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BIOCHAR - A PRODUCT WITH VALUABLE APPLICATIONS

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Abstract

Biochar, a product manufactured through a technology with negative emissions obtained through the valorisation and superior use of agro-wastes, proves to have multiple uses (agriculture, environment, industry). The use in agriculture as an amendment or in the composition of some fertilizers that improve their nutrient supply properties contributes to the decrease of farmers` dependence on chemical fertilizers and the reduction of their application doses. This technology of using biochar supports farmers by combating soil degradation, increasing carbon content, simultaneously decreasing leached nutrients (especially nitrogen) and greenhouse gases, and decreasing the content of contaminants in agricultural products through the retention effect in the biochar structure of pesticides and heavy metals, which affect the production and quality of crops. At the same time, biochar represented a means of combating climate change, improving the physico-chemical properties of the soil and offering benefits to agricultural crops

Key words*: biochar, agriculture, soil, carbon, fertilizer.*

INTRODUCTION

In addition to the development of new technologies such as precision agriculture, genetically modified crops, robotics, etc., inspiration can also be found in the application of traditional methods of improving soil fertility in modern agriculture. History shows a number of useful examples where people have tried to improve soil properties by applying charred wood (Sheil et el., 2012; Downie et al., 2011; Ogawa & Okimori, 2010; Blackmore et al., 1990).

The best-known example in the scientific literature is the creation of anthropogenic chernozems, also called Terra Preta de Índio, more than 8000 years ago (Glaser, 2007).

These soils resulted from a substantial accumulation of organic waste, such as household waste, excrement, and residual biomass, along with unburned woody debris. These were further broken down and resulted in soils of surprisingly high fertility (Glaser & Birk, 2012).

The phenomenon of Terra Preta de Índio has become the main inspiration of many scientists in the last two decades or so, with the main focus of their research on the role of biochar in improving soil properties and the question of whether the effect observed in Amazonia can be reproduced in other areas of the world (Horák et al., 2020).

An economic way to manage agricultural waste is to transform it into a valuable product called biochar.

Biochar production is becoming an alternative strategy for using agricultural waste in agricultural input. Residue production in large quantities in agro-forestry could be used as an abundant source of biochar preparation and become a solution for waste management (Gwenzi et al., 2015; Meng & Chen, 2013).

Biochar, a product manufactured through a technology with negative emissions obtained through the valorization and superior use of agro-wastes, proves to have multiple uses (agriculture, environment, industry).

The use of biochar covers several directions, making this material a valuable and multipurpose product due to its properties, namely:

- waste management (recycling of waste and promotion of green energy) (Das et al., 2022);
- climate mitigation (decrease green house gases) (Šimanský et al., 2016; Cayuela et al., 2013; Ennis et al., 2012; Kameyama et al., 2012);
- soil enchancement (improve soil quantity and fertility) (Burachevskaya et al., 2020;

Horák et al., 2020; Yazhini et al., 2020; Gondek et al., 2019; Shareef & Zhao, 2016);

- environmental remediation (removal of organic and inorganic polluants) (Toková et al., 2020; Mohamed et al., 2017; Gwenzi et al., 2015; Meng & Chen, 2013; Teixidó, et al., 2011; Cao et al., 2009);
- energy storage (Liu et al., 2019);
- carbon dioxide capture (sequesters carbon dioxide in good amounts, descreasing climate effects) (Fawzy et al., 2022; Horák et al., 2020; Van Zwieten et al., 2010);
- hydrogel - composite (supports growts of plants, increase plant available water) (Ambika et al., 2022; Das et al., 2022);
- nano-technology (supports nano-structuresuch as nano fertilizers) (Tan et al., 2016).

More and more studies are dedicated to analysing the properties of biochar to better understand the potential benefits and risks of large-scale application in agriculture and environmental remediation. Therefore, the development, obtaining and application of biochar is very important and can predicts its benefits and behavior in the future (Lian & Xing, 2017; Mierzwa-Hersztek et al., 2017).

Biochar is a stable "black carbon" that can be obtained from the pyrolysis of plant material, biomass, under anaerobic conditions. Biochar has gained great attention worldwide due to its specific properties and versatile activities in agriculture and the environment. Several definitions of biochar have been supported by several researchers. Of these, the most standardized and accepted definition is: “A solid material obtained from thermochemical conversion of biomass in an oxygen limited environment” (European Biochar Foundation-EBC 2012; International Biochar Initiative-IBI 2012).

