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Carbon Sequestration Potential of Soil Applied with Different Rates of Vermichar

Angelo V. Capurian*[1], Artemio A. Martin Jr.[2], Melchor C. Madrid[3], Lucila V. Rocha[4]
[1] Isabela State University, Echague, Isabela, Philippines
[2, 3, 4] Faculty of College of Agriculture, Isabela State University, Echague, Isabela, Philippines
*Corresponding Author email: *capurianangelo@gmail.com*

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Abstract
Aim: Climate change is a pressing global issue, and carbon sequestration plays a vital role in mitigating its effects. This study aimed to evaluate the carbon sink potential of soil applied with different rates of vermichar.
Methodology: This study was conducted in a field experiment at a farmer's field school in FDN Integrated Farm, Ballesteros, Aurora, Isabela. A series of test was conducted, which included the following: comparison of the physico-chemical composition of the formulated vermichar; determination of the microbial population count of soils applied with vermichar; and evaluation the efficacy of vermichar as a nutrient supplement to the crop. The study employed Randomized Complete Block Design with three replications.
Results: The application of different rates of vermichar has greatly affected the soil physico-chemical properties as well as the microbial activity in the soil. The T6 Vermichar 75:25 showed the highest potential for enhancing the carbon sequestration capacity of the soil, due to the increased microbial activity and diversity and T3 Vermicast showed also the highest potential for enhancing the carbon sequestration capacity of the soil, due to the increased fungal count. The increased microbial activity and fungal communities in these treatments contributed to the improved stabilization and long-term storage of organic carbon in the soil. Higher proportion of vermicast (75:25) appears to be the most effective soil amendment based on their superior organic matter and nutrient content, making them ideal choices for improving soil fertility and plant growth.
Conclusion: The application of vermichar as soil amendments can significantly enhance the carbon sequestration potential of soils. Its usage is applicable for the attainment of sustainable agriculture practices and climate change mitigation. It has shown a significant increased in the soil organic matter content. The increase in soil organic matter is beneficial for improving soil fertility, water-holding capacity, and overall soil health

Keywords: *vermichar, carbon sequestration, vermicast, soil amendments, physic-chemical properties*

INTRODUCTION

The rapid increase in waste volume is a major environmental problem that hinders global development. The Philippine Organic Agriculture Act (RA 10068) promotes and implements organic farming practices to improve soil fertility, increase farm productivity, reduce pollution and environmental destruction, and address Sustainable Development Goal (SDG) No. 15 on the Life on Land to restore and reverse land degradation.

Using organic amendments in problematic soils is essential to restore degraded soils and create a better environment for soil microorganisms and plants. Organic fertilizers can enhance biodiversity, and long-term soil productivity, and serve as a large reservoir for excess carbon dioxide. Carbon sequestration, capturing and storing atmospheric carbon dioxide, is crucial for mitigating climate change. Soil plays a significant role in carbon storage, and enhancing its capacity can contribute to climate change mitigation efforts through the Sustainable Development Goal (SDG) No. 13 to combat climate change and its impacts, especially in agriculture.

Continuous use of organic fertilizers has been found to increase soil organic matter, reduce erosion, improve water infiltration and aeration, boost soil biological activity, and increase crop yields. The benefits of organic fertilizers, the availability of raw materials, and the high costs of chemical fertilizers favor the production of organic fertilizers.

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A growing body of literature has highlighted the significant impact of organic feedstock composition on the characteristics and carbon sequestration potential of vermichar. Studies have investigated using of various organic waste streams, including agricultural residues, food waste, and lignocellulosic biomass, as feedstocks for vermicomposting (Gómez-Brandón, 2021; Yadav, 2020).

Biochar, a carbon-rich material produced through the pyrolysis of organic matter, has the potential to sequester carbon in the soil. Similarly, vermichar, a biochar-like material created by combining biochar and vermicast, has been explored as a soil amendment to enhance carbon storage and improve soil health.

The findings suggest that the lignin and cellulose content of the organic feedstock play a crucial role in determining the recalcitrance and long-term stability of the resulting vermichar. Vermichar derived from woody biomass and lignocellulosic materials has been shown to exhibit a more stable carbon fraction, with a slower rate of mineralization compared to vermichar from more labile organic sources (Jindo, 2020; Lazcano, 2021).

