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LABORATORY INCUBATION STUDIES OF BIOCHAR AMENDMENT ON NON-CO_2 GREENHOUSE GAS EMISSIONS FROM SOIL CULTIVATED TO COCONUT SEEDLINGS

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ABSTRACT
Biochar is a carbon rich product obtained when biomass such as wood, manure or leaves is heated in a closed vessel with little or no air. It is an appropriate tool for sequestrating carbon dioxide in soils for long time in order to mitigate climate change. The objective was to determine the effects of biochar amendment on greenhouse gas emissions from soil cultivated to the coconut seedlings. The palm fronds biochar produced at 300^{o}C for three hours was characterized in terms of pH, attrition, porosity, bulk density, ash content, conductivity, surface charge, nutrient value, yield% and surface area. Soil samples collected were prepared and analyzed for physico-chemical properties in the laboratory using standard techniques. Glass jars (5L) with air-tight lids filled with 1.5kg dry wt soil, biochar at variable rate of (10-50)t dry biochar ha^{-1},and mesocosms were maintained in the dark at 23°C. Jars were sealed for 24 hours prior to headspace gas sampling. NH_3, CH_4, N_2O emissions, soil pH, cation exchange capacity (CEC), potassium (K) availability, and water retention in the soil were determined. Emission of N_2O-N ranged from 12 to 1255 µg N m^{-2}, hr^{-1} during 148 hours of the studies. Flux of CH_4 varied between 20 to 100 g CH_4 m^{-3}, hr^{-1}, however, increased sink of CH_4 flux in the soil was observed in the treatments. Biochar addition to the soil also caused reduced ammonification compared to the control The physico-chemical properties of the biochar–soil mixture samples showed significant ($p<0.05$) improvement.

Keywords: Biomass, Greenhouse gases, Climate change, Soil amendment, Biochar.

INTRODUCTION
Climate change caused by an increase in atmospheric concentrations of greenhouse gases (GHGs) is predicted to cause catastrophic impacts on our planet. This provides the impetus to take action to reduce emissions and increase removal of GHGs from the atmosphere.The soil is both a significant source and sink for the greenhouse gases carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O). As the global warming potential of N_2O and CH_4 is 298 and 25 times greater, respectively, than the equivalent mass of CO_2 in the atmosphere, small reductions in their emissions could potentially provide significant benefits for the environment.

Biochar application to soil has been shown to affect carbon (C) and nitrogen (N) transformation and retention processes in soil..

These processes, along with other mechanisms influenced
by biochar, can play a significant role in reducing emissions and increasing sink capacity for GHGs. The present communication presents a preliminary studies of the effect of palm frond biochar amendment on greenhouse gas emissions from soil resulting from rewetting air-dried soil in short-term laboratory experiments'

MATERIALS AND METHODS

Materials

Fronds of the African oil palm tree (*Elaeis guineensis*) were obtained from the premises of the Nigerian Institute for Oil Palm Research, Benin City, Nigeria. The sprouted coconut seedlings and the soil were of the institute.

Preparation of the Biochar

The Palm Fronds were separated from the palm stalk, reduced to small sizes for ease of handling and processing. 4.0 kg samples were pyrolyzed at 300°C for 3h. The Biochar obtained was then milled to fine powder using a mechanical grinder, and sieved through a mesh size of 150 µm. The Biochar particles that passed through the screen were collected, characterized and used for further analysis.

Characterization of the Biochar and the Soil samples

The Biochar was characterized as follows: % yield (dry weight basis) on pyrolysis was obtained from the weight difference pre- and post pyrolysis, ash content was determined using the method described in ASTM D1762-84, (1983); the bulk density was determined using the method described by Ahmedna et al (2000); the pH was determined using ASTM D 1512 (1983) method; the method used for surface area measurement was iodine adsorption, (Ishak and Baker,1995); conductivity of biochar was determined using the conductivity meter. Determination of total surface functional group was carried out by the method described by Boehm (1994). Attrition was determined using the method described by Marshal et al (1988); Porosity was determined using the method described in ASTMD1584 (1983). Calcium and magnesium concentrations were determined by EDTA titration, while the sodium and potassium concentrations were determined by flame photometry (Model 410, Sherwood, England) and the nutrient values were determined using AOAC standard methods.

Soil samples from surface to a depth of 30 cm were collected using auger and prepared for further analysis. All the reagents used for analysis were of analytical grade and were used without further purification

The soil samples were analyzed as follows: bulk density was measured by core method, Soil pH was measured in 1:1 soil-water ratio. Soil organic carbon was estimated by combustion at 840°C, while total nitrogen was obtained by microKjeldahl method. Cation exchange capacity was measured using ammonium acetate leaching at pH 7.0. Available phosphorus was determined by Olsen method.

