 60 t/a compost application*

Treatment 2: Biochar only - 15 t/a 'biochar' *

Treatment 3: Compost and biochar mix - 60 t/a compost and 15 t/a biochar

Treatment 4: Fertilizer only - equivalent rates of nitrogen to compost*

Control: No additional nutrients were added to the soil (0 t/a)

*The application rates are determined based on the results evaluated from the previous experiment at the Yigo (southern Guam) research station for optimum yield production. These application rates provide estimated equivalent rates of 0 and 130 kg/ha of total nitrogen applied. The fertilizer application rate used by local farmers ranges from 120 to 150 kg/ha of nitrogen-based fertilizers.

Rotation with Sunn Hemp

Corn (*Zea mays* L.) was the main crop throughout the study period. However, due to negative drawbacks of monoculture farming (i.e., depletion of soil nutrients and intensive use of agricultural chemicals), sunn hemp (*Crotalaria juncea* L.) was incorporated in the soil between each cropping seasons as a rotating cover crop to help suppress invertebrate pests (e.g., plant-parasitic nematodes) that can cause severe damage to corn or other crops.

Sunn hemp is an annual legume commonly used in rotation with the main crop to improve soil health and soil quality. Its roots form a symbiotic relationship with N-fixing bacteria by taking nitrogen gas from the atmosphere and converting it to nitrate in the soil. It can suppress pests, particularly plant-parasitic nematodes (roundworms) that take away energy and nutrients by attacking the roots. As a rotating cover crop, it effectively controls weeds [27]. However, residual effects can be short-term. Thus, it was continually planted between each cropping season.

In northern Guam, the soil is porous and lacks organic matter. However, sunn hemp offers a solution to this problem. With its rapid growth and fibrous stalks, it can produce more than 5,000 lb. of biomass and 100 lb or more of nitrogen per acre [28]. By increasing organic matter and nitrogen in the soil, farmers can reduce water use and fertilizer application. Additionally, using sunn hemp can minimize the use of pesticides, herbicides, and fertilizers that could potentially contaminate the aquifer in northern Guam which is the primary source of drinking water for 80% of the island's population. Therefore, both local farmers as well as the public stand benefit from incorporating sunn hemp into their farming practices.

Soil Analysis

The study plots were examined for changes in soil composition as compared to the control plots after applying composted organic waste, biochar, and fertilizer. Soil samples were taken from 0- to 8-inch depths and tested for plant nutrients, pH levels, carbon content, and organic matter (OM). The FlashSmart Analyzer instrument was utilized to accurately measure the total carbon (TC) and total nitrogen (TN) present in both the soil and compost.

CO_2 Efflux

Intensive soil tilling in agricultural ecosystems releases greenhouse gases (GHG) into the atmosphere. A study conducted in southern Guam compared the effects of no-tillage farming and biochar application with volcanic soils. Previous results have indicated [9] that biochar-amended soils and no-tillage practices have low CO_2 efflux measured from the soil surface using sealed containers with sodium hydroxide (Figure 3). The CO_2 captured from soil respiration was determined using the titration method. The concentration of CO_2 was determined using the titration method based on the following formula: Mass of CO_2 = Volume of titrant (L) X molarity of standard acid X molecular weight of CO_2.

Figure 3: Sealed Containers With 3M Of Sodium Hydroxide-Filled (NaOH) Erlenmeyer Flasks Were Placed Above the Soil Surface to Capture CO_2 Efflux In 24 Hours.

Weather Station Data Logger and Irrigation System

A weather station was used to monitor precipitation, humidity, soil moisture, and temperature to detect the overwatering or underwatering of crops (Figure 4). Drip irrigation emitters also provided a gradual water supply to plant roots (Figure 4).

Figure 4: A Weather Station Data Logger (Red Circle) Was Used for Efficient Irrigation.

Crop Production

Crop production, or crop yield, refers to the weight of grain harvested from a specific land area during a single growing season. It is commonly measured as yield per unit area, such as tons per acre or metric tons per hectare (t/ha) [29]. Corn was collected from three of five rows per plot for this project.

