Frequently Asked Questions
Biochar & Agronomy

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Summary

1- PRODUCT
What is biochar, how was it discovered, and how is it produced?

Biochar is a solid, carbon-rich material produced from biomass waste. Its use in agriculture originated from the study of fertile soils found in the Amazon, known as "Terra Preta de Índio" (TEIXEIRA et al., 2009). It is classified as a soil conditioner due to its high stability and ability to retain nutrients and water, as well as reduce the amount of carbon dioxide (CO2) in the atmosphere, helping to mitigate climate change (LEHMANN et al., 2015). When incorporated into the soil, under specific conditions, it has the potential to increase the quality and yield of crops (JEFFERY et al., 2011; ROGERS et al., 2022). Biochar is produced through a process called pyrolysis, in which biomass is heated to high temperatures under a limited supply of oxygen, causing its thermal decomposition. Biochar production temperatures typically range from 350°C to 700°C (LEHMANN et al., 2015), which allows for obtaining a material rich in stable carbon and with unique properties.

2 - COMPOSITION
What is the composition of biochar and what are its physical, chemical, and biological characteristics?

Biochar is a porous, carbonaceous material produced by the pyrolysis of biomass from a range of organic wastes, for example, agricultural, agro-industrial, or forestry residues. The composition of biochar can vary depending on the type of biomass used and production conditions (JIA et al., 2018). However, generally, biochar mainly contains carbon, as well as smaller amounts of hydrogen, oxygen, nitrogen, phosphorus, potassium, calcium, magnesium, sulfur, and a variety of micronutrients (KIGGUNDU; SITTAMUKYOTO, 2019). According to studies carried out by Joseph et al. (2021) and Ye et al. (2020), here are some physical, chemical, and biological characteristics of biochar.

Physical characteristics:

- Color: Biochar is usually black or dark brown due to the presence of carbon.
- Porosity: Biochar has a porous microstructure that can vary due to biomass and production conditions. This porosity helps retain water and nutrients and promotes microbial activity in the soil.
- Density: Biochar has a lower density than many soils, which can help improve aeration when applied to the soil.
- Particle size: The size of biochar particles can range from fine to coarse, depending on the production process. These particles form aggregates that can increase water infiltration into the soil, aeration, and drainage.

Chemical characteristics:

- Stability: Biochar is highly stable, meaning it does not decompose quickly in the soil. This helps to retain carbon and nutrients in the soil for a long period.
- pH: Biochar has an alkaline pH, which can help neutralize the pH of acidic soils.
- Cation exchange capacity (CEC): Biochar can have a high cation exchange capacity, which allows it to retain nutrients present in the soil in the form of ions, making them available to plants. Biological characteristics of biochar.
- Microorganisms: Due to the porous structure of biochar, it can house beneficial soil microorganisms, such as bacteria and fungi that help decompose organic matter and fix nitrogen. Furthermore, it can house phosphorus and potassium solubilizing microorganisms and increase the availability of these nutrients to plants (RAFIQ et al., 2020).

Improved plant health: Biochar can help improve plant health by reducing nutrient loss, improving water retention, and promoting microbial activity in the soil (SANCHEZ-REINOSO et al., 2022).

3 - BENEFITS
What are the main benefits of the production and application of biochar, and what benefits is biochar expected to bring to agriculture and the climate?

Biochar is a sustainable solution that can benefit agriculture and the environment in several ways, from carbon sequestration to improving soil quality and increasing agricultural production (BAHRUN et al., 2019; KIGGUNDU; SITTAMUKYOTO, 2019). Here are some of the main benefits of biochar:

Nutrient and water retention: Biochar can help retain nutrients and water in the soil, improving plant health and productivity. It can also reduce the need for irrigation, as the soil becomes more efficient at retaining water (JOSEPH et al., 2021).

Reduction in the use of fertilizers: The use of biochar can reduce the need for chemical fertilizers, either by the direct provision of nutrients or by increasing plant usage efficiency, thus potentially reducing the recommended doses of fertilizers or increasing crop yields (SANCHEZ-REINOSO; LOMBARDINI; RESTREPO-DÍAZ, 2022). This translates into lower production costs for the farmer, especially in a context of rising fertilizer prices.

