Response of babassu coconut shell and açai biochar on soil attributes and gas emission

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ABSTRACT

Biochar from waste produced by pyrolysis benefits soil fertility, increases water and nutrient retention and reduces greenhouse gas emissions, promoting more sustainable agricultural practices. Thus, the objective of this study was to investigate the benefits of biochar produced from babassu and açaí coconut shells on the physical, chemical and biological attributes of the soil, as well as on the mitigation of greenhouse gas emissions. A comprehensive literature review was carried out, exploring articles and books in scientific databases. The results showed that the biochar of babassu coconut shells and açaí have significant impacts on the soil. In terms of soil attributes, an increase in water retention capacity, improvement in soil structure and an increase in the availability of essential nutrients for plants were observed. In addition, there was a reduction in the emission of gases such as carbon dioxide-CO2, methane-CH4 and nitrous oxide-N2O, important greenhouse gases, indicating the potential of biochar in mitigating climate change when incorporated into agricultural practices.

Keywords: Biochar, Waste, Pyrolysis, Greenhouse effect, Soil quality.

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INTRODUCTION

The emission of gases began to be a concern for the scientific community around 1988, as there was a drastic and rapid change in climatic conditions, with fossil fuels being the main responsible for the increase in the concentration of greenhouse gases (Hansen *et al*., 1988; Rezende, 2011; WMO, 2020).

Fossil fuels are the main source of primary energy in the world, accounting for more than 85% of the total energy supply (Rezende, 2011). The rest of the energy supply is composed of nuclear, hydroelectric, and renewable sources, such as biofuels, wind, geothermal, and solar energy (IEA, 2020; Rezende, 2011; WEC, 2019).

Given the large amount of gases emitted into the atmosphere, biochar emerges as a fast, economical, and effective solution to store carbon in the soil and improve its quality. Biochar, also known as biochar, is produced by burning plant biomass at a high temperature, with a reduced and controlled amount of oxygen (Jeffery *et al*., 2011; Lehmann; Joseph, 2009; Lehmann *et al*., 2011; Maia, 2011).

In addition, biochar has a heterogeneous structure composed of aromatic carbon and minerals from ashes, resulting from the pyrolysis process of biomass obtained in a sustainable way, using clean technologies and under controlled conditions (Maia, 2011; SSSA, 2024). The biomass used can be made up of materials of plant origin, including waste such as babassu coconut shells and açaí almonds (Loo, 2008).

Throughout history, biochar production originated among indigenous peoples, who traditionally used the technique of burying plant and animal waste. This method resulted in the decomposition of these materials, which contributed significantly to improving soil quality and increasing soil fertility (Glaser *et al.,* 2001; IBI, 2024; Souza, 2023). These ancestral management practices played a crucial role in the transformation of Amazonian soils, making them more fertile and conducive to subsistence agriculture (Lehmann *et al.,* 2006; Souza, 2023).

Biochar, a modern product derived from these traditional practices, offers several benefits, such as reducing nutrient leaching into the soil, optimizing fertilizer use, and positive environmental contributions, including capturing carbon dioxide from the atmosphere and reducing greenhouse gas emissions (EMBRAPA, 2022).

In the Amazon region, where babassu and açaí coconut palms are abundant, the shells and fruits of these native species have significant potential to be used in the production of biochar. This practice not only reduces agriculture's dependence on chemical fertilizers, but also provides substantial economic and environmental benefits (EMBRAPA, 2024; Glaser *et al.,* 2001).

In this context, this literature review aimed to investigate and learn about the benefits of biochar produced from babassu and açaí coconut shells in the physical, chemical and biological attributes of the soil, as well as in the mitigation of greenhouse gas emissions.

DEVELOPMENT

BIOCHAR FROM BABASSU COCONUT SHELLS AND AÇAÍ

The babassu coconut palm is native to Brazil and found mainly in the Amazon region, where it grows naturally in transition areas between the cerrado, the Amazon rainforest and the semi-arid region of northeastern Brazil (Chaves; Axe; Antoniassi, 2006).