Results

Carbon (C) and Nitrogen (N)

Soil samples from study plots were collected and analyzed for total carbon (TC) and total nitrogen (TN) (Figures 5 and 6). Soil organic carbon (SOC) is derived from organic matter, such as plant residues (Table 1). SOC was estimated based on the assumption that SOM is 58% C. In contrast, soil inorganic carbon (SIC) (Table 2) is from inorganic carbonates, like calcium carbonate or lime [30].

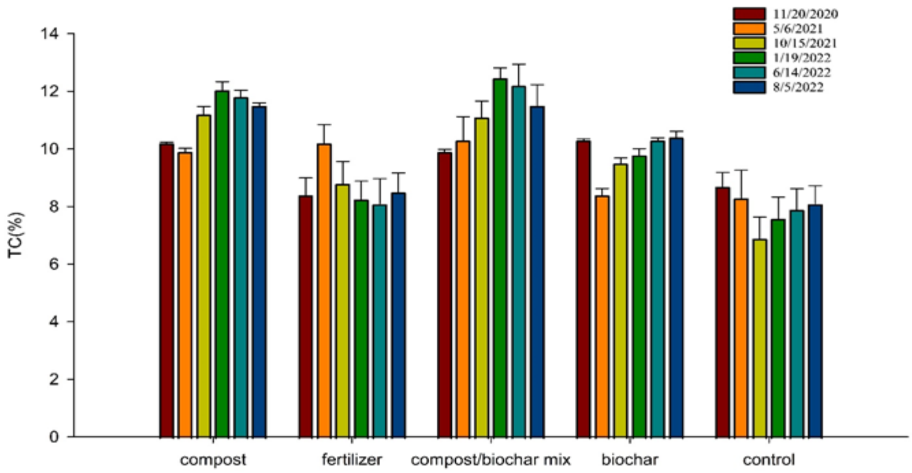

Figure 5: Total Carbon Content (TC) Of the Soil for The Duration of The Experiment (2020-2022).

As shown in figure 5, Compost, Biochar-Compost mix, and Biochar-only treatments had higher carbon contents compared to fertilizer and control, and the difference was statistically significant. On the other hand, the carbon content in control plots was higher than in the fertilizer plots although, not statistically different.

Table 1: Soil Organic Carbon (Soc) Content (%).

Treatment	11/20/2020	5/6/2021	10/15/2021	1/19/2022	6/14/2022	8/5/2022
compost	5.71	5.70	6.76	6.83	6.40	5.97
fertilizer	4.62	4.04	4.83	4.16	4.19	3.82
compost/biochar mix	5.44	5.85	5.91	8.15	6.87	6.55
biochar	5.43	4.40	4.43	4.62	4.30	4.26
control	4.33	3.97	4.04	4.01	3.82	3.91

Table 2: Soil Inorganic Carbon (Sic) Content (%).

Treatment	11/20/2020	5/6/2021	10/15/2021	1/19/2022	6/14/2022	8/5/2022
compost	4.57	4.20	4.44	5.37	5.40	5.53
fertilizer	3.78	6.16	3.97	3.64	3.91	4.68
compost/biochar mix	4.46	4.45	5.19	3.35	5.33	4.95
biochar	4.87	4.00	5.07	4.98	6.00	6.14
control	4.37	4.33	2.86	2.89	4.08	4.19