The sustainable production of biomass and its non-energetic use in materials or in the form of pyrolysis products (biochar and pyro-oils) is the simplest, safest and fastest method that can be implemented globally.

Growing interest and research in soil biochar applications has been steadily increasing in recent years (Lehmann & Joseph, 2015; Verheijen et al., 2014).

Biochar has physico-chemical properties that allow it to be used for a long time, safely accumulate carbon in the environment and improve soil health (Wang et al., 2021; Meena et al., 2020; Joseph et al., 2020).

Numerous studies carried out in different soil and climate conditions have indicated a positive effect of biochar on soil chemistry (Horák et al., 2020; Gondek et al., 2019), of its ability to supply crops with nutrients (Beusch et al., 2019; El-Naggar et al., 2019; Mia et al., 2017; Yavari et al., 2015), improving the biological and physical properties of the soil (Ajayi & Horn, 2016; Biederman & Harpole, 2013; Lehmann et al., 2011).

Incorporating biochar into soil can help reduce soil erosion by improving soil structure and increasing water infiltration. This can be particularly beneficial in areas prone to erosion or landslides.

It should be noted that many studies have focused on problem soils (acidic, saline, with low soil organic carbon content) where biochar addition has led to substantial improvements in physical, chemical and biological characteristics (El-Naggar et al., 2019; Nguyen et al., 2018; Hseu et al., 2014; Jien & Wang, 2013).

However, it has been observed that biochar application can have the greatest effect on more fertile agricultural soils, where there is great economic and practical potential. Although there are many studies focusing on the short-term effects of biochar application on soil properties, there have been only a limited number of published studies looking at the medium-term effects of biochar (>5 years).

These studies can be divided into several groups. Some studies focus on the effect of repeated application of biochar over a period of several years (El-Naggar et al., 2019; Nguyen et al., 2018).

The other group of studies includes works with a single application of biochar at the beginning of the establishment of the experiment, followed by a monitoring period reaching up to 3-4 years (Aydin et al., 2020).

There is a huge body of literature devoted to the results of biochar testing on almost all soil types. There are numerous studies on agricultural use that show that biochar can serve as an excellent soil amendment

(Burachevskaya et al., 2020; Shareef & Zhao, 2016).
From the total number of articles studied, they were chosen for this paper only those that refer to some of the properties of biochar and its use in agriculture (143). We used the Web of Science and Google search engines Academic following the keyword: biochar.