Laboratory Incubation Studies

In laboratory incubation studies, glass jars (5L) with air-tight lids were filled with 1.5kg dry weight equivalent soil (2mm sieved) in triplicates. No fertilizer were added to the soil. The biochar was applied at a variable rate of (10-50)t dry biochar ha^{-1} (0–0.05m profile), and thoroughly mixed into the soil. Acid-washed sand were added to the control treatment at an equivalent rate to the biochar.

Soil moisture was increased to 70 percent water-holding capacity and maintained (by mass) for the duration of the incubation. Mesocosms were maintained in the dark at 23°C in a controlled temperature chamber. Jars were sealed for 24 hours prior to headspace gas sampling. CH_4, N_2O emissions, soil pH, cation exchange capacity (CEC), potassium

(K) availability, and water retention in the soil were determined.

Collection of gas samples was carried out by the closed chamber technique. Concentration of NH_3, CH_4 and N_2O in the gas samples was estimated by gas chromatograph fitted with a flame ionization detector (FID) and electron capture detector (ECD), respectively.

Statistical analysis

The results presented are the mean values ± standard errors obtained from at least three replicates. Significant differences between the treated and control soil were determined using ANOVA F-test ($P< 0.05$). Statistical analyses were conducted using the statistical software package Genstat 12.

RESULTS AND DISCUSSION

Results of greenhouse gas emissions from soil

The results of the physico-chemical properties of the biochar were presented in previous work, Ekebafe, (2011)

The greater the surface area, the more effective the biochar in relation to affecting soil properties (although the nature of the surfaces play an equally important role). Biochar macropores are also relevant to the movement of roots through soil; they store water and act as habitats for a vast variety of soil microbes.

The present studies have indicated that incorporating biochar within soil reduces N_2O emissions and increases CH_4 uptake from soil, which could contribute to mitigating greenhouse gas emissions. However, there is currently very limited understanding of the mechanisms through which biochar impacts upon fluxes of CH_4 and N_2O.

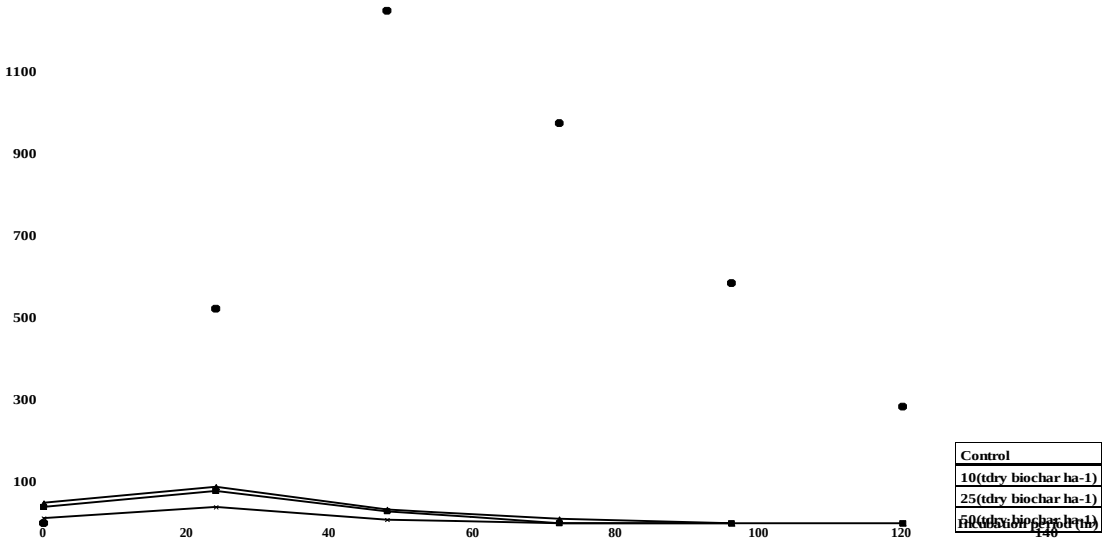
Emission of N2O

Emission of N_2O-N ranged from 12 to 1255 µg N m^{-2}, hr^{-1} during 148 hours of the experiment, Figure. 1. Denitrification of nitrate in anaerobic soil condition was presumably responsible for the formation of N_2O. A peak was observed in all the treatments at 48hr incubation period followed by a decline to reach a low level. Increased emission from all the jars at the early stage of incubation could be due to nitrification. Considerable emission of N_2O on the 48 hr incubation period was due to formation of N_2O during denitrification of nitrate N already present by enzymes. These enzymes sequentially convert nitrate to nitrite (*Nar*), nitrite to NO (*Nir*), NO to N_2O (*Nor*) and N_2O to N_2 (*Nos*), respectively:

NO_3 –_*Nar* NO_2 –_*Nir* NO _*Nor* N_2O _*Nos* N_2

N_2O production through the denitrification process is a balance between N_2O-producing mechanisms, involving *Nar*, *Nir*, *Nor* enzymes and N_2O-reducing mechanisms, involving *Nos* enzyme. The findings corroborated earlier research by Yanai et al (2007) who used biochars derived from municipal biowaste pH 9.3 and total C 38 per cent and showed a decrease in emissions of N_2O in laboratory chambers when soil was re-wetted to 73 per cent water-filled pore space.