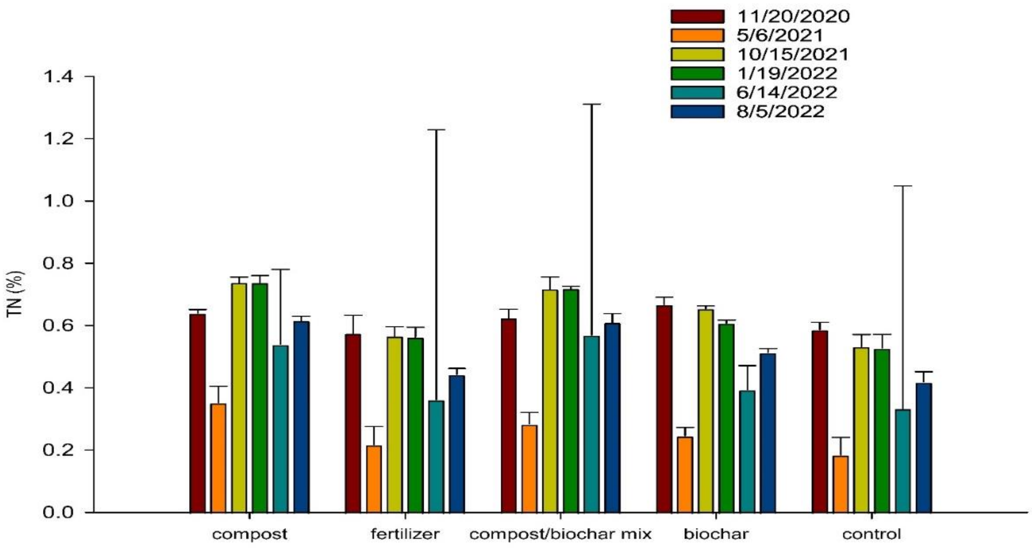

Figure 6: Total Nitrogen (TN) Of the Soil for The Duration of The Experiment (2020-2022).

Carbon and Nitrogen Ratio (C:N)

Maintaining the optimal ratio of C to N in agricultural soils is crucial for ensuring healthy crop growth and microbial activity. It is suggested that a ratio of 10:1 as the ideal balance between these two essential nutrients in the soil [31]. However, a ratio of 25:1 is also considered normal or appropriate for field crops. The carbon to nitrogen ratio helps facilitate the breakdown of organic matter, which releases nutrients for plants to feed on while promoting the growth of beneficial soil microorganisms. For long-term maintenance of soil health and also to achieve maximum crop yield, it is highly recommended to follow the appropriate ratio. Table 3 shows the C:N ratio of the soil plots throughout the cropping seasons.

Table 3: Carbon to Nitrogen Ratio (C: N) Throughout the Cropping Seasons.

Treatment	11/20/2020	5/6/2021	10/15/2021	1/19/2022	6/14/2022	8/5/2022
Compost	16:1	17:1	15:1	16:1	24:1	19:1
Fertilizer	15:1	16:1	15:1	14:1	20:1	19:1
Compost/biochar mix	16:1	15:1	16:1	16:1	20:1	19:1
Biochar	15:1	14:1	15:1	16:1	26:1	20:1
Control	15:1	14:1	14:1	12:1	26:1	19:1

Soil Organic Matter (SOM)

The content of organic matter from both the compost and compost/biochar mix was significant compared to the other treatments (Figure 7).