Considering the known benefits of biochar mixed in compost (Sanchez-Monedero, 2018), hypothesized that vermicomposting of blended organic feedstock with biochar may lead to improved vermicompost or vermichar characterized by a higher content of enzyme-coated biochar. Many studies have reported that enzymes reach a maximum activity in the first 2-3 weeks of vermicomposting and decrease progressively by the end of decomposing maturation phases (García-Sánchez, 2017; Sudkolai & Nourbakhsh, 2017; Usmani, 2018). The reduction of enzyme activity is explained by the decline in microbial biomass and its activity is linked to a decrease in the earthworm activity as the final vermicompost is stabilized (García-Sánchez, 2017; Cui, 2018). Thus, the addition of biochar in vermicomposting could serve as a physical storage for retaining extracellular enzymes actively produced in the first phase of vermicomposting, avoiding their further degradation in the later composting stages.

Biochar improves soil physical properties including the increase of porosity and water storage capacity, as well as the decrease of bulk density. Biochar may also be used as a sustainable amendment to enhance soil chemical properties (Lehmann, 2011). Besides the direct amendment of biochar on soil's properties, biochar can also alter the microbial and nutritional status of the soil within the plant rooting zone by changing soil physical properties (bulk density, porosity, and particle size distribution). Overall, the improved physical properties of soil, such as bulk density, water holding capacity, and aggregation ability, may increase the retention of both water and nutrients, which benefits soil fertility directly.

The integration of biochar into the vermicomposting process has gained further attention, as it has been shown to synergistically improve the carbon sequestration capacity of the resulting vermichar. Studies have explored the co-application of biochar and vermichar, as well as the incorporation of biochar directly into the vermicomposting system (Fornes, 2018). Additionally, the use of other soil amendments, such as compost and mineral additives, has been investigated in combination with vermichar to further enhance soil properties and carbon storage (Lazcano, 2021; Yadav, 2021).

The properties of vermichar, such as its carbon content, nutrient profile, and recalcitrance, can vary depending on the organic feedstock used, the vermicomposting process, and the specific earthworm species involved. Studies have shown that the choice of organic materials, including agricultural crop residues, food waste, and woody biomass, can significantly influence the characteristics of the resulting vermichar (Lazcano, 2008; Domínguez, 2010).

The incorporation of vermichar into soil has been demonstrated to enhance carbon sequestration by increasing the stable carbon content and improving soil properties (Liang, 2017; Jindo, 2012). However, the long-term stability and persistence of the applied vermichar in the soil are crucial factors in determining its carbon storage potential (Beesley, 2011; Lehmann, 2011). The incorporation of biochar into the vermicomposting process has been studied as a strategy to enhance the carbon sequestration potential of the resulting vermichar. The synergistic effects of biochar and vermicomposting have been shown to improve soil properties and increase the stability of the carbon-rich amendments (Hua, 2009; Fornes, 2012).

Because composting and vermicomposting share many functional characteristics (Lim, 2016), it is reasonable to assume that the addition of biochar to vermicomposting will have comparable effects as those described for co-composting feedstock with biochar (Kammann, 2015; Sanchez-Monedero, 2018; El-Naggar, 2019). Indeed, biochar appears to be an excellent additive for increasing vermicomposting efficiency (Malińska, 2016), and reducing metal toxicity of hazardous feedstocks such as sewage sludges (Malińska, 2017). Colonization of biochar surface by microorganisms may explain the synergistic effects of biochar and these decomposing processes. Additionally, the presence of earthworms in the aerobic decomposition phase may introduce further benefits. In particular, earthworm mucus could act as a cross-linking substance, favoring extracellular enzyme binding to the biochar surface.

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Objectives

Generally, this study aimed to evaluate the carbon sink potential of soil applied with different rates of vermichar.

Specifically, it was conducted to:

1. compare the physico-chemical composition of the formulated vermichar; and
2. determine the microbial population count of soils applied with vermichar and idenfication of microorganism in the soil.

METHODS

Vermichar Production Process

Biochar was produced via pyrolysis at the Organic Fertilizer Production Facility in ISU-Echague Campus using coconut husk & shells as the organic material. Vermicast was also procured from the same facility.

Vermichar was produced by combining and mixing the biochar and vermicast. The formulated vermichar was then allowed to stay 2-3 days for further processing before the application to the soil.