Improved soil quality: Biochar can improve soil quality by increasing water and nutrient retention capacity, improving soil structure, and promoting the growth of beneficial microorganisms (ANTONANGELO; SUN; ZHANG, 2021; JOSEPH et al., 2021).

Increased agricultural production: The use of biochar can increase agricultural productivity since it improves soil quality and increases nutrient and water retention and can have a synergistic effect with chemical fertilizers (MELO et al., 2022).

Carbon sequestration: Carbon sequestration: Biochar is an effective carbon sequestration solution, as the pyrolysis process stabilizes the carbon captured from the atmosphere by the biomass. The high stability of biochar means that this carbon can remain in the soil for hundreds or even thousands of years (LEHMANN et al., 2021).

Reduction of greenhouse gas emissions: The production of biochar can be done sustainably, using agricultural and forestry waste that would otherwise be burned or left to rot, becoming environmental liabilities. In addition, using fewer synthetic fertilizers thanks to biochar means lower greenhouse gas emissions linked to the production and use of these fertilizers, especially nitrogen ones (SHRESTHA et al., 2023).

Cogeneration of energy: In addition to producing biochar, controlled pyrolysis produces biogases and bio-oil, which can be used as sources of renewable energy (LEHMANN et al., 2021), especially for electricity production. The residual heat from pyrolysis can also be recovered for drying uses (e.g., coffee drying).

4 - QUANTITY
How much biochar needs to be applied to the soil and why?

The amount of biochar to be applied varies depending on its chemical composition, the type of soil and nutrient availability, and the crop. Thus, the amount of biochar applied should be defined on a case-by-case basis based on assertive agronomic recommendation. However, Ye et al. (2020) report that they did not find agronomic responses with doses higher than 10 t/ha in studies with biochar application.

5 - APPLICATION
How does biochar need to be applied to the soil?

There are several ways to apply biochar to the soil, and the choice of method will depend on the characteristics of the soil, the crops grown, and the objectives of the application. Some of the most common ways to apply biochar to the soil are:

1- Mechanical incorporation: In this method, biochar is mixed with the soil through incorporation equipment, such as plows, harrows or subsoilers. This method is more suitable for sandy or clay soils, where incorporation is easier.

2- Manual incorporation: Same methods discussed above, but applies to cases where mechanical application is not possible.

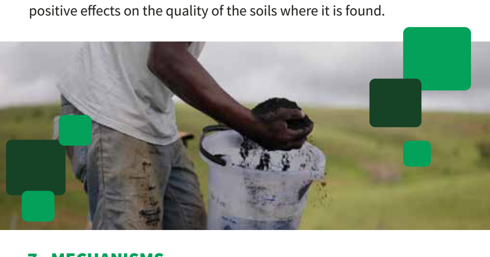
3- Surface application: In this method, biochar is applied directly to the soil surface, without the need for incorporation. Incorporation occurs naturally over time through cultural practices, by the action of rain, interaction with plant roots, and microorganisms. This method should be used on flat terrain to prevent the biochar from being washed away by rain and is more suitable for compacted soils or with high moisture or even in farming systems that do not till the soil (e.g., perennial crops like coffee or no-till farming).

4 -Mixing with fertilizers: Biochar can be mixed with fertilizers, such as urea or superphosphate, to increase application efficiency. This can help reduce the amount of necessary chemical fertilizers and improve crop productivity (BAI et al., 2022; MELO et al., 2022).

Regardless of the chosen method, it is important that biochar is applied in the right place in the soil (e.g., in strips under the canopy of plants or in holes before planting perennial crops etc.), near the roots of plants, so that it can act effectively. It is also important to ensure that the biochar used is of good quality, free of impurities and contaminants. In addition, the application of biochar should be accompanied by monitoring to assess its effect on the soil and crops over time.

6 - FREQUENCY
Why don't you need to apply biochar again after the first application, and for how long will the impact be sustained in terms of soil benefits/fertilization?