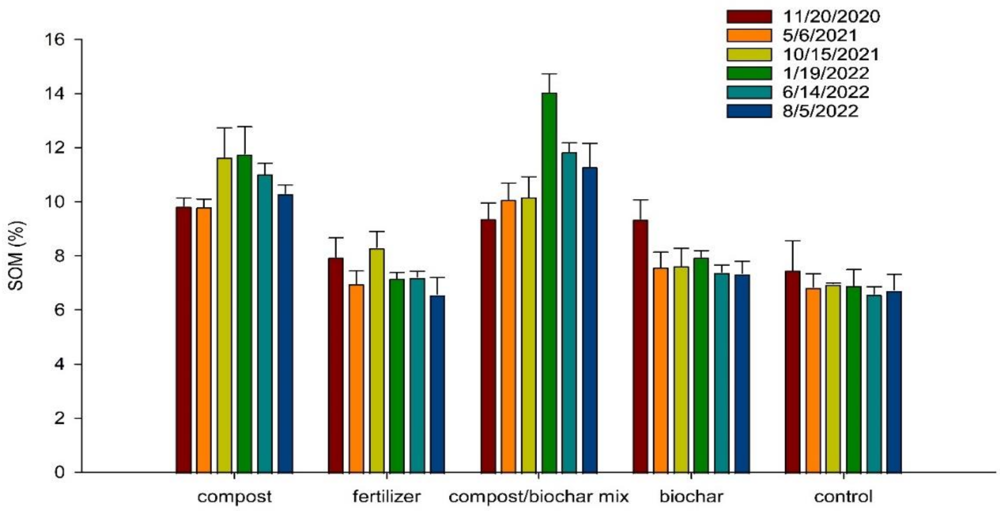

Figure 7: Soil Organic Matter (SOM) Throughout the Cropping Seasons

Soil Nutrients: K, Mg, P (Po4), Ca

As shown in Figure 8, both 'compost' and 'compost/biochar mix had the highest values for nutrients, especially with potassium and manganese content. However, the nutrient analysis results have shown (Table 4) that lower 'available' phosphorous in all treatments could possibly be due to high calcium content of the soils which bind the phosphorous and make it less available.

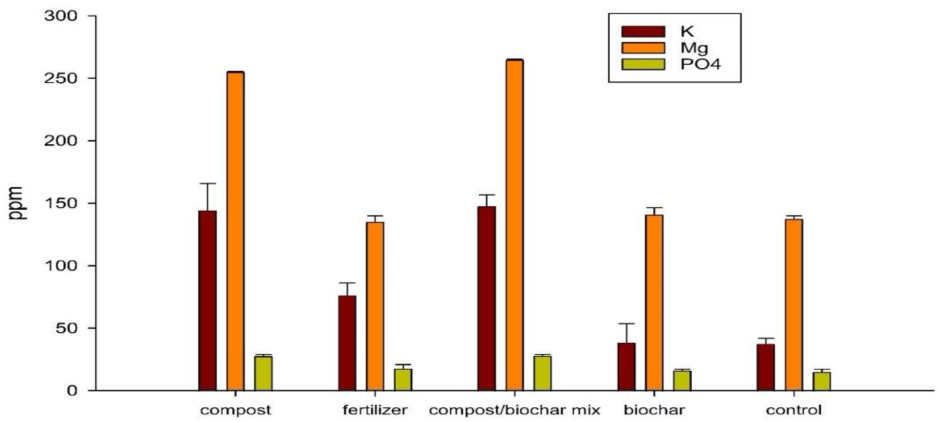

Figure 8: Nutrient Analysis of Potassium (K), Magnesium (Mg), And Phosphorus (P) In the Form of Phosphate (Po4) (June 14, 2022)

The Potential of Hydrogen (pH)

A measure of acidity or alkalinity (pH) affects soil's biological, chemical, and physical properties as it also determines the availability of essential plant nutrients. Soil pH of 6.5 is considered optimum for nutrient availability for most crops [32]. However, results of a general nutrient analysis showed the soil pH of all treatments ranged from 7.4 to 7.5 (Table 4).

Table 4: Showing the result of the soil Nutrient analysis from all treatments.

Treatment June 14, 2022	K (ppm)	Ca (ppm)	Mg (ppm)	PO4 (ppm)	% Organic Matter (OM)	pH
compost	129.4	5104.8	254.8	27.8	11.0	7.5
fertilizer	76.2	4705.5	135.0	18.0	7.2	7.5
compost & fertilizer m	147.4	5095.9	264.5	28.0	11.9	7.4
biochar	38.6	4819.2	140.8	16.2	7.4	7.4
control	73.5	4649.5	137.4	15.2	6.6	7.4

Soil Biological Activity - Lab Test

The term "soil microbial activity" refers to the various heterotrophic activities of macro-fauna, micro-fauna, and generally, the microorganisms that make up the soil food web. As Franzluebbers (2021) [33] explained by measuring the soil respiration (CO_2), we can quantify the efficient nutrient cycling and soil health, which is a fundamental heterotrophic process of reusing carbon in the soil to balance the autotrophic process of photosynthesis and carbon cycle [34,35].

Understanding the impact of organic matter and nutrients on crops and the environment requires knowledge of potential carbon (C) and nitrogen (N) mineralization as well as soil microbial biomass C (SMBC). As microorganisms are the primary agents of decomposition, they account for more than 90% of heterotrophic respiration. Additionally, the biological activity test serves as an indicator of total organic matter in the soil.

