FOREST DEBRIS-BASED BIOCHAR APPLICATION IN COMPOSTING PROCESS TO REDUCE GREENHOUSE GAS EMISSIONS: A NATURE BASED SUSTAINABLE SOLUTION

Rupesh SINGH[1, 2], Henrique TRINDADE[2], João Ricardo SOUSA[2]

[1]University of Trás-os-Montes and Alto Douro (UTAD),
Quinta de Prados - Folhadela, Vila Real, Portugal
[2]Centre for the Research and Technology of Agro-Environmental and Biological Sciences,
Vila Real, Portugal

Corresponding author email: rupesh@utad.pt

Abstract

Biochar is being produced from biosolids waste of several industrial sectors, including Agri industries by pyrolysis process. Present investigation aims to evaluate the biochar produced from forest debris. Animal farming is a major agri industry and produces huge amounts of waste solids and liquid fractions which are a major source for composting of organic residues. Large amounts of greenhouse gases (carbon dioxide, nitrous oxide) and ammonia are released to the environment during the composting process and become a major concern for environmental health. The solid biowaste from cattle farms was inoculated with biochar and emissions of methane, carbon dioxide, nitrous oxide and ammonia were measured in comparison to control. Present study may develop a sustainable method in the composting process to reduce the greenhouse gas emissions and improve the environmental health for a better tomorrow.

***Key words**: biochar, greenhouse gases, environmental health, sustainable composting process, nature-based solutions.*

INTRODUCTION

Biochar is a nature-based product obtained from different biosolid materials by the thermal conversion process with limited oxygen delivery at temperatures of less than 700ºC (Wang et al., 2021).

Biochar exhibits special pores particle structure that facilitates the carbon sequestration, greenhouse gas reduction, increased soil fertility, improved structure, and increased crop production (Lu et al., 2020; Wang et al., 2019).

In the past decades, biochar emerged as a potential nature-based material to improve the composting process of organic residues and showed positive effects on multiple issues (Agegnehu et al., 2017; Xiao et al., 2018a; 2018b; Xiao et al., 2023).

Organic wastes are rich sources of organic matter which has been composed by traditional methods since many centuries where the waste residues were piled up in open spaces and left for a long time to decompose by natural process. These traditional practices are very time consuming and produce unpleasant smells to the environment. Additionally, the process releases the pollutants and eutrophic materials to water bodies and soil (Tang et al., 2020 and 2021).

Increasing global population is leading the pressure on agriculture, where animal farming is a major concern which produces a huge number of organic residues. Management of these organic residues became a major challenge, especially in reference to greenhouse gas emissions during the composting process. Large amounts of greenhouse gases, mainly carbon dioxide, nitrous oxide and ammonia are released to the environment during the composting process and become a major concern for environmental health. Present investigation aimed to evaluate the biochar, produced from forest debris on waste solids from cow farms. Biochar was procured from commercial sources which contained 2-5 mm particle size. The solid biowaste from the cow farm was inoculated with biochar and nano-biochar and emissions of carbon dioxide, nitrous oxide and ammonia were measured in comparison to control.

Present study may develop a sustainable method in the composting process to reduce the greenhouse gas emissions and improve the environmental health for a better tomorrow.

MATERIALS AND METHODS

Forest debris-based Biochar was procured from Portuguese commercial sources. The Biochar was produced from *Acacia* biomass which is an invasive plant species in Portugal and covers the forest land rapidly. This species grows 2-5 m in height as a tree and competes with the native species. Biomass obtained from land cleaning actions, such as water lines and the periphery of plantation areas when they are cut. The plant material was crushed into small pieces and pyrolyzed at 500ºC for 14 h, followed by cooling for 20 h at room temperature.

Plastic containers of 135 L total capacity have been used to set up the experiment. The containers were insulated with rock wool to keep the temperature. The bottom part of each container was drilled to place a tube to provide a continuous forced air circulation by connecting to an air pump (KNF, model N010. KN.18) at a rate of 20 L h^{-1} kg^{-1} DM (dry matter). Cow slurry was separated into solid and liquid fractions by screw press method. The solid fraction (organic residue from cow slurry) has been collected and treated with biochar (3% w/w) separately while one part of organic residue was kept untreated which serves as control. The experiment was performed in triplicates and is presented in Figure 1.

Figure 1. Apparatus setup for the greenhouse experiments on composting of solid fraction with different additives (control and Biochar). Each treatment and control have 3 replicates

RESULTS AND DISCUSSIONS

The organic matter was observed for microbial growth where high microbial growth was observed in Biochar treatment while no growth was observed in control upon 7 days (Figure 2a and 2b). The biochar treated material was completely covered with white coloured mycelia growth after 7 days of incubation. The temperature outside was recorded 32°C while inside organic matter was 55°C. The microbial dynamics are needed to characterize by molecular tools in order to obtain the specific community.