Combining biochar and vermicast to produce vermichar was carried out to leverage the beneficial properties of both organic amendments and a 2-3 day curing period allowed for further integration and stabilization of the vermichar before it was applied to the experimental plots.

Preparation of Vermichar Treatments

The preparation of vermichar treatments by specific ratio was prepared the three (3) formulated vermichar of the following:

a. 9 kg Vermicast: 9 kg Biochar at 3 tons/ha;
b. 4.5 kg Vermicast: 13.5 kg Biochar at 3 tons/ha;
c. 13.5 kg Vermicast: 4.5 kg Biochar) 3 tons/ha.

Collection of Soil Sample and Analysis

Soil samples were randomly collected from the experimental area using farm tools. The soil samples were processed by spreading in PORTASOL Trays with newspaper, air dried, pulverized, and screened. A one-kilogram of the composite soil sample was set aside and submitted to the Department of Agriculture (DA)- Cagayan Valley Research Center (CVRC)-Soils Laboratory, San Felipe, City of Ilagan, Isabela, and Department of Agriculture (DA)-Cagayan Valley Integrated Agricultural Laboratory (CVIAL), Carig Sur, Tuguegarao City, Cagayan for the analysis of pH and nutrients.

Fertilizer and Microbial Analysis

The formulated vermichar sample products were brought to the Fertilizer Pesticide Authority (FPA), Quezon City, Manila for fertilizer analysis. The soil samples per treatment for microbial analysis were collected and pre-initial media preparation at the Soils Laboratory, College of Agriculture, Isabela State University, Echague, Isabela, and the final result of the analysis is couriered with the assistance of the Department of Science and Technology Region 02 (DOST R02) - Regional Science and Technology Laboratory (RSTL) in Carig Sur, Tuguegarao City, Cagayan.

Data Gathered

1. **Soil Physico-Chemical Properties.** The physicochemical properties of soil were recorded based on the results of the analysis before and after the conduct of the study.
2. **Microbial Count Plate and Identification.** The soil samples for microbial analysis were collected from at least 100 grams of moist soil for the microbial count and identification of microorganisms after 60 days of planting in each treatment.

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Statistical Analysis

The collected data was analyzed using the ANOVA for Randomized Complete Block Design in the Statistical Tool for Agricultural Research (STAR) computer package. Any differences among treatment means were compared using Tukey's Honest Significant Difference (HSD).

RESULTS and DISCUSSION

A. Soil Properties before Application of Soil Amendments

The chemical composition of the soil before amended with organic materials is presented in Table 1.

Table 1. Chemical Composition of Soil Before without Soil Amendments

Chemical Properties	Level	Qualitative Description	Range
Soil pH	6.72	Slightly Alkaline	5.5-8.5
Organic Matter (%)	2.19	Low	>3.00%
Organic Carbon (%)	1.27	Low	0.5-3.0
Nitrogen (%)	0.10	Low	>0.227%
Available P (ppm)	9.69	Low	>30 ppm
Exchangeable K (ppm)	211.64	Low	>240 ppm

The pH of the soil used in the experiment is 6.72 which is described as "slightly alkaline". Soil pH is a measurement of the acidity or basicity of soil, specifically affects the plant nutrient availability by controlling the chemical forms of the different nutrients and influencing the chemical reactions they undergo. Soil organic matter content is considered low at 2.19 percent; organic carbon and nitrogen are also low at 1.27 and 0.10 percent, respectively. Sustainable crop production can only be attained when the soil contains 3.44 percent organic matter. Sustainability is achieved because soil organic matter (SOM) above 3.44 percent stabilizes the soil structure, decreases the bulk density, and promotes heightened nutrient cycling. Soils with SOM content of 2.06 percent are susceptible to degradation. The critical limit of the soil available P for crop production is 10 ppm. This means that the soil (9.69 ppm) contained low Phosphorus. Potassium aids the plant in using water efficiently, preventing many diseases and heat damage. Potassium helps cycle nutrients through leaves, roots and stems. The soil in the study contains a "low" amount of potassium at 211.64 ppm.

B. Nutrient Composition of Soil Amendments

The formulated vermichar products were analyzed for Soil Organic Matter (SOM), Soil Organic Carbon (SOC), Nitrogen (N), Phosphorus (P), Potassium (K) and Carbon (C) and Nitrogen(N) (C:N) ratio. Table 2 presents the nutrient content of the soil amendments.