Soil Incubation

Soil-test biological activity (STBA) may be an important indicator of soil N availability (Franzluebbers 2020). Testing was conducted to measure soil-test biological activity (STBA), cumulative carbon (C) mineralization (CMIN), basal soil response (BSR), (Figures 9 to 13) (Franzluebbers, 2021) [33]. STBA was measured through three days of aerobic incubation at 50% water-filled pore space and 25°C, while CMIN was measured through 24 days of aerobic incubation under the same conditions. Soil basal respiration (BSR) refers to the constant rate of respiration in soil that results from the breakdown of organic matter. This rate can be determined by measuring the amount of CO_2 released (Figure 15) or O_2 consumed.

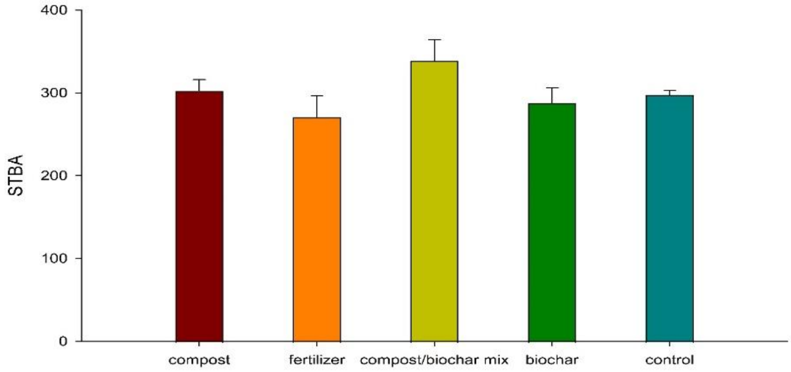

Figure 9: Soil-Test Biological Activity (STBA) Data (May 6, 2021) For All Treatments.

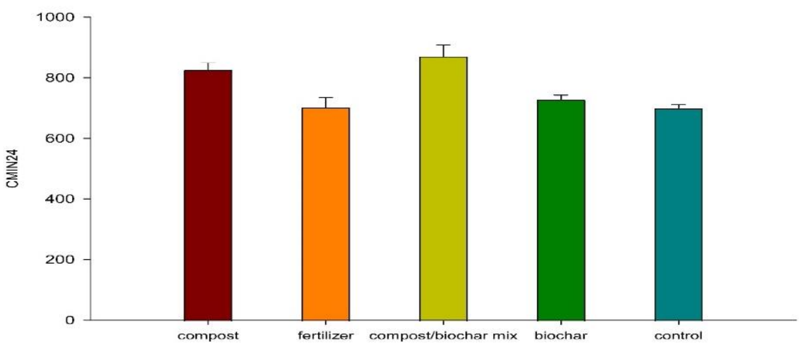

Figure 10: Cumulative C Mineralization In 24 Days (CMIN24) (May 6, 2021)

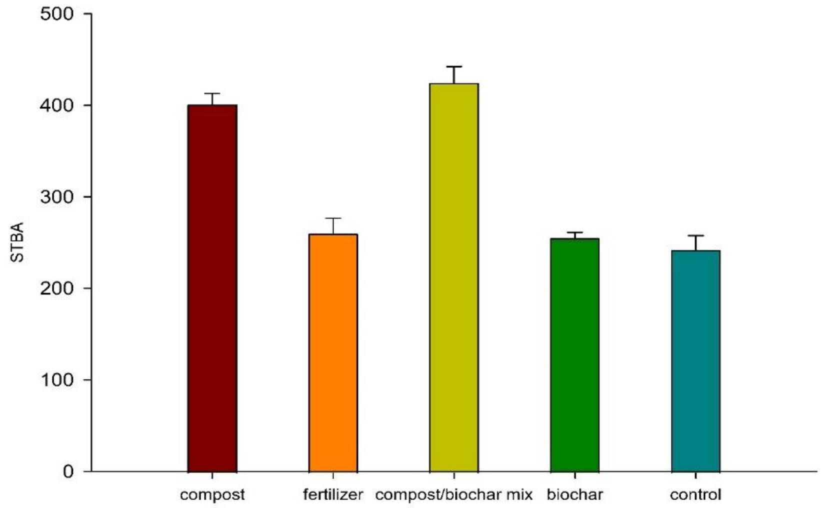

Figure 11: Soil-Test Biological Activity (STBA) Data (June 14, 2022)