The strategy of applying biochar should be done in a way to optimize time and available resources, mainly seeking synergy within the production system. For example, if there is sufficient availability of biochar, one may choose to apply doses typically between 5-10 t/ha with intervals of several years between applications. Numerous studies report an increase in crop productivity for several years after a single application of biochar, when associated with the application of fertilizers (YE et al., 2020). Additionally, it is reiterated that biochar remains stable in the soil for hundreds, even thousands of years, and that agr nomic effects can last for a long time. See the example of the Amazonian "Terra Preta", which still today after hundreds of years produces positive effects on the quality of the soils where it is found.



7 - MECHANISMS
What is the mechanism of action of biochar in the soil? What are the physical, chemical, and biological implications for soil quality and how do they occur?

The mechanism of action of biochar in the soil is multifaceted and involves a combination of physical, chemical, and biological factors that improve soil quality and promote greater agricultural productivity (JOSEPH et al., 2021; KIGGUNDU; SITTAMUKYOTO, 2019). According to the authors referenced, some of the main effects of biochar on the soil are:

1- Soil structure improvement: Biochar is porous and can have a large surface area, which helps improve soil structure by increasing porosity, allowing better aeration and drainage. In addition, it helps reduce soil compaction, making it easier to cultivate.

2- Increase in water retention capacity: Biochar has a high water retention capacity, which helps increase availability to plants. This is particularly important in sandy soils or with low water retention capacity.

3- Increase in nutrient retention capacity: Some types of biochar have a high nutrient adsorption capacity, which helps retain nutrients in the soil and make them more available to plants. It can also help reduce nutrient leaching, preventing water pollution.

4- Stimulation of the growth of beneficial microorganisms: Biochar provides a favorable habitat for the growth of beneficial microorganisms, such as bacteria and fungi, which help decompose organic matter and cycle nutrients. In addition, it helps increase the diversity of microorganisms in the soil, which can improve soil resistance to diseases and pests. These effects are the result of the interaction between biochar and soil, and may vary depending on the type of soil, the quality of the biochar, and the dose applied. In general, the application of biochar can significantly improve soil quality, promoting more sustainable and resilient agriculture.

8 - YIELD
How much productivity increase can be expected with the application of biochar?

The increase in productivity with the application of biochar to the soil can vary depending on the type of soil, the quality of the biochar, and the cultivation conditions. However, several studies have shown that the application of biochar can significantly increase agricultural productivity in different crops and regions. For example:

- In a meta-analysis published in 2021, the authors compiled the results of various articles and showed that biochar can increase crop productivity from 10% to 42%, with the greatest increases observed in phosphorus-fixing soils (acidic tropical soils) and sandy soils due to the increase in nutrient and water retention capacity in these types of soil (JOSEPH et al., 2021).

- Another study published in 2017 that compiles results from several meta-analyses in a wide variety of crops shows that in tropical regions, the yield increase with biochar application was 25% on average (JEFFERY et al., 2017).

In addition to increased productivity, the application of biochar to soil can also improve the quality of agricultural products, such as nutrient concentration and resistance to diseases and pests (ROGERS et al., 2022).

However, it is important to remember that the application of biochar is not a single solution for improving agricultural productivity. The application of biochar should be seen as part of an integrated soil management plan, which includes other agricultural practices, such as crop rotation, organic fertilization, and water management. In addition, the application of biochar should be done with the accompaniment of a technician or agriculture specialist to determine the appropriate amount, the ideal time, and frequency of application.

9 - NUTRIENTS
Which nutrients currently applied chemically are expected to be reduced with the application of biochar, and why?

The application of biochar to the soil can, over time, reduce the need for some nutrients, such as nitrogen, phosphorus, and potassium, by improving their retention and availability in the soil, making them more accessible to plants (JOSEPH et al., 2021). Biochar can also provide some of these nutrients. For example, coffee husk biochar is rich in potassium and can partially replace mineral potassium in the first year of application.

Nitrogen is one of the main nutrients required by plants for growth and production, and it is often supplied in the form of synthetic chemical fertilizers. However, excessive application of nitrogen can lead to environmental problems, such as water pollution through nitrate leaching. Biochar can reduce the need for nitrogen fertilizers by retaining and storing nitrogen in the soil. Moreover, biochar can improve the soil's biological activity, which can favor nitrogen fixation by bacteria and reduce denitrification and nitrous oxide emissions, a potent greenhouse gas (ANTONANGELO; SUN; ZHANG, 2021).