In terms of SOM, all the soil amendments showed high amounts of OM. However, the vermicast has the maximum at 30.84 percent, while biochar has 8.8 percent. Among the vermichar products, the vermichar with vermicast and biochar at 75:25 ratio had the highest at 14.31 percent, followed by the 50:50 ratios with 11.86 percent. The lowest organic matter is noted on the vermichar with 25:75 vermicast/ biochar ratios with a minimum value of 8.37 percent. Organic matter serves as a reservoir of nutrients and water in the soil, aids in reducing

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compaction and surface crusting, and increases water infiltration into the soil. Organic matter contributes to plant growth through its effect on the physical, chemical, and biological properties of the soil. The presence of organic carbon in compost helps improve soil's physical and chemical properties. The vermicast, vermichar (75:25), vermichar (50:50) have very high amounts of organic carbon at 17.8, 8.29 and 6.87 percent, respectively. While biochar and vermichar (25:75) have low amounts of OC with 5.1 and 4.85 percent, respectively.

Table 2. Chemical Composition of Biochar, Vermicast and Vermichar Products.

Treatments	OM (%)	OC %	N (%)	P (%)	K (%)	NPK	C:N Ratio
Biochar	8.80	5.10	0.44	1.13	0.82	2.39	11.59
Vermicast	30.84	17.8	0.93	0.97	1.54	3.44	19.13
Vermichar (50:50)	11.86	6.87	0.47	4.41	0.45	5.33	14.62
Vermichar (25:75)	8.37	4.85	0.38	4.58	0.34	5.30	12.76
Vermichar (75:25)	14.31	8.29	0.67	3.02	0.56	4.25	12.37

The vermicast and vermichar (75:25) have very high amounts of nitrogen at 0.93 and 0.67 percent, respectively. While biochar with 0.44 percent, vermichar (50:50) and vermichar (25:75) have low amounts of nitrogen with 0.44, 0.47, and 0.38 percent, respectively. Available phosphorus of the soil amendments is considered very high at 0.97 to 4.58 percent, with vermichar (25:75) being the maximum, and the minimum value is noted on the vermicast. Exchangeable potassium was excessive in all the soil amendments with values ranging from 0.34 to 1.54 percent. The total NPK of the soil biochar, vermicast, and vermichar (75:25) were 2.39, 3.44, and 4.25, which is lower than the 5% required for a material to be considered organic (PNS for Organic Fertilizer). Only the vermichar (50:50) and vermichar (25:75) with NPK values of 5.33 and 5.30 reached the required NPK to be considered organic soil amendment.

C. Soil Properties after Application of Soil Amendments

The chemical properties of soil amended with organic materials for 3 months are presented in Table 3.

Table 3. Soil chemical properties with soil amendments after 3 months.

Treatments	pH	OM (%)	OC (%)	N (%)	P (ppm)	K (ppm)	C:N Ratio
Control	7.18	1.82	1.05	0.09	15.47	347.81	11.73
Biochar	7.81	2.77	1.60	0.14	115.96	381.68	11.47
Vermicast	7.06	2.70	1.56	0.14	55.98	417.55	11.18
Vermichar (50:50)	7.53	2.43	1.41	0.12	40.13	348.80	11.74
Vermichar (25:75)	7.53	2.43	1.41	0.12	28.67	365.74	11.74
Vermichar (75:25)	7.55	2.13	1.24	0.11	29.42	365.74	11.23

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Soil pH. Table 3 shows the pH level of the amended soils after 3 months. There is a significant increase in the soil pH of soils amended with the five organic materials. The pH of soil amended with biochar (T_2) is the highest with 7.81. Application of vermicast increased soil pH by 0.34 units, while vermichar (50:50) and vermichar (25:75) improved the pH by 0.81 units and 0.83 units for vemichar (75:25). Surprisingly, untreated soil decreases the pH by 0.12 units, while vermichar (75:25) application remains the same with the biochar at 7.81. From the original soil pH of 6.72, there is strong evidence that the vermicast and vermichar application intervention raised the soil pH.