BIOCHAR IN AGRICULTURE

The management of crop residues is a difficult problem for farmers to ensure a balance between costs and that of sustainable agriculture. Although burning is the easiest way to destroy plant waste, it not only causes drastic environmental changes through the greenhouse gases generated, but also large amounts of nutrients are removed. Therefore, a technique is needed that protects the environment and, at the same time, improves the quality of the soil. Therefore, pyrolysis of biomass residues can become an alternative technique, viable compared to previous approaches. Biochar can be produced through the pyrolysis process and can be used as a soil amendment. The application of biochar improves the physico-chemical properties of the soil and improves production in the context of an ecological, sustainable agriculture (Yazhini et al., 2020).
In recent years, the application of biochar as a soil amendment or attempts to formulate fertilizers with biochar content represents a new trend, mainly to reduce the leaching of nutrients and to improve the efficiency of their use, simultaneously with the improvement of the physical properties soil chemistry and the reduction of greenhouse gas emissions, in the context of carbon sequestration policy (Shy et al., 2020; Olad et al., 2018; Lehmann & Joseph, 2015; Zheng et al., 2013).
Dependence only on inorganic, classical fertilizers for future agricultural growth would mean further loss of soil quality, possibilities of groundwater contamination and environmental pollution. In addition, the use of conventional fertilizers is expensive due to low nutrient use efficiency.
Therefore, a rational and "personalized" fertilization of crops, effective, taking into account the pedo-climatic conditions, must be achieved by using technologies that do not disturb the environment, preserve, improve soil fertility, simultaneously with the improvement of the efficiency of agricultural systems and the implementation of sound and ecological agronomic practices (Francis et al., 2020; da Costa et al., 2019; Wu, 2011).
One of the characteristics of biochar that makes it attractive as a soil amendment is its highly porous structure, potentially responsible for improved water retention and increased contact surface area. The addition of biochar to soil has also been associated with increased nutrient use efficiency, either through the nutrients contained in the biochar or through physico-chemical processes that allow better use of soil-own or fertilizer-derived nutrients (Kumawat et al., 2021; Trenkel, 2021; Francis et al., 2020; Shi et al., 2020; da Costa et al., 2019; Wu, 2011).
A number of studies have shown that biochar as a soil amendment has the potential to mitigate the effects of climate change by increasing soil organic carbon content and improving soil quality (Zhang et al., 2012; Laird et al., 2010).
Importantly, it is the apparent biological and chemical stability that allows biochar to act as both a carbon sink and provide long-term soil benefits (Fawzy et al. 2022; Das et al., 2020).
A preliminary analysis shows that European countries are already taking steps towards greater efficiency in the use of resources, mainly due to economic concerns related to their dependence, the energy crisis and the increase in the prices of raw materials worldwide.
Crop quality and productivity can be improved by implementing responsible nutrient fertilization, combining the application of mineral, organo-mineral fertilizer products with slow/controlled nutrient release fertilizers and biofertilizers, respectively (Kumawat et al., 2021; Trenkel, 2021; Shi et al., 2020; Bhatt et al., 2019; Hermida & Agustian, 2019; Iftime et al., 2019; Cole et al., 2016; Bhattacharjee & Dey, 2014; Xiaoyu et al., 2013).
Kuwagaki & Tamura, 1990 proposed seven properties to be measured for an agronomic biochar quality assessment: pH, volatile compounds content, ash content, water holding

capacity, bulk density, pore volume and specific surface area.

The potential benefits of biochar as a soil amendment are well identified in the literature. These include carbon sequestration, improved crop yields and increased water retention (Yu et al., 2013). According to several studies, an improvement in soil quality could be long lasting after the addition of biochar (Bruun et al., 2017), but also improving the state of soil fertility (Mašek et al., 2019; Atkinson et al., 2010). Despite the fact that biochar is of increasing interest through the possibility of being used both as an amendment and in fertilizer products with slow/controlled nutrient release properties, their release mechanism and formulation face limitations that still require multiple and complex interdisciplinary research (Pogorzelski et al., 2020; Chen et al., 2018; El Sharkawiet al., 2018; Wen et al., 2017). Biochar application improves soil physical qualities, i.e., improves aeration, water holding capacity, increases porosity and reduces evapotranspiration and soil bulk density (Schulz et al., 2014; Mukherjee & Lal, 2013; Herath et al., 2013). However, the actual effect of this amendment depends on the type of biochar, production conditions, soil condition and the amount of biochar applied (Wang et al., 2018).

Aslam et al. (2014) attributed the improvement in soil physical properties after biochar introduction to the type of input material, pyrolysis conditions, biochar application rate, and the type of soil in which the biochar was applied and incorporated (Šimanský et al., 2019). Different mechanisms have been proposed that increase nutrient availability to plants in different ecosystems provided by biochar application. Among these mechanisms are: the incorporation of soluble nutrient sources in biochar for a better availability for the needs of crops (Biederman & Harpole, 2013; Sohi et al., 2010), reduction of nutrient leaching due to the physico-chemical properties of biochar (Liang et al., 2006) and minimizing nitrogen losses through NH_3 volatilization and denitrification (Šimanský et al., 2016; Cayuela et al., 2013; Ennis et al., 2012; Kameyama et al., 2012). Biochar has a large surface area and different functional groups like carbonyl (R-C=O), carboxyl (-O-C=O), hydroxyl (-O-H), ethers (C-O-C), aromatic or alkyl groups (Prasannamedha et al., 2021; Kameyama et al., 2012), with a role for the transport of nutrients (El-Naggar et al., 2018; Xu et al., 2016; Prommer et al., 2014; Biederman & Harpole, 2013) and the elimination of pollutants (Qian et al., 2019; Tan et al., 2015; Cao et al., 2009).