Phosphorus is another important nutrient for plant growth and is often added to the soil in the form of phosphate fertilizers. However, phosphorus can bind to soil particles and become less available to plants.

Biochar can improve the availability of phosphorus in the soil, making it more accessible to plants (JOSEPH et al., 2021). In addition, it can reduce phosphorus leaching in sandy soils, preventing water pollution. Biochar can also directly provide potassium (e.g., coffee husk biochar) in the first year after its application or can help improve the efficiency of potassium use applied through mineral fertilizers.

It is important to note that biochar application does not completely eliminate the need for chemical fertilizers but only reduces the demand, either by direct supply or by contributing to increased nutrient efficiency.

10 - RISKS
Are there known negative side effects of using biochar? What are they and how do they occur? Are there risks to soil quality and the environment?

In some cases, if the application does not follow technical criteria based on soil analysis and the application is excessive, negative effects on crop productivity may occur. Similarly, excessive doses (up to 120 t/ha) can inhibit seed germination. Negative effects from the application of high doses (>50 t/ha) can also occur in the availability of nitrogen and phosphorus (JOSEPH et al., 2021).

However, applications at correct doses following technical criteria should not pose risks to the soil and environment.

11 - OTHER QUESTIONS
Is it possible to produce biochar from any type of biomass? Is it possible to use the pruning residues of crops (shells, branches, trunks, and leaves) in the production of biochar? How?

Theoretically, yes, any type of biomass can be used. Adjustments in the production process, mainly in the drying and pyrolysis stages, will always be necessary, depending on the characteristics of the biomass used. Indeed, the production of biochar from plant residues is extremely flexible in relation to the type of biomass to be used, and is a way to take advantage of materials that could be discarded and transform them into a valuable resource to improve soil quality. The pruning residues of crops, such as shells, branches, trunks, and leaves, can be totally used in the production of biochar. These materials are generally rich in lignocellulose, which is the main source of carbon in biomass, and can be carbonized to produce biochar. To produce biochar from pruning residues, it is important to ensure that the material is clean and free of contamination by heavy metals or other pollutants. In addition, the material must be shredded into small pieces to ensure that it is carbonized uniformly and efficiently.

Why is biochar more effective than composting?

In studies conducted by Antonangelo et al. (2021), it is reported that biochar is more effective than composting due to several aspects, among them we can mention:

I) the production process of biochar allows for energy recovery using the gases generated in pyrolysis;

II) the product generated (biochar) has carbon that is much more stable than compost;

III) during composting there is significant emission of greenhouse gases, whose emission is difficult to control, which does not occur in the production process of biochar;

IV) composting requires a large demand for water, unlike the process of producing biochar;

V) there is less need for physical space (area) for the production of biochar compared to composting;

VI) composting can produce significant leachate with potential to pollute soil and water, which does not occur in the production process of biochar. In addition, compost must be reapplied frequently due to its relatively rapid decomposition in the soil. On the other hand, biochar has a long-lasting effect on the soil because it has a highly stable carbon fraction.

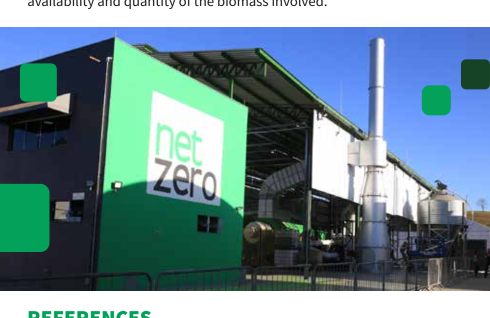
Are there other people producing and using biochar? Where and how? In which agricultural crops?

In several European countries, United States, China, Japan, and more, there is already commercial production of biochar. However, even in these countries, the production is very localized and there is a great potential for market growth. In Brazil, apart from NetZero, there is no commercial production of biochar on a scale. NetZero is the largest company in the world producing biochar from agricultural waste, and no other company is producing biochar on a scale in the world for this purpose.