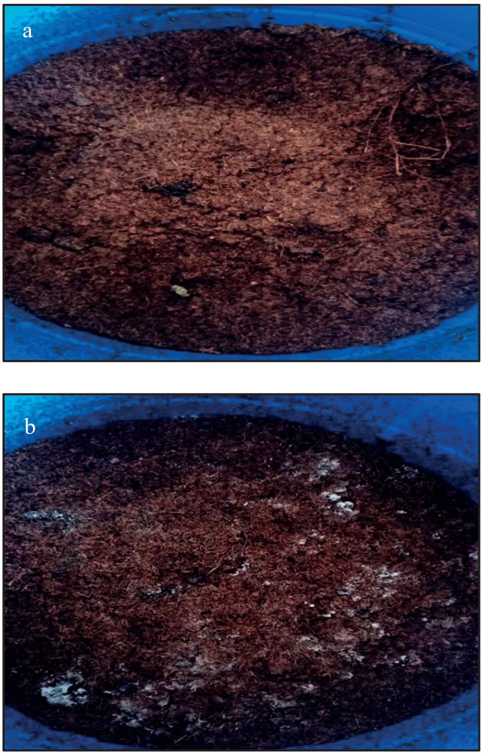

Figure 2. Composting of solid fraction without any treatment after 7 days (a). Treatment with Biochar (b)

The gas emissions were recorded over 7 days by using INNOVA 1412 Photoacoustic Field Gas-Monitor. The tube was placed inside the container and measurements were recorded in triplicates.

NH_3 was reduced by 50% in the biochar treated solid fraction in comparison to control upon 7 days of incubation (Figure 3).

N_2O was reduced by 45% in the biochar treated solid fraction (Figure 4) while emission for CO_2 was recorded 19.05% in the biochar treated fraction (Figure 5).

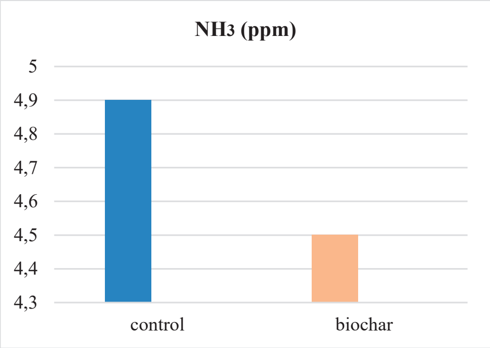

Figure 3. NH_3 mitigation by biochar

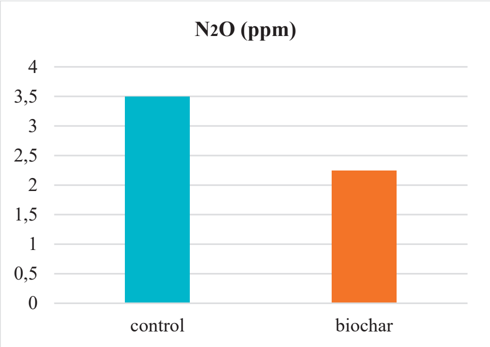

Figure 4. N_2O mitigation by biochar

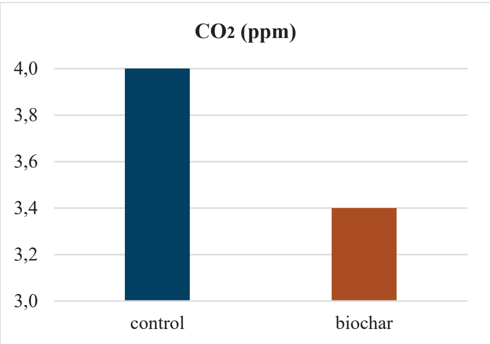

Figure 5. CO_2 mitigation by biochar

Biochar is a nature-based organic material which carries specific functional groups and porosity in structural form and proved as potential mitigation strategy to reduce the greenhouse gas (GHG) emissions during management of waste organic products from the agriculture sector.

Present study demonstrated the reduction of GHGs emissions for methane (CH_4), carbon dioxide (CO_2), nitrous oxide (N_2O) and ammonia in the initial phases. Previous reports suggested the mitigation of GHGs emissions but largely depends upon the source of Biochar preparation material, pyrolysis temperature and size of the end product (Yin et al., 2021). The Biochar used in present study had small particle size in comparison to previous reports and produced from woody tree species which has been suggested as better material. Amount of Biochar application also affects the mitigation, significant reduction in GHGs emissions were reported by using 10% addition where present study demonstrated significant reduction by 3% addition. More detailed study is required to generate better data and to understand the mechanism behind. Moreover, the improved microbial dynamics may have a correlation between lower emissions, which also need to be investigated.

Accordingly, new methods may be considered by adding microbial cells with biochar as combined formulation should be the new line of research in the upcoming future. Interestingly, the mode of action of GHGs emissions upon Biochar application at molecular level is still not clear and needs attention in near future. The findings observed in the present study may explore the granular biochar application to mitigate GHG emissions from compost.