In the North and Northeast regions of Brazil, there are extensive areas for the collection of babassu coconuts, which are essential for the subsistence of several communities, however, due to the low value of the product, there is no significant incentive to increase its exploitation (Chaves; Axe; Antoniassi, 2006). Thus, the production of biochar emerges as a sustainable alternative for extractive families who, when they break the fruit, can sell the endocarp, and use the waste to sell or transform it into by-products to supplement their income.

The açaí tree is another palm tree native to the Amazon, whose local economy largely depends on the sale of the fruit's pulp (Nascimento, 2008). With this, the production of biochar for agricultural purposes would increase the income of these communities through the sale of seeds after pulping.

In the soils of the Cerrado, it is common to find small pieces of charcoal, known as C-pyr or black carbon, resulting from natural fires or human interventions (Petter, 2010). These materials are often found in the Terras Pretas de Índio in the Amazon, compounds that persist in the soil for centuries and are fundamental to their fertility (Neves *et al*., 2003).

Understanding the degradation of C-pyr in the soil is fundamental for its use, aiming at capturing carbon from the atmosphere (Petter *et al.*, 2016). The long-term stability of C-pyr in soil, without significant changes in its composition, may contribute to the reduction of CO2 emissions in the short term (Petter *et al.*, 2016). The ability of biochar to retain carbon in the soil is related to its chemical stability (Lehmann; Joseph, 2009).

Thus, the production of biochar from the waste from the processing of açaí can be an effective solution to deal with the improper disposal of this waste, transforming it into a resource that improves soil properties and reduces the risks of environmental contamination.

However, it is essential to conduct additional tests and studies to adjust the production conditions of biochar, ensuring that its environmental and agronomic properties are optimized according to the best available practices (Sato, 2019).

EFFECT OF BABASSU COCONUT SHELL BIOCHAR ON SOIL ATTRIBUTES

Biochar, obtained through the pyrolysis of biomass, has stood out as a sustainable alternative for the improvement of agricultural soils. This process involves the thermochemical degradation of biomass under anaerobic conditions or with low oxygen concentration and high temperatures (Lehmann; Joseph, 2009; Schmidt, 2002).

The babassu coconut shell (*Orbignya phalerata*) presents itself as a viable option, especially in the Northeast region of Brazil, where it is found in great abundance. Babassu is a palm tree native to Brazil, predominant in the Northeast and in the state of Maranhão, widely exploited both for oil extraction and for the use of its fibers and bark (Pereira; Luiz, 2013; Silva; Rodrigues, 2011; Teixeira; Costa, 2016)

The fruit of the babassu fruit has a fibrous layer called epicarp, which represents 11% of the total weight of the fruit and surrounds a central layer, the mesocarp or pulp, which is rich in starch and fiber, corresponding to 23% of the fruit (Lorenzi, 2004; Saints; Silva; Oliveira, 2008; Silva; Filho, 2007). Further inward, there is the endocarp, a very resistant layer, with a thickness of 2 to 3 centimeters, which constitutes 58% of the fruit. This layer is essential for the production of charcoal, having a higher calorific value than mineral coal (Andrade; Birth; Silva, 2005; Lorenzi, 2004). In the core of the fruit are almonds, which represent 8.7% of the total weight of babassu and are the source for oil extraction (Gomes, 2017; Brook; Olive tree; Lima, 2020; Pear tree; Silva; Oliveira, 2016).

Traditionally considered an agro-industrial waste, the babassu coconut shell has great potential when transformed into biochar, thanks to its favorable physicochemical properties. The use of biochar derived from babassu coconut shells in agriculture aims not only to improve soil quality, but also to offer a sustainable solution for reducing greenhouse gases (GHG), contributing significantly to the mitigation of global warming (Almeida; Martins; Ribeiro, 2019; Nunes; Souza; Silva, 2018; Saints; Olive tree; Carvalho, 2019).