How much biochar will NetZero produce in its plants? How much biomass is needed? At what distance from the plant and in what quality?

The amount of biochar to be produced by each NetZero plant will depend greatly on the region where it will be implemented. Typically, considering the use of coffee husk waste, for example, each NetZero production unit containing two pyrolysis reactors will have the capacity to produce about 4,500 tonnes of biochar per year. For each tonne of biochar produced, approximately 4 tonnes of biomass are needed. In this case, each NetZero plant will consume approximately 16,000 tonnes of biomass per year.

NetZero's main business model is completely circular, that is, the biochar produced in a plant returns to the same agricultural producer who supplied the biomass to be pyrolyzed. For logistical reasons, NetZero has established a "maximum distance" of about 30 km for this "circular business" to be viable. Even so, slightly longer distances may still be possible, depending on the specifics of each region and the availability and quantity of the biomass involved.



REFERENCES

ANTONANGELO, J. A. et al. The roles of co-composted biochar (COMBI) in improving soil quality, crop productivity, and toxic metal amelioration. Journal of Environmental Management, v. 277, p. 111443, Jan.2021.

BAHRUN, A. et al. Effect of Different Types of Biochar on Growth of Cocoa Seedlings (Theobroma cacao L.). Asian Journal of Crop Science, v. 12, n. 1, p. 12–18, Dec.2019.

BAI, S. H. et al. Combined effects of biochar and fertilizer applications on yield: A review and meta-analysis. Science of the Total Environment, Elsevier B.V., Feb.2022.

JEFFERY, S. et al. A quantitative review of the effects of biochar application to soils on crop productivity using meta-analysis. Agriculture, Ecosystems & Environment, v. 144, n. 1, p. 175–187, Nov.2011.

JEFFERY, S. et al. Biochar boosts tropical but not temperate crop yields. Environmental Research Letters, Institute of Physics Publishing, Apr.2017.

JIA, Y. et al. Study of the effect of pyrolysis temperature on the Cd2+ adsorption characteristics of biochar. Applied Sciences (Switzerland), v. 8, n. 7, Jun.2018.

JOSEPH, S. et al. How biochar works, and when it doesn't: A review of mechanisms controlling soil and plant responses to biochar. GCB Bioenergy, John Wiley and Sons Inc, Nov.2021.

KIGGUNDU, N. et al. Pryloysis of Coffee Husks for Biochar Production. Journal of Environmental Protection, v. 10, n. 12, p. 1553–1564, 2019.

LEHMANN, J. et al. Biochar in climate change mitigation. Nature Geoscience, Nature Research, Dec.2021.

LEHMANN, J. et al. Biochar for environmental management: science, technology and implementation. 2a ed. [s.l.] Routledge, 2015.

MELO, L. C. A. et al. Biochar-based fertilizer effects on crop productivity: a meta-analysis. Plant and Soil, Springer Science and Business Media Deutschland GmbH, Mar.2022.

RAFIQ, M. K. et al. Biochar amendment improves alpine meadows growth and soil health in Tibetan plateau over a three year period. Science of The Total Environment, v. 717, p. 135296, May.2020.

ROGERS, P. M. et al. Effects of Biochar on Soil Fertility and Crop Yields: Experience from the Southern Highlands of Tanzania. Tanzania Journal of Science, v. 48, n. 2, p. 256–267, Jun.2022.

SANCHEZ-REINOSO, A. D. et al. Physiological behaviour and nutritional status of coffee (Coffea arabica L. var. Castillo) trees in response to biochar application. Journal of Agricultural Science, v. 160, n. 3–4, p. 220–234, Jun.2022.

SHRESTHA, R. K. et al. Biochar as a negative emission technology: A synthesis of field research on greenhouse gas emissions. Journal of Environmental Quality, May.2023.

TEIXEIRA, W. G. et al. As terras pretas de índio da Amazônia: sua caracterização e uso deste conhecimento na criação de novas áreas. 1a ed. Manaus: Embrapa Amazônia Ocidental, 2009. v. 1

YE, L. et al. Biochar effects on crop yields with and without fertilizer: A meta-analysis of field studies using separate controls. Soil Use and Management, Blackwell Publishing Ltd, Jan.2020.