Emission of Greenhouse gases from soil is not only a major environmental issue, but also leads to huge loss of nutrients and agronomic characteristics of lands (Wang et al., 2018). Biochar application as soil amendment has been investigated intensely since the past decade and suggested a potential positive effect in soil to reduce the emission and increase the nutrients availability (Agyarko-Mintah et al., 2017a; Wang et al., 2018).

CO_2, CH_4 and N_2O are major greenhouse gases which have been investigated in present study. Among three, N_2O is the most important which is being generated upon incomplete nitrification of NH4 + -N (Czepiel et al., 1996), also by incomplete denitrification of NOX-N at low availability of oxygen. In present study, N_2O has been reduced significantly in biochar and nanobiochar application in comparison to control soil samples. Previous reports suggested that application of biochar potentially increase the aeration and promote the porosity of soil, reduce the formation of big clumps, followed by reduction in emission of N_2O (He et al., 2017). Previous reports suggested lower total N_2O emission by application of biochar in pig organic matter management (Wang et al., 2013) in later stage of incubation while another report on biochar application in chicken organic waste upon biochar also reduce the N_2O and methane emission (Agyarko-Mintah et al., 2017).

CO_2 is another important Greenhouse gas and biochar addition that showed different results in different studies made in the past. This emission was largely dependent on biochar source material and quantity of application. The report on tobacco stalk biochar at the rate of 10% was effective positive to decrease the CO_2 emissions by 33.90%

(Wang et al. 2018) while biochar derived from bamboo stalks in granular form was applied and observed significant emission reduction (He et al., 2019).

Although, some reports showed a negative result in CO_2 emission upon biochar application

Which was corelated by increasing the temperature and induce the CO_2 synthesis (Czekała et al., 2016). Moreover, biochar addition may improve the aeration in samples and improve the oxygen availability for higher synthesis of CO_2 (Steiner et al., 2010).

Other studies in soils amended with biochar treated compost material demonstrated the lower flux of CO_2 and N_2O in comparison to control and soils amended with chemical fertilizers (Agegnehu et al., 2015). Differential increase in CO_2 while decrease in N_2O in the same experiment was recorded and corelated with weak carbon bonds in biochar which may depend on the source material (Zhang et al., 2012) and (Case et al., 2012). Methane emission has been considered a major concern as well from agriculture industry and biochar application reduced the CH_4 emission by 50.39 % in very later stages of incubation (He et al., 2019).

In brief, biochar application in present study at the rate of 1% showed potential results in N_2O emission reduction while differential emissions were observed for CH_4 and CO_2 emissions. Detailed study with different quantities of biochar and amendments are needed to explore the full potential of this material for longer time incubations. Biochar addition to soil or in organic matters may be a potential and nature-based strategy to address multiple issues of Greenhouse gas emissions and nutrients recovery from organic matters. Additionally, the instability effect may be a major parameter which depends on soil type and their interaction with biochar material. Biochar pyrolysis temperature and particle size is also a major factor which awaits exploration in the near future. Biochar application in combination with organic matter to the soil is still a major interest which requires the detailed exploration of mechanism behind to answer the insignificant results with different soil types or different organic matters.

FUTURE PERSPECTIVE

Biochar application and results were influenced by type of biochar, raw material or resources for pyrolysis process, pyrolysis temperature and resting conditions, doses of biochar and different organic matter types for composting for different time duration. Detailed studies are still lacking to evaluate all these parameters together to achieve the maximum potential.

Biochar particle size is another important character to influence the maximum output. The biochar may promote aeration in composting process, facilitate the oxygen availability and increased temperature may influence the emission, mainly carbon dioxide gas. Detailed investigation regarding biochar particle size is another interest of research.

Biochar generated from crop residues or waste of plant-based sources contain a significantly higher number of ashes (Zhu et al., 2017). The higher ashes improve the cation exchange capacity upon application in soil and also balance the nutrients availability. Biochar produced from the woody species takes more time during pyrolysis and loses the acidic group in molecular structure. This biochar is recommended to apply in acidic soils to pH correction strategy, followed by reduction in ammonia emission and further improving the nutrients content.

The biochar used in present study was prepared from *Acacia* plants, which is an invasive species in Portugal. This invasive plant is an opportunity which ensures the large number of raw materials for the biochar industry. Further research in characterizing and investigating the application for longer times with different organic matters may develop a potential sustainable strategy for waste management.

CONCLUSIONS

Biochar treatment was observed to induce the fungal growth in solid fraction after 7 days of incubation. The gases (NH_3, N_2O, CO_2) were reduced significantly in biochar treatment. The preliminary studies observed significant potential of using biochar for the composting process, although the detailed study is needed for further evaluation. The physiochemical properties of biochar affect the composting process, as well as the agronomic characters upon application of amended compost to soil. Biochar of good quality character may result in value addition in composting as well as nutrients management upon application to the field.

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