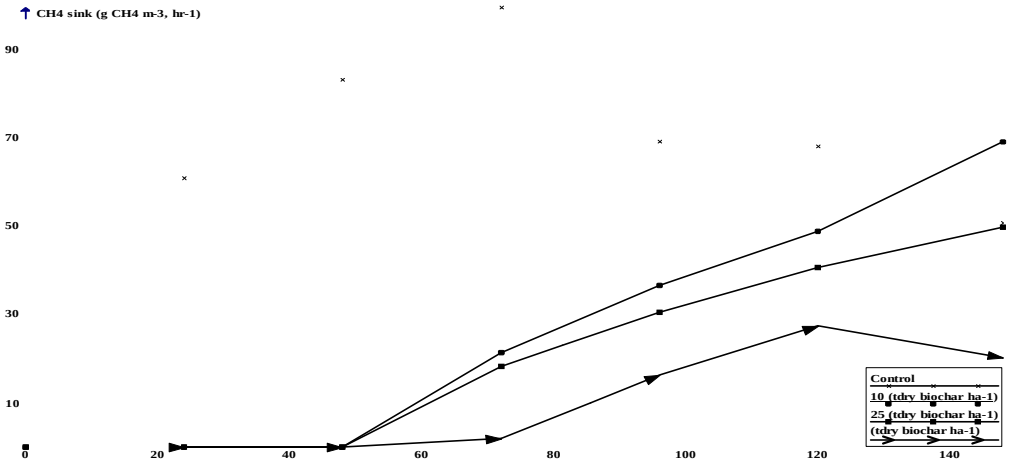
Figure 1: N_2O generated from a oil palm soil amended with biochar in laboratory mesocosms



CH_4 Sink

Flux of CH_4 varied between 20 to 100 g CH_4 m^{-3}, hr^{-1},Figure 2, however, increased sink of CH_4 flux in the soil was observed in the treatments. In first 48 hours, the emission was not detected because of intermittent drying of the soil. The soil moisture level went below saturation many times during the incubation and thus anaerobic condition required for the formation of CH_4 in soil did not exist. Therefore, in this experiment flux of CH_4 was dictated by moisture availability. The CH_4 uptake capacity of soil varies with land use, management practices (Saggar et al, 2007) and soil conditions (Schutz et al, 1990). In contrast, large emissions of CH_4 are common where anaerobic conditions (e.g. wetlands, rice paddies and landfills), coupled with warm temperatures and the presence of soluble C, provide ideal conditions for the generation of CO_2 and incompletely oxidized substrates, thus supporting high activity of methanogenic microorganisms.

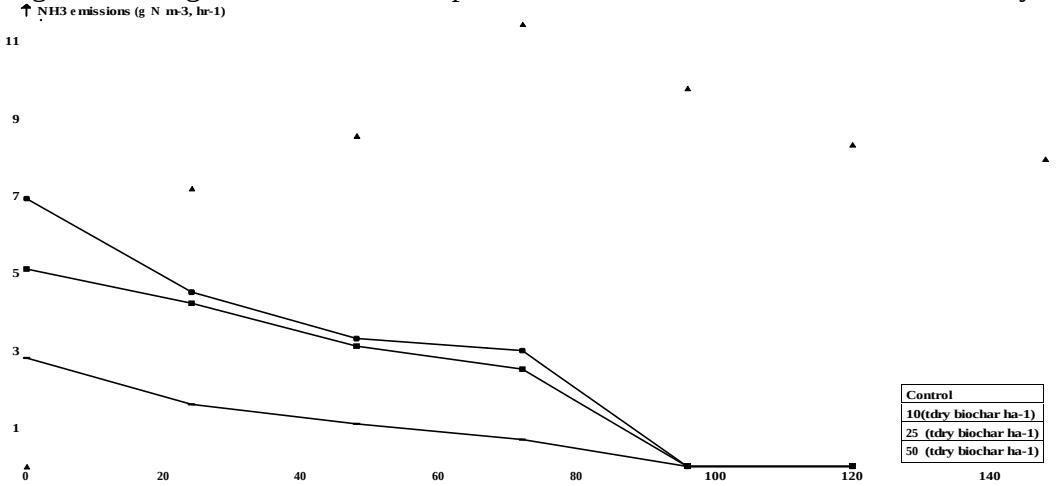
Figure 2 CH_4 sinked from a oil palm soil amended with biochar in laboratory mesocosms