These attributes increase the nutrient retention capacity of biochar, even nitrate and phosphate anions (Prommer et al., 2014; Biederman & Harpole, 2013; Kameyama et al., 2012; Major et al., 2010). Thus, biochar could stabilize soil organic matter and increase respiration and reduce the bioavailability and phytotoxicity of heavy metals (Ennis et al., 2012; Park et al., 2011). Biochar has also been shown to increase crop yields (El-Naggar et al., 2018; Xu et al., 2016; Biederman & Harpole, 2013), reduces greenhouse gas (GHG) emissions and increases soil carbon storage (Horák et al., 2020; Rizhiya et al., 2019; Zhao et al., 2019; Horák et al., 2017; Kameyama et al., 2012; Zhang et al., 2012; Galinato et al., 2011; Van Zwieten et al., 2010; Lehmann et al., 2006). A nutrient-deficient or degraded soil can be treated with biochar, which is produced from a certain raw material and certain conditions of the pyrolysis process, ensuring the modification of the specific properties of the soil and the improvement of production (Robb et al., 2020; Ippolito et al., 2012). Various studies have reported a positive effect of biochar on soil hydrophysical and hydraulic properties (Salinas et al., 2018; Lehmann & Stephen, 2015; Arthur et al., 2015; Hardie et al., 2014). Biochar application positively affected bulk density (Zhang et al., 2012), soil porosity (Walters et al., 2018; Mukherjee et al., 2013; Jones et al., 2010), soil water capacity (Karhu et al., 2011) and soil hydraulic conductivity (Lei & Zhang, 2013; Makó et al., 2020). Due to the highly porous nature of biochar, its incorporation into soil can improve soil physical properties by creating new pores (Jones et al., 2010) attributed the partial filling of large cavities between coarse sand particles to the application of biochar.

Castellini et al. (2015) consider that biochar has a potential impact on the physical properties of the soil and therefore may affect the water balance of the ecosystem. The study of Sun & Lu (2014) showed a positive effect of biochar application on soil porosity and the ability to retain water and make it available to plants, resulting in an increase in crop yields.

Biochar can serve as a habitat for beneficial soil microbes, including bacteria and fungi, that promote nutrient cycling and plant growth. This can lead to healthier, more productive agricultural systems.

The appearance of some changes in the function and structure of the soil microbiome through the application of biochar is due to the modification of the C and N cycle, soil respiration and the flow of nitrogen oxides. Biochar coating tends to reduce nitrous oxide emissions (Zhang et al., 2016; Jia et al., 2010; Van Zwieten et al., 2010).

The application of biochar improves the quality of the soil by improving its physico-chemical properties, its fertility and the efficiency of using nitrogen from fertilizers (Chan et al., 2007).

Applying biochar to the soil will become the affordable solution for soil modification with low nutrient content, acidity, increased salinity (Yazhini et al., 2020; Tian et al., 2018; Dai et al., 2017; Lin et al., 2015; Carter et al., 2013; Asai et al., 2009). The results of the experiments carried out so far clearly confirm the positive effect of biochar application on the organic content of the soil shortly after application (Igaz et al., 2018; Juriga et al., 2018) which was noticed up to 3 years after the experiment (Horák et al., 2020; Šimanský et al., 2018).

However, negative or no effects on soil characteristics and crop yields were also recorded (Jeffery et al., 2017), emphasizing the need for further studies to analyze the effects of biochar in a diversity of soil types and cropping systems. It was found that, despite the variability introduced by soil and climate, the addition of biochar to soil generally increased crop yield, soil microbial biomass, plant and soil nutrient concentration, and total soil carbon. Despite the ability of the biochar to favourably modify the physico-chemical properties of the soil it also has some disadvantages:

-the selection of raw material needs more attention;

-sometimes the results may not show the significant effect of increasing crop yields by increasing nutrient availability (Spokas et al., 2012);

-hazardous by-products such as polycyclic aromatic hydrocarbons have the potential to result during the pyrolysis process (Weidemann et al., 2018; Gasco et al., 2016; Laghari et al., 2016).

In addition, due to the very stable nature of biochar it cannot be easily removed from the soil ecosystem (Jones et al., 2012).