Biochar offers a solution that integrates energy and food production, while promoting increased soil nutrition and fertility, as well as contributing to carbon sequestration (Wolf *et al*., 2010). This makes biochar one of the few technologies available with the potential to address challenges related to soil degradation, food and fertilizer scarcity, competition for biomass, and reduced greenhouse gas emissions (Lehmann; Joseph, 2015).

According to Asai *et al.* (2009), the use of biochar provides a series of environmental and agronomic benefits. Among them are decreasing nitrogen leaching, neutralizing soil pH, reducing the amount of available aluminum, decreasing soil density, increasing saturated hydraulic conductivity, and improving soil water permeability (Asai *et al.*, 2009)). In addition, biochar contributes to greater phosphorus availability for plants, which strengthens soil and crop health (Kammann *et al.,* 2010; Lag *et al.,* 2017; Spokas; Koskella; Baker, 2009).

Thus, the application of biochar in agriculture is a promising practice for the improvement of soil physical and chemical properties, especially in tropical regions where organic matter plays a crucial role in maintaining cation exchange capacity (CEC) (Lehmann; Joseph, 2015; Glaser; Lehmann; Zech, 2002).

Although the chemical structure of biochar and its particulate nature, together with its porous structure (Figure 1), influence properties such as cation exchange capacity, water retention, and nutrient retention and availability (Uchimiya *et al*., 2010), the effects of biochar on soil are still the subject of debate. Some studies have demonstrated the beneficial effects of biochar on the physical, chemical and biological attributes of the soil (Liang *et al.,* 2006; Steiner *et al.,* 2007; Ouyang *et al.,* 2013).

Figure 1. Representation of biochar particles.

Source: Author (2024).

Other studies have shown that the application of biochar had no significant effect on the physical and chemical properties of the soil (Carvalho, 2015; Reed *et al.,* 2017). In addition, some research indicates that biochar may even reduce the water-holding capacity of the soil (Krull *et al.,* 2010; Tammeorg *et al.,* 2014).

In this context, it is essential to explore and understand the effects of babassu coconut biochar on soil attributes, evaluating its implications for agricultural productivity and environmental sustainability.

EFFECTS OF AÇAÍ BIOCHAR ON SOIL ATTRIBUTES

Sato (2018) states that biochar derived from residues from açaí processing has shown potential to serve as a conditioner in Amazonian soils. However, the control of pyrolysis conditions, particularly temperature, is essential to determine the characteristics and efficacy of the biochar obtained from these residues (Galinato *et al.*, 2011; Oliveira *et al.*, 2017).

At lower temperatures (300 and 400 °C), biochar exhibits a higher yield, but with a strongly hydrophobic tendency (Zhang *et al.*, 2016; Kuzyakov; Bogomolova; Glaser., 2014). On the other hand, when produced at higher temperatures (600 and 700 °C), the material has higher pH values, greater recalcitrance and greater water retention capacity (Li *et al.,* 2016; Mukherjee; Lal, 2013).

Considering the advantages of biochar produced at low and high temperatures, the intermediate temperature (500 °C) and a longer residence time (3 hours) are considered ideal for the production of biochar from açaí seeds. This approach incorporates a set of beneficial characteristics for these soils, without presenting significant limitations of use Mukherjee; Lal, 2013; Fernandes *et al.*, 2017).

Because of these properties, in recent years, several studies have emphasized the positive effects of biochar on various physicochemical characteristics of the soil, including decreased density, increased pH in acidic soils, increased cation exchange capacity (CEC), and contribution as a source of increased organic carbon in the soil (Yan *et al.,* 2021; Chintala *et al.*, 2014; Liu *et al.*, 2012).

Thanks to the predominance of long-lived carbon, biochar emerges as an effective alternative for carbon capture, contributing to the reduction of greenhouse gas emissions and to the increase of organic matter levels in the soil (Woolf *et al.*, 2018).