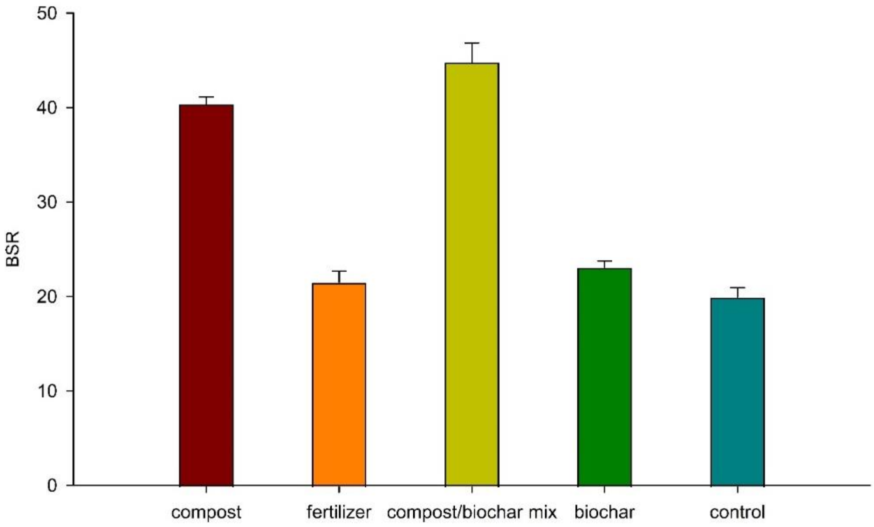

Figure 12: Basal Soil Respiration (BSR) Data (June 14, 2022)

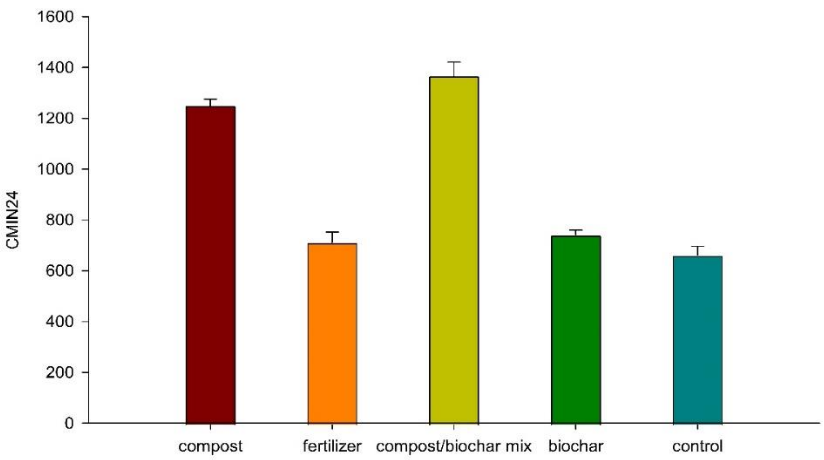

Figure 13: Cumulative C Mineralization In 24 Days (CMIN24) Data (June 14, 2022).

Carbon Dioxide (CO_2) Efflux

As shown in figure 14, land application of compost produced the highest amount of CO_2 as compared to the other treatments. Compost/biochar mix was the second highest CO_2 producer possibly due to the compost being in the mix. On the other hand, the application of biochar produced the lowest amount of CO_2 possibly due to retention (carbon sequestration) of the soil C to biochar thus preventing it from being emitted as carbon dioxide into the atmosphere.