NH_3 Emissions

Flux of NH_3 varied between 0 to 9.0 g NH_3 m^{-3}, hr^{-1},Figure 3, however, decreased volatilization of NH_3 flux in the soil was observed in the treatments, reason being that ammonia volatilization in agricultural soils is favoured at alkaline pH and when high concentrations of NH_4^+ are present (Stevenson and Cole, 1999). Biochar additions to agricultural soils, as well as acid forest soils, have been found to reduce NH_4^+ concentrations, which could be a result of volatilization; but it is more likely that surface adsorption of NH_4^+ reduces soil NH_4^+ concentrations and reduces the potential for NH_3 volatilization. Biochar addition to soil also caused reduced ammonification compared to the control as shown in figure 3.This is possibly due to NH_4^+ adsorption to biochar.

Figure 3 NH_3 generated from a oil palm soil amended with biochar in laboratory mesocosms



Effect on soil properties

Tables 1 summaries the effect of biochar amendment on the properties of soil supporting the coconut seedlings . The result showed a significant improvement on the soil pH, cation exchange capacity, available potassium and nitrogen in the soil compared to the control, also the water retention volume over the period showed the tendency for biochar to enhance the water holding capacity of the soil. However, there is a remarkable reduction in the total acidity of the soil obviously due to the high level of cation exchange capacity of the biochars and the pH and hence a reduction in the soil electrical conductivity. The Bulk density of the soil decreases resulting in increase penetrability of the water and other ions in the soil. The table shows the immediate positive effect of the biochar amendment on the physico-chemical properties of the soil over the period.

There is evidence that when pH of a soil is increased (e.g. by liming), denitrification liberates less N_2O and the ratio of N_2O/N_2 is decreased. In other words, alkalinity through biochar addition could potentially encourage the activity of N_2O reductase enzymes of denitrifying microorganisms (Yanai et al, 2007). Both methanogenic and methanotrophic communities can be active under a wide range of soil pH conditions. This Studies have shown that soil CH_4 production can increase with an increase in soil pH from 5 to 7.5, whereas increased soil acidity can reduce CH_4 consumption and production rates in the soil. However, whether biochar application would increase the activity of methanogens or methanotrophs through changes in soil pH will depend upon soil moisture and aeration conditions, as well as the influence of biochars on these conditions.

Table 1: Effect of biochar amendment on selected soil physico-chemical properties during the incubation studies

Soil/biochar (t dry biochar ha^{-1})	pH	CEC (mg/Kg)	WRV (%)	K, (mg/Kg)	EC (µs)	BD (g/ml)	N, (g/Kg)
Control	5.8±0.1	2092.2±10.5	13±0.05	907±11	1720±602	1.58±0.05	0.104±0.02
10	6.3±0.2	2411.0±9.3	24±0.02	951±05	1511±114	1.51±0.01	0.155±0.01
25	6.9±0.1	2687.6±5.1	33±0.01	968±12	1627±98	1.48±0.02	0.187±0.02
50	7.5±0.1	2901.1±11.7	41±0.05	985±08	1499±101	1.45±0.01	0.211±0.01

WRV: water retention value, K: potassium, EC: electrical conductivity, BD: bulk density, N: nitrogen, CEC: cation exchange capacity.

CONCLUSION

In this study, we have shown that biochar can, under certain conditions, reduce soil NH_3, N_2O and CH_4 emissions. The results show that biochar prepared from palm fronds influenced reduction of nitrous oxide emissions in soils cultivated to coconut seedlings and increased methane oxidation in the soil. The development of biochar as a tool to reduce GHG emissions from soil will require detailed understanding of the interactions between biochar and site specific soil and climate conditions, and management practices that alter the greenhouse source sink capacity of soils. Further studies are needed to explore how the key non-CO_2 GHG emission control mechanisms (e.g. soil aeration, moisture, pH, microbial processes, soil structure, nutrient levels and easily mineralizable C pools) interact with biochar to influence soil GHG emissions. Variations in these controlling factors can play a significant role in altering soil microsite conditions, which will probably alter diurnal dynamics of soil non-CO_2 GHG emission and uptake. An improved understanding of the role of biochar in reducing non-CO_2 GHG emissions will promote its incorporation within climate change mitigation strategies and, ultimately, its commercial availability and application.

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