PROPERTIES OF BIOCHAR

Biochar is obtained from thermal conversion of biomass. biochar is the main pyrolysis product, obtained by the thermochemical conversion of biomass in the absence of free oxygen at temperatures varying between 450 and 850 ˚C for a period between 6 and 8 h (Tibor & Grande, 2022). The biochar is a solid carbon-rich, porous material produced by the thermochemical conversion of a diverse range of biomass feedstocks under an inert atmosphere (i.e., in the absence of oxygen) (Ghodake et al., 2021). Feedstocks are a primary factor governing the chemical and physical properties of biochar. Carbonization of agricultural waste can be advantageous compared to disposal as waste by other means (Demirbas, 2006). The properties of biochar vary greatly depending on the type of raw material used and the pyrolysis conditions. If the content of lignocellulosic material in the feedstock is high, it gives a higher biochar yield because the lignin is converted to carbon during the pyrolysis process (Ippolito et al., 2020; Antunes et al., 2017; Schimmelpfennig & Glaser, 2012; Antal & Grønli, 2003). Biochar has heterogeneous properties due to the different raw materials that can be subjected to pyrolysis, such as stalks, cereal husks, seeds, wood waste, manure and sludge, vegetable and household waste, and others (Haddad et al., 2021; Khiari et al., 2020; Pariyar et al., 2020; Qian et al., 2019; Ahmed et al., 2018; Dunnigan et al., 2018; Shaaban et al., 2014; Angın, 2013; Kim et al., 2013; Tang et al., 2013; Ahmad et al., 2012; Zhang et al., 2012; Galinato et al., 2011; Atkinson et al., 2010). The increasingly advanced study of biochar, as well as pyrolysis technologies, deliberately controls the production of biochar, which allows obtaining a product with specific properties defined and suitable for the way of use (Rajapaksha et al., 2016). Thus, increasing the pyrolysis temperature results in a larger surface area, a higher fixed carbon and a lower oxygen content (Ippolito et al., 2020; Manyà, 2012). Higher pyrolysis temperatures result in lower ash content, higher pH, higher buffering capacity and finally an increase in the aromatic structure of the biochar which provides a high heating rate, heating time and post-pyrolysis of the biochar (Ippolito et al., 2012; Manyà, 2012). The technology for obtaining biochar is one of the few that is carried out with negative emissions, an important aspect for limiting global warming (Mašek et al., 2019). Biochar has a large, negatively charged internal surface that is resistant to degradation. Due to its properties, biochar acts as a porous carbonaceous sorbent generally produced from materials of biological origin (Tan et al., 2015). Thus, the control of these factors can lead to obtaining a biochar with specific characteristics such as surface area, volume and pore size, adsorption capacity, pH, carbon percentage, chemical composition, physical characteristics and cation exchange capacity (Ippolito et al., 2020; Somerville & Jahanshahi, 2015; Cimò et al., 2014; Ronsse et al., 2013). For example, the pore volume for the biochar obtained from wheat straw at 400°C increased from 0.016 (cm^3g^{-1}) to 0.034 (cm^3g^{-1}) in the case of pyrolysis at 600°C of the same raw material (Manna & Singh, 2015). In addition, the heating temperature of the raw material influences the surface of the biochar. For example, rice husk pyrolysis at 350°C and 650°C having the surface area of 32,7 (m^2g^{-1}) and 261,72 (m^2g^{-1}) (Schmidt et al., 2015; Claoston et al., 2014). Another study mentions that the surface area of biochar obtained from wood increased from 1 m^2g^{-1} to 317 m^2g^{-1} by increasing the temperature of the pyrolysis process from 450°C to 700°C (Brewer et al., 2014).

CONCLUSIONS

Biochar is a material that has received attention in the last 20 years, a fact proven by the large number of articles. An increase in the importance of the use of this material can be seen against the backdrop of environmental policies and the current political context. Based resistance to microbial decomposition and, therefore, it will improve carbon sequestration (Ippolito et al., 2012; Spokas et al., 2012; Singh et al., 2010). The properties of biochar can be influenced by the nature of the raw material, the pyrolysis process and the various process variables such as: pressure, heating temperature,

on our findings, biochar application leads to sustainable soil management in terms of carbon sequestration and conservation of soil structure. Although there are numerous studies from which the positive effects on the soil, agricultural yields and the environment result, there remain knowledge gaps regarding the biochar-soil-plant-environment relationship and interactions in the field in the long term. Important aspects that require research are related to the yield and long-term effects of repeated applications and the influence on the mobilization / retention of heavy metals for planning doses and frequency of applications.

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