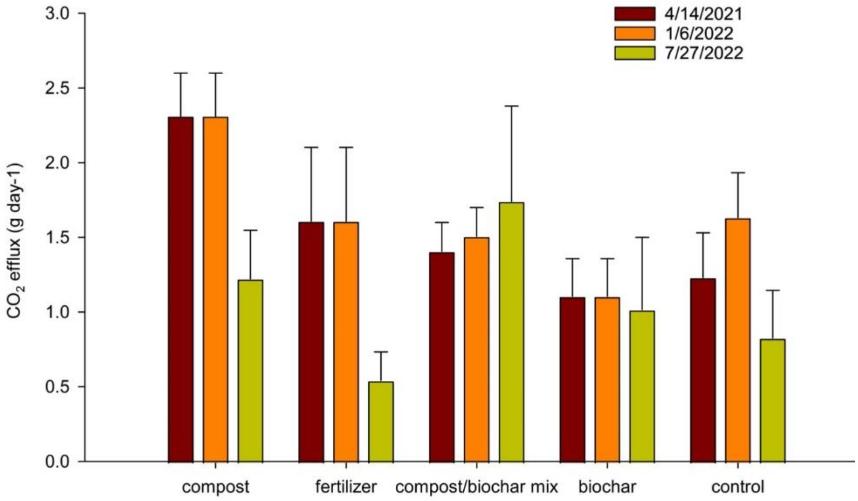

Figure 14: CO_2 Efflux from All Treatments Throughout the Cropping Seasons

Crop Yield

During Season 1 (May 7, 2021, Figure 15), the crop yield for compost, fertilizer, and compost/biochar mix treatments was equivalent. However, the biochar plot outperformed the control plot in terms of yield (Table 5).

In Season 2 (Jan. 1, 2022), the crop yield from biochar plots was higher and statistically different from the control group. Fertilizer plots yielded significantly more than compost and compost/biochar mix groups (Figure 15). However, significant damage from insects and wild chickens likely impacted the data.

In Season 3, another dry season, the same experiment showed that the biochar and control groups did not yield statistically different results. Nevertheless, the biochar yielded greater results compared to the control group (Figure 15). There was a decrease in fertilizer plot yield during the rainy season. This is most likely due to leaching of fertilizer caused by heavy rain, which significantly impacts the porous soil in the northern region by washing in the fertilizers below the root zone (Figure 15).

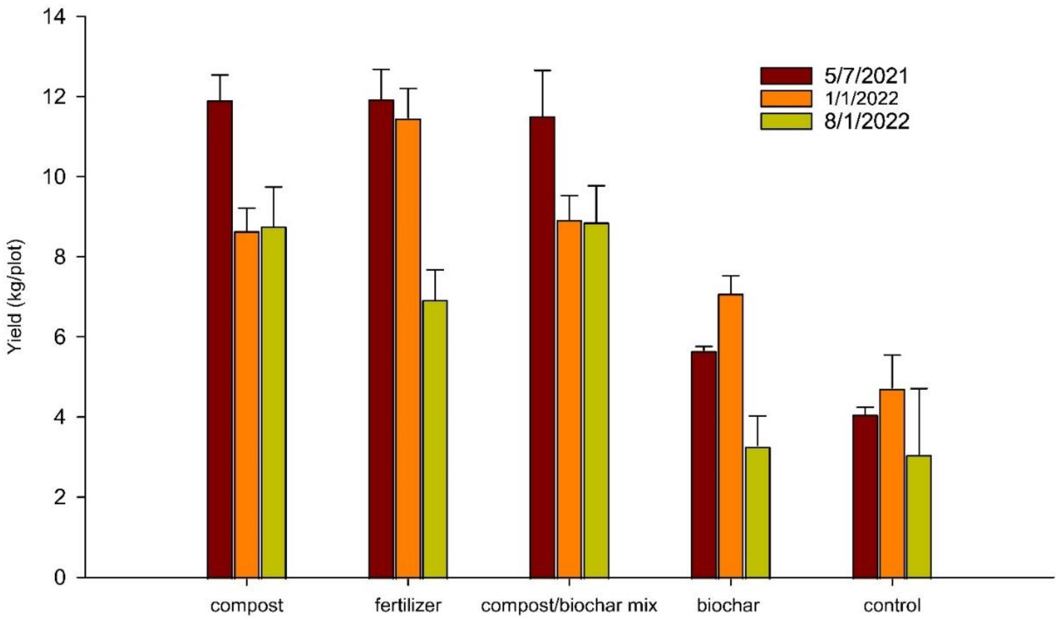

Figure 15: Crop Yield (2021-2022).