Organic Matter. The change in organic matter content of soils amended with five types of organic soil amendment was visibly indicated in Table 3. All the materials used as organic soil amendment increased the soil organic matter by 17.03 percent (vermichar 75:25), 33.52 percent (vermichar 25:75 and 50:50), 48.35 percent (vermicast) and 52.20 percent (biochar). The increase in the soil organic matter content was associated with the organic material application. Organic matter plays an important role in maintaining soil fertility as a buffering agent of toxic microelements present in the soil. In addition, organic matter in acidic soil also increases the pH to be optimum for plant growth. Many studies have shown that biochar improves the physicochemical properties of soil, particularly maintaining the soil organic matter levels (Chan, 2007). Furthermore, the application of organic materials to soils is a practical method to aid in the long-term maintenance of the soil's organic carbon contents and soil fertility. The application of organic material to soils can maintain SOM levels and soil aggregation stability (Kimetu & Lehmann, 2010) because these contain recalcitrant Carbon from microbial degradation and by a charged surface with organic functional groups.

Organic Carbon. The organic carbon content of the soil ranges from 1.05 to 1.60. SOC acts as a nutrient reservoir, providing a steady supply of essential elements for plant uptake. It enhances nutrient retention, reduces nutrient leaching, and improves nutrient cycling within the soil. This results in improved nutrient availability for plants, promoting healthy growth and higher crop yields. The biochar, vermicast, and vermichar formulated have obtained the highest OC% of 1.60, 1.56, and 1.41, respectively, while the control and vermichar 75:25 have the lowest amount of OC% of 1.05 and 1.24, respectively. Soil organic carbon affects soil carbon efflux by serving as a source of carbon dioxide (CO2) emissions when decomposed by microorganisms in the soil. The amount of organic carbon in the soil varies majorly depending on factors like soil type, land use, and management practices. It generally ranges between 1% and 6% of the soil's weight.

Nitrogen. According to Mukherjee and Zimmerman (2013) and Zheng (2013), any material of organic origin has great potential as a source of available nutrients and could release large amounts of nitrogen. Table 3 further indicates that there is a significant difference in the nitrogen contents of the organic-treated soils and the control. Unamended soil had 0.09 percent nitrogen after the experiment, while biochar and vermicast application improved it by 55.56 percent. Application of vermichar increased soil nitrogen by 33.33 percent (vermichar 50:50, 25:75) while vermichar (75:25) had the least increment at 22.22 percent.

Available Phosphorus. Adequate phosphorus nutrition enhances many aspects of plant development including flowering, fruiting, and root growth. The phosphorus contents of soils amended with organic materials significantly increased as evidenced by the P values in soils applied biochar higher by 115.96 ppm, vermicast by 55.98 ppm, and vermichar by 28.67 to 40.13 ppm relative to the untreated soil. The untreated soil (control) obtained the lowest P content with a value of 15.47 ppm. The function of phosphorus in plants is very important. It helps a plant convert other nutrients into usable building blocks with which to grow. Phosphorus is one of the main three nutrients. Phosphorus is one of the most important elements for plant growth and metabolism. It plays key roles in many plant processes such as energy metabolism, the synthesis of nucleic acids and membranes, photosynthesis, respiration, nitrogen fixation, and enzyme regulation (Raghothama, 1999).

Exchangeable Potassium. Table 3 further shows the potassium contents of the amended soils after 3 months. Except with vermicast which improved the potassium content of the soil by 20.05 percent, the application of biochar and vermichar indicated a slight improvement with 9.74 percent with the biochar application and 0.28 to 5.16 percent from vermichar regardless of ratio. From the original K level of 347.81 ppm, organic soil amendments slightly improve the potassium availability in the soils. The vermicast-amended soils indicated the greatest potential to improve potassium levels relative to the control.

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C:N Ratio. The C:N ratio is a quick way to evaluate the balance between two elements present in the soil that are both essential for crop growth and microbial health. The C:N ratio in the organic matter of agricultural soils ideally averages about 10:1. Table 3 shows the ranges from 11.18 to 11.74. This is considered an indication of a dynamic equilibrium condition that can and should be maintained. When organic material is added to the soil in root residue, manure, corn stalks, etc., the increased carbon triggers microbial growth.

Microbial Plate Count of Soils and Idenfication of Microorganism

Microbial Count of the Soils applied with Vermichar. Microbial plate count analysis was done on soil applied with organic materials. Soil microorganisms play a crucial role in the carbon sequestration process by transforming plant residues into smaller carbon molecules that are more likely to be protected and sequestered (Six, 2006). This serves as the basis whether the organic materials had enhanced the biological activities of the microorganisms present in the biochar, vermicast and vermichar products.

The sample with the highest bacterial count is T_6 - Vermichar (75:25). The total bacterial count in this treatment is 8.6 X 10^6, which is significantly higher than the other treatments. Increased microbial activity and diversity, as indicated by the higher bacterial count, can enhance the soil's ability to sequester and stabilize carbon. Microorganisms play a crucial role in the decomposition and transformation of organic matter, which is essential for carbon sequestration.

Table 4. Microbial Count of the Soils applied with different rates of vermichar

Samples	Bacteria (CFU/ml)	Fungi (CFU/ml)
T1- Soil (No amendment)	4.2 X 10^6	1.7 X 10^6
T2- Biochar	1.5 X 10^6	1.6 X 10^5
T3- Vermicast	1.4 X 10^6	1.8 X 10^5
T4- Vermichar (50:50)	1.6 X 10^6	2.1 X 10^6
T5- Vermichar (25:75)	1.7 X 10^6	1.6 X 10^6
T6- Vermichar (75:25)	8.6 X 10^6	1.8 X 10^5

The use of vermichar, a type of biochar produced through vermiculture, in the T6 treatment appears to have created a favorable environment for the microbial communities to thrive. Biochar has been shown to improve soil physical, chemical, and biological properties, which can promote carbon sequestration. A higher proportion of vermichar (75:25) in the T_6 treatment seems to have had a synergistic effect, leading to the highest bacterial count among the treatments. The increased bacterial count in the T_6 treatment suggests that this treatment may have the highest potential for carbon sequestration in the soil. The active and diverse microbial communities can facilitate the stabilization and long-term storage of organic carbon in the soil. In contrast, the other treatments, such as T_2 (Biochar), T_3 (Vermicast), T_4 (Vermichar 50:50), and T_5 (Vermichar 25:75), showed lower bacterial counts, indicating a relatively lower potential for carbon sequestration compared to the T_6 treatment.

For the fungi (Yeast & Molds), the treatment with the highest mean CFU (Colony Forming Units) count is T_3 - Vermicast. The total mean CFU count in this treatment is 2.1 X 10^6, which is the highest among all treatments. Fungi play a crucial role in the decomposition of organic matter and the formation of stable soil organic carbon. Therefore, an increased fungal count can indicate enhanced potential for carbon sequestration in the soil. The use of vermichar, particularly in the T_3 treatment, appears to have created a favorable environment for fungal growth. This

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suggests that the application of vermichar may promote the proliferation of fungi, which can contribute to the enhancement of carbon sequestration potential in the soil. The T_6 treatment with vermichar (75:25) also shows a relatively high mean CFU count of 1.8 X 10^5, indicating that this treatment may also have a positive impact on fungal activity and potentially on carbon sequestration. In contrast, the T_2 treatment with biochar has the lowest mean CFU count of 1.6 X 10^5, suggesting a relatively lower potential for promoting fungal activity and carbon sequestration compared to the other treatments.

Soil fungi and bacteria play an important role in processing soil organic matter and soil carbon sequestration by maximizing the amount of carbon allocated to the soil and producing compounds that improve aggregate stability. These decomposition processes are essential to maximizing biomass production and ensuring that carbon is converted into stable forms that remain protected in soil (Six, 2006).

Conclusions

The application of vermichar as soil amendments can significantly enhance the carbon sequestration potential of soils. Its usage is applicable for the attaintment of sustainable agriculture practices and climate change mitigation. It has shown a significant increased in the soil organic matter content. The increase in soil organic matter is beneficial for improving soil fertility, water-holding capacity, and overall soil health

Recommendations

Based on the results of the study, the vermicast and the formulated vermichar (75:25 and 25:75) increased the soil pH. The vermicast and the vermichar with a higher proportion of vermicast (75:25) appears to be the most effective soil amendment based on their superior organic matter and nutrient content, making them ideal choices for improving soil fertility and plant growth. Thus, the study recommends their utilization.

The application of vermichar has greatly affected the soil physicochemical properties as well as the microbial activity in the soil. The increased microbial activity and fungal communities in these treatments contributed to the improved stabilization and long-term storage of organic carbon in the soil.

For the future researchers who would like to pursue the same study, explore, innovate and collaborate with prospective financiers who would like to invest in commercialization of the technology and to create impact on sustainable agriculture.

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