The extensive surface and pores of biochar can favor the retention of nutrients in the soil, since positive and negative ions can be retained on its surface through adsorption. (Yan *et al.,* 2021; Xu *et al.,* 2014).

The temperature during pyrolysis directly affects the physical properties of biochar (Trompowsky *et al.,* 2005). During the burning of organic matter, volatile compounds are released, including "cell juice", hemicellulose, cellulose, and lignin, forming carbonized compounds (Petter *et al.,* 2016).

These compounds decompose, creating pores of different sizes that increase the specific surface area of the biochar. Typically, this area increases with temperature to some extent, 500 to 700 ºC (Petter *et al.,* 2016). However, at high temperatures (>1000 ºC), the carbonized compounds undergo fusion due to the degradation of the aromatic compounds, resulting in the loss of carbon and desirable physical characteristics, such as porosity (Petter *et al.,* 2016).

The use of biochar derived from açaí seeds has resulted in improvements in soil physical properties, including increased aeration porosity and improved soil aggregation. In addition, in soils of different textures, biochar had positive effects on water retention and availability for plants.

These effects were more evident in soils with a sandy texture and increased with the amount of biochar applied. The addition of biochar to the soil improved the mesopores fraction in all soil types, resulting in a higher saturated hydraulic conductivity (Sato *et al.*, 2020).

Biochar can also be used as an improver to increase the effectiveness of nitrogen (N) fixation in the soil and mitigate its volatilization, consequently improving soil fertility and promoting plant growth and development (Xu; Tan; Gai, 2016).

Additionally, mineral nutrients such as phosphorus (P) are captured by biochar during the pyrolysis process, and, therefore, several studies suggest that biochar can be effective in increasing the availability of this element in the soil (Costa, 2021).

Similar to organic matter, the addition of biochar to the soil also promotes an increase in the number of pH-dependent loads due to the presence of functional groups with predominantly negative residual load. This is influenced by the increase in pH caused by the carbonates present in the biochar ash.

As a result, the cation exchange capacity (CEC) increases, as there are more negative charges at the exchange sites, reducing the competition of cations with H+ ions for these sites and, consequently, decreasing the leaching of the bases along the soil profile (Gul *et al.,* 2015). These advantages are especially relevant when considering tropical soils, in which the intense weathering process accelerates the degradation of organic matter and the constant leaching of basic nutrients (Sato, 2018).

As observed by Malavolta (2006), the low fertility present in acidic soils is mainly linked to the scarcity of exchangeable bases and the excess of aluminum and manganese. Therefore, the inclusion of biochar in these soils could reduce nutrient losses, especially of bases, by leaching, resulting in a more efficient use of the nutrients present in the soil (Sato *et al.*, 2020).

Sheng and Zhu (2018) found that the addition of biochar in acidic soils resulted in a substantial increase in soil pH and a significant modification in the composition of the microbial community. There were notable increases in Bacteroides and Gemmatimonadetes, while Acidobacteria decreased significantly.

The regulation of soil pH by biochar has been identified as the main factor responsible for this change in the structure of the soil microbial community (Gorovtsov *et al.,* 2020). All due to the alkaline properties which have the ability to raise the pH of the soil, especially in acidic soils (Chan; Xu, 2009).

In addition, Palansooriya *et al.* (2019) found that biochar increases soil pH, exerting a positive effect on the metabolic activity of soil microorganisms and their community structure. Biochar reduces the bulk density of the soil, increases its water and moisture holding capacity, modifies soil nitrogen dioxide (N2O) emissions, and has effects on nitrifying and denitrifying bacterial communities present in the soil (Huang *et al.,* 2023). Where through the increase of CEC through the application of biochar can result in an increase in the population of nitrogen-fixing bacteria, rhizobacteria and nitrifying and denitrifying bacteria in the soil, promoting plant growth and reinforcing their ability to face environmental stresses (Glaser; Lehmann; Zech, 2002).

Thus, in recent decades, several studies have highlighted the benefits of biochar in various physicochemical properties of the soil (Costa, 2021). In addition to being seen as an ecologically viable substance, it can be used in the soil to stimulate the retention and availability of nutrients in soils with low fertility or with disadvantageous properties for adequate plant growth (Chandra; Medha; Bhattacharya, 2020).

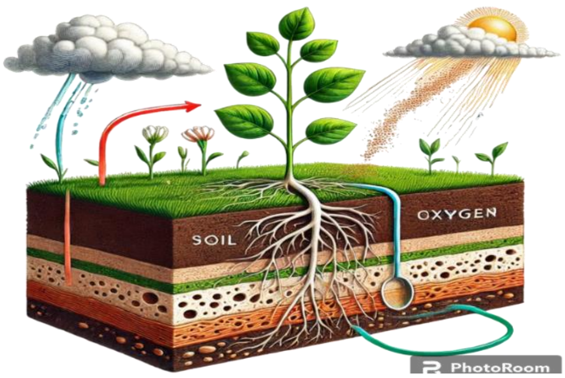
POTENTIAL OF BIOCHAR IN SOIL GAS MITIGATION

Biochar is a biomass carbonized through the pyrolysis process, which means that it is rich in carbon and results from the heating of organic matter in an environment with low oxygen presence (Mendonça, 2019).

According to Yakuwa (2021), the characteristics of biochar vary according to several factors, including the type of biomass used and the temperature of the pyrolysis process. It has a resistant internal structure, comparable to graphite, and a reactive outer layer, due to the existence of several chemical groups capable of joining organic compounds, water and chemical elements that serve as nutrients for plants (Downie; Crosky; Munroe, 2009)

The emission of greenhouse gases is a problem for the survival of the biodiversity of planet earth. According to the National Emissions Registry System (SIRENE), in 2023, the average annual CO_2 emission was 0.0385 tons per megawatt-hour, equivalent to 38.5 kg of emission per megawatt-hour. This situation is likely to persist until the end of the century (IPCC, 2021) (Figure 2).

Figure 2. Climate action on the emission of gases in the soil-plant-atmosphere system.



Source: Author (2024).

The use of these carbonized materials in agricultural soils may represent an important process of carbon capture and waste management (Lehmann, 2007).

In addition, the use of carbonized materials in the soil or as raw material for the manufacture of granular mineral, organic or organomineral fertilizers, which release nutrients in a controlled or gradual manner, can bring other benefits, such as: changes in soil microbial communities, with increased biological diversity; increased agricultural productivity; reduced emissions of methane and nitrous oxides; decreased need for fertilizers; reduced runoff nutrients and, mainly, the improvement of the agronomic efficiency of fertilizers (Jeffery *et al*., 2011; Kammann *et al*., 2012; Spokas; Reicosky, 2009).

Carbonized materials contain condensed aromatic groups that contribute to their resistance to decomposition in the soil, thus making them an effective option for carbon storage, especially considering that soil represents the largest surface deposit of this element (Glaser; Lehmann; Zech, 2002).

Thus, in addition to the immediate economic gains, it is also crucial to consider the environmental benefits, especially with regard to global climate change (carbon storage and reduction of emissions of other greenhouse gases) and greater energy efficiency in agriculture, resulting from increased productivity, reduced use of fertilizers and lower nutrient losses (Cerri *et al*., 2009; Steiner *et al*., 2004).

FINAL CONSIDERATIONS

Biochar has a strong link with the recovery and improvement of soil quality, helping to reduce the effects of climate change and increase plant productivity. In addition, the use of biochar promotes better soil aggregation, favoring greater water and nutrient retention.

Therefore, biochar can be widely used in the face of current climate change, as it has significance in reducing greenhouse gases, which makes it an important ally in the search for sustainability on the planet. Thus, biochar has potential as a mitigator of polluting gases, and can be pointed out as an effective resource to improve sustainable soil quality.

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