Table 5: Crop Yield (Kg/Plot) And Sem.

Treatment	5/7/2021	SEM	1/1/2022	SEM	8/1/2022	SEM
compost	11.916	0.625	8.655	0.556	8.773	0.967
fertilizer	11.940	0.744	11.465	0.733	6.942	0.733
compost/biochar mix	11.522	1.133	8.933	0.601	8.876	0.898
biochar	5.669	0.087	7.098	0.438	3.289	0.735
control	4.082	0.160	4.724	0.816	3.078	1.633

The Consequences of Insect Damage

In January 2022 (Season 2, as indicated in Figure 15), 144 ears of corn were damaged by Japanese beetles and wild chickens. However, no cases of the disease were observed. In contrast, no plants went missing or damaged during Season 1. Eighteen plants were reported missing during Season 3. Damages caused by insects and other animals (data not shown) may have contributed to the unsatisfactory yield of both compost and compost/biochar mix, causing inconsistency in the data.

Discussions

In this study, all soil plots exhibited a range of 8%-12% for TC and 0.3% to 0.7% for TN. Compost-enriched plots contained the highest levels of C, with biochar surpassing both fertilizer and control, which have comparatively lower rates. Compost and compost/biochar mix plots overall contained more N, as statistical data showed. Although compost and compost/biochar mix exhibited a low nitrogen level, they managed to produce similar crop yield during most of the cropping season, comparable to plots treated with fertilizers. However, fertilizer plots suffered lower yields during the wet season, likely due to the lack of SOM and/or leaching of the applied fertilizer which was caused by intense rainfall during the season.

During the dry seasons however, the compost/biochar mix had lower CO_2 efflux than compost-only plots. Lab testing showed that the BSR of compost and compost/biochar mix had the highest response to treatments.

One of the concerns is the use of biochar in alkaline soils, such as those found in northern Guam, and its potential to increase soil pH and subsequently impact the availability of macro and micro nutrients for plant growth. When the pH level is above 7, phosphate binds with calcium or calcium carbonate. This results in phosphorus becoming immobile and inaccessible for plants to use. However, compost proves to be particularly advantageous during wet seasons as it lessens the necessity for frequent application in contrast to inorganic fertilizer. On the other hand, over-application of inorganic fertilizer can harm the environment significantly. In addition, farmers will likely increase the use of other agricultural chemicals along with fertilizers which will have negative impact on the environment al-in-all.

Conclusion

To achieve sustainable and climate-resilient farming, it is crucial to prioritize soil fertility that fosters favorable chemical, physical, and biological conditions with minimal environmental harm. Incorporating biochar and compost into the soil has the potential to contribute to these goals. Our findings demonstrated that using biochar, either on its own or as a mixture in conjunction with compost, can significantly decrease the amount of CO_2 emissions from the soil while enhancing crop production. However, biochar's long-term agronomical and environmental impact is unknown, and further study is recommended to reach a conclusive answer.

Declaration of Competing Interest:

Authors declare no conflict of interest.

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Authors' Contribution:

Mr. Ferdinand Galsim, is a research associate at the Western Pacific Tropical Research Center, College of Natural & Applied Sciences, University of Guam who conducted the research and collected the data throughout the study period for testing and analysis. He also, preformed statistical analysis for all the data collected throughout the study period.

Mohammad H. Golabi, Professor of Soil and Environmental Sciences, at the Western Pacific Tropical Research Center, College of Natural & Applied Sciences, University of Guam. Dr. Golabi supervised the research project and drafted and developed the manuscript into its final version, and he is the corresponding author for the paper.

Alan J. Franzluebbers, Plant Science Research Ecologist at the U.S. Department of Agriculture, Agricultural Research Service, North Carolina State University. Dr. Franzluebbers, provided the analysis and the test results for the biological activities in the soil samples from the field plots under the study.

Clancy Iyekar is a Research Associate at the UOG Soil Lab and assisted with all the soil testing and soil sample analysis throughout